Route Optimization of Travelers' Intermodal Transport Considering Bounded Rationality

Zongfang Wang, Changfeng Zhu, Jinhao Fang, Linna Cheng, and Jie Wang

***Abstract*—To enable travelers to reach their destination in a relatively short time while reducing travel costs, this paper establishes a multi-objective path optimization model by analyzing the impact of factors such as weather reduction coefficient and road congestion coefficient on travelers' route selection. And combine quantum genetic algorithm with an elite strategy to solve multi-objective models. Finally, the rationality of the model and algorithm is verified by a case. The results show that in the travelers' intermodal transport network considering bounded rationality, the choice of travel route will change with the change of road traffic congestion and weather conditions, and travelers need to make decisions according to the specific requirements of the day of departure. Using bounded rationality to describe travelers' expectations can reflect their travel needs well.**

***Index Terms*—Integrated transportation, travelers' intermodal transport, improved quantum genetic algorithm, mixing time window**

I. Introduction

TRAVELERS' route choice behavior is fundamental in optimizing the travel routes and formulating relatively reliable and reasonable travel plans. Travelers' intermodal transport can reduce travel costs and promote the coordinated development of the different transport modes. However, the problem is influenced by such complex factors as travel time, travelers' psychology, and the external environment.

As the transport network continues to expand in size and become more complex in structure, it is difficult for a single mode of transport to meet the travel needs of travelers. Travelers' intermodal transport can better describe the actual travel needs of travelers. [1] built a portrait database based on the historical travel data of travelers to explore the differences in travel demands of road and railway combined transport derived from passenger heterogeneity. [2] constructed multiple logit models to describe travelers' transfer and transfer behaviors in travelers' intermodal transport. [3] analyzed the main factors for the success of air and rail combined transportation. From the economic point of view, [4] studied the impact of shortening air and rail transfer time on the interests of railway, aviation, and airport transportation enterprises and passenger costs. [5] optimized the multimodal transport network between high-speed rail and highway by establishing a double-layer programming model. [6] established a multi-objective model based on cost, time, and reliability by analyzing the water, railway, and highway transport network. Some scholars are devoted to studying the travel mode choice model. The relationship between travelers' characteristics and travel patterns is analyzed, and the functional relationship between travelers' characteristics and constructed travel characteristics using the discrete selection model [7]. [8][9] have established multiple logit models to analyze the potential psychological factors of travelers and the impact of public transport user groups on travel modes. [10][11][12] by establishing a hierarchical mixed logit model, discussed the impact of personal values and age on travel choice behavior. To analyze the effect of traffic information on passenger route choice behavior, [13][14] simulated residents' choice of residence and travel mode based on behavioral analysis and established a multidimensional relationship between residents' choice behavior and travel mode in the vicinity of public transport. Optimize travel paths by proposing a combined travel traffic allocation model with fixed demand [15]. However, the above research was carried out in a deterministic network, without considering the uncertainty in the traffic network.

Therefore, some scholars have focused on studying path optimization models in uncertain networks, where [16][17] established a network balance model in a stochastic road network. To describe the travel choice behavior of travelers, [18] demonstrated a multimodal bounded rational layered logit model. Under the premise of considering three travel modes, [19] compare the optimal route selection of the cumulative prospect theory and the expected utility theory in different scenarios. Considering the impact of travelers' risk perception on the path selection, [20] proposed a discrete selection model based on the risk perception. To reveal travelers' decision-making process, [21] established a traveler utility selection model. However, in addition to the traffic network uncertainty, travelers are also affected by their habits, cognition, and environment, so it is challenging to make entirely rational decisions [22][23]. Prospect theory

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to describe the path selection behavior of travelers in an uncertain environment was applied to the path optimization problem [25]. The formation and evolution process of reference points was discussed by analyzing travelers' risk attitudes [26]. Therefore, when constructing a path selection model, some scholars set a reference point as the dividing point for judging profits and losses. How selecting a reference point will directly affect the final selection result, as shown in Table I.

TABLE I
REFERENCE POINT SELECTION

Author	Reference point
[27]	Positive and negative ideal way of travel
[28]	Time reference point and demand reference point
[29], [30]	The earliest arrival time and the latest arrival time
[31], [32]	Average values of travel time and travel costs
[33]	Previous trip expenses
[34], [35]	Expected time at different stages

To sum up, relevant scholars have researched the problem of travelers' intermodal transport route optimization, but there are still the following deficiencies. Firstly, most scholars mainly study the path optimization of a single mode of transportation in cities, with only a few considering the combination of multiple modes of transportation for path optimization. In addition, some scholars have studied the optimization of routes under bounded rationality, and most have considered a single static reference point. Finally, most of the literature does not consider the impact of weather, road crowding, and other factors on travelers' travel.

Based on this, by analyzing the complexity of travelers' intermodal transport problem and the characteristics of travel behavior under bounded rationality, taking the expected travel time and expected travel cost as dual reference points, considering the impact of weather, road crowding, and other factors, under the condition of bounded rationality, the model and algorithm of travelers' intermodal transport route optimization for travelers are constructed.

II. ANALYSIS OF ROUTE CHOICE BEHAVIOR

The complex network is simplified into the superposition of different traffic networks to accurately describe the characteristics of travelers' intermodal transport network. However, each network has its independent topology structure, and the sub-networks of different transport modes are interrelated through transfer behavior, thus forming a network diagram, as shown in Fig.1, described as: $G = G(E, M)$, among: E represents a collection of nodes; M represents the set of transport modes.

Considering the influence of the weather reduction and road congestion coefficients on the travel choice behavior, the hub station is regarded as a network node and established an effective relationship with the decisive factors affecting the travel process.

$$T_{ij}^{m} = \frac{d_{ij}^{m}}{v_{ij}^{m} \cdot \eta \cdot \lambda} + t_{ij}^{d} + (1-\sigma)\sum_{H=1}^{n} t_{ij}^{m_H} \tag{1}$$

Where, T_{ij}^{m} represents the total time of transportation mode m from node i to node j; d_{ij}^{m} represents the distance of transportation mode m from node i to node j; v_{ij}^{m} represents average travel speed of transportation mode m from node i to node j; η represents road congestion factor, $\eta \in (0,1)$; λ represents the discount rate for travelers travel speed, $\lambda \in (0,1)$; t_{ij}^{d} represents the additional time for the travelers to travel, including the time for picking up tickets, waiting for the bus (airport), and waiting according to the schedule; $t_{ij}^{m_H}$ represents the transfer time between m transportation mode and another transportation mode, which is a 0-1 variable, H is the number of transfers, when $H < 1$, $\sigma = 1$, otherwise, $\sigma = 0$.

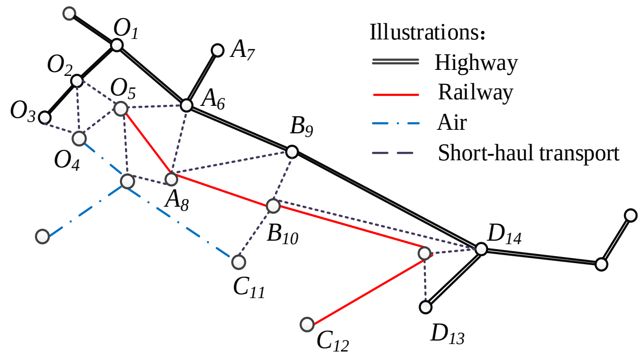

Fig. 1. Travelers' intermodal transport network

According to the actual situation of travelers' intermodal transport, the setting of the time window has certain particularity. As shown in Fig. 2, $[ET_1, LT_1]$ is the time error interval that the travelers can actually accept, $[0, ET_1]$ is the waiting time of travelers, $[LT_1, BT_1]$ represents the latest arrival time that travelers can tolerate, $[BT_1, +\infty]$ indicates that the traveler abandons the trip, and the penalty function becomes the maximum value. The penalty coefficient for late arrival is greater than that for early arrival.

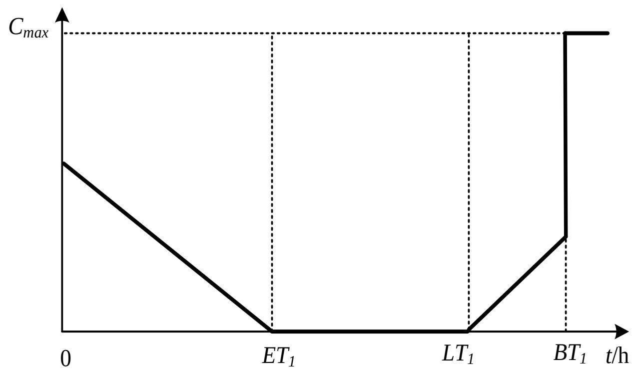

Fig. 2. Mixing time window

When $t_1 \notin [ET_1, LT_1]$ the corresponding penalty coefficient φ:

$$\varphi = \begin{cases} \varphi_1, & t \in [0, ET_1] \\ \varphi_2 & t \in [LT_1, BT_1] \end{cases} \tag{2}$$

Where, φ_1 represents the penalty coefficient of early arrival; φ_2 represents the penalty coefficient of late arrival.

$$c(t,\varepsilon)=\varphi_1\cdot\varepsilon\cdot\left(ET_1-t_1\right)+\varphi_2\cdot\left(1-\varepsilon\right)\left(t_1-LT_1\right) \tag{3}$$

Where, ε represents a 0-1 variable, if $t\in[0,ET_1]$, and $\varepsilon=1$, otherwise, $\varepsilon=0$.

$$C_{ij}^m=[(1-\sigma)\cdot c_{ij,H}^m+\sigma\cdot c_{ij,0}^m]+c(t,\varepsilon)+c_{ij}^m\cdot d_{ij}^m \tag{4}$$

Where, C_{ij}^m represents the total cost of transportation mode *m* from node *i* to node *j*, yuan; c_{ij}^m represents the unit travel cost from node *i* to node *j* of transportation mode *m*, yuan; σ is a 0-1 variable, and *H* is the number of transfers, when *H*<1, $\sigma=1$, otherwise $\sigma=0$; $c_{ij,H}^m$ represents the cost of the *H-th* transfer when the mode *m* is selected from node *i* to node *j*, yuan; $c_{ij,0}^m$ represents the cost of transportation mode *m* without transfer from node *i* to node *j*, yuan; $c(t,\varepsilon)$ represents penalty cost, yuan.

III. Model Building

A. Prospect Theory Values Function

Different travelers have different cognition, influenced by cultural differences, education levels, and other factors. Therefore, prospect theory was introduced to describe the values function of travel time and cost [36].

The reference point of travel time is the travelers' psychological expectation of travel time. According to human travel habits, travelers will assume their reference point based on personal requirements and experience. Of course, travelers will have different reference points, the reference points of travel time are expressed as $T_i=\{T_1,T_2,T_3\cdots\}$.

$$\nu(T_{ij})=\begin{cases}\left(T_{ij}^m-T_i\right)^\alpha, T_{ij}^m-T_i<0\\ -\lambda\left(T_i-T_{ij}^m\right)^\beta, T_{ij}^m-T_i\geq 0\end{cases} \tag{5}$$

Since travel costs are generally determined by travel distance, the reference point is set as the average travel cost of multiple transportation modes.

$$\nu(C_{ij})=\begin{cases}\left(C_{ij}^m-\frac{1}{g}\sum_{m=1}^{g}C_{ij}^m\right)^\alpha, C_{ij}^m-\frac{1}{g}\sum_{m=1}^{g}C_{ij}^m<0\\ -\lambda\left(\frac{1}{g}\sum_{m=1}^{g}C_{ij}^m-C_{ij}^m\right)^\beta, C_{ij}^m-\frac{1}{g}\sum_{m=1}^{g}C_{ij}^m\geq 0\end{cases} \tag{6}$$

Where, α represents the gain sensitivity coefficient, β represents the loss sensitivity coefficient, reflects the concave-convex nature of the values function, describes the traveler's gains and losses, the greater the concave-convex nature of the values function, the more likely travelers are to take risks. λ is the loss aversion coefficient, reflecting the sensitivity of the traveler to the loss, the λ larger, the greater the loss aversion, $\alpha=\beta=0.88$, $\lambda=2.25$.

B. Subjective Probability Function

The subjective probability function is used to simulate the psychological effect of the travelers. Due to the subjective probability function being a psychological evaluation, judgment has an apparent subjectivity. When travelers face losses, they maintain a risk-preference attitude; when travelers face benefits, they retain a risk-averse attitude.

$$\varpi(p)=\begin{cases}\varpi^+(p)=\dfrac{p^\gamma}{\left[p^\gamma+(1-p)^\gamma\right]^{1/\gamma}}\\ \varpi^-(p)=\dfrac{p^\delta}{\left[p^\delta+(1-p)^\delta\right]^{1/\delta}}\end{cases} \tag{7}$$

Where, $\omega(p)$ represents the perceived probability of an event occurring; *p* represents the actual probability of the travel mode chosen by the travelers; in the case of gain, $\gamma=0.61$, and in the case of loss, $\delta=0.69$.

Based on the double reference points of time expectation values and cost expectation values, this paper analyzes the behavior theory of the choice of travelers' intermodal transport routes, considers the influence of weather, road congestion and other factors, takes the expected travel time and the expected travel cost of travelers as the dual objectives, and establishes the travelers' intermodal transport route optimization model under the condition of bounded rationality.

$$\max \quad P_1=\sum_{i\in E}\sum_{j\in E}\omega_{ij}\cdot\nu(T_{ij}) \tag{8}$$

$$\max \quad P_2=\sum_{i\in E}\sum_{j\in E}\omega_{ij}\cdot\nu(C_{ij}) \tag{9}$$

Travelers can only take one mode of transportation from node *i* to node *j* during the travelers' intermodal transport route selection process.

$$\sum_m x_{ij}^m\leq 1,\forall i,j \tag{10}$$

During the journey from node *i* to node *j*, travelers can only transfer once.

$$\sum_m\sum_h r_{ij}^{mh}\leq 1,\forall i,j \tag{11}$$

In order to ensure the continuity of the transportation process, travelers have only one complete path to each destination.

$$\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m-\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m=1,\forall i=o \tag{12}$$

$$\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m-\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m=0 \tag{13}$$

$$\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m-\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m=-1,\forall i=d \tag{14}$$

To ensure the continuity of transportation mode, when the transportation mode entering node *i* is *m*, and the transportation mode sent by the node is *h*, node *i* will be converted from mode *m* to mode *h*.

$$\sum_{i\in E}\sum_{j\in E}x_{ji}^m+\sum_{i\in E}\sum_{j\in E}x_{ij}^h\geq 2r_i^{mh},\forall m,h\in M,m\neq h \tag{15}$$

The decision variable is set to quickly and accurately locate the trip path and mode of travelers. When $x_{ij}^m=1$, it means that travelers pass nodes *i*; otherwise, the traveler does not go through node *i*; when $r_{ij}^{mh}=1$, it means that when the travelers pass node *i*, the transportation mode *m* is changed to the transportation mode *h*.

$$x_{ij}^{m} \in \{0,1\}, \forall (i,j) \in E \tag{16}$$

$$r_{ij}^{mh} \in \{0,1\}, \forall (i,j) \in E \tag{17}$$

When traveling from the place of departure to the destination, travelers can only go to the only station from the departure position. If the place of departure and the arrival position is in the same city, they can choose short-distance transportation.

$$\{i, j \mid i = M_n, j = M_{n+i}\}, 0 < k \le 3 \tag{18}$$

IV. Algorithm Design

The non-dominated sorting operator and crowding degree selection strategy in non-dominated sorting genetic algorithm-II (NSGA-II) are introduced into the quantum genetic algorithm, and an improved quantum genetic algorithm is proposed to solve the problem.

A. Quantum Coding

When encoding, the first *m* item is the transportation node, and the latter $(n-1)*m$ item represents different transportation modes, where indicating the probability of conversion to 0, indicating the probability of conversion to 1, and $i = 1,2,3\cdots k$.

$$\begin{aligned} p_i &= \Bigg[\underbrace{\begin{vmatrix}\alpha_{i,1}\\ \beta_{i,1}\end{vmatrix}\cdots\begin{vmatrix}\alpha_{i,m}\\ \beta_{i,m}\end{vmatrix}}_{\text{Transportation node}}\underbrace{\begin{vmatrix}\alpha_{i,m+1}\\ \beta_{i,m+1}\end{vmatrix}\cdots\begin{vmatrix}\alpha_{i,2m}\\ \beta_{i,2m}\end{vmatrix}}_{\text{Transportation mode 1}}\cdots\underbrace{\begin{vmatrix}\alpha_{i,(n-1)m+1}\\ \beta_{i,(n-1)m+1}\end{vmatrix}\cdots\begin{vmatrix}\alpha_{i,nm}\\ \beta_{i,nm}\end{vmatrix}}_{\text{Transportation mode } n}\Bigg] \\ &= \Bigg[\underbrace{\begin{vmatrix}\cos(t_{i,1})\\ \sin(t_{i,1})\end{vmatrix}\cdots\begin{vmatrix}\cos(t_{i,m})\\ \sin(t_{i,m})\end{vmatrix}}_{\text{Transportation node}}\underbrace{\begin{vmatrix}\cos(t_{i,m+1})\\ \sin(t_{i,m+1})\end{vmatrix}\cdots\begin{vmatrix}\cos(t_{i,2m})\\ \sin(t_{i,2m})\end{vmatrix}}_{\text{Transportation mode 1}} \\ &\quad\cdots\underbrace{\begin{vmatrix}\cos(t_{i,(n-1)m+1})\\ \sin(t_{i,(n-1)m+1})\end{vmatrix}\cdots\begin{vmatrix}\cos(t_{i,nm})\\ \sin(t_{i,nm})\end{vmatrix}}_{\text{Transportation mode } n}\Bigg] \end{aligned} \tag{19}$$

Where, α and β satisfies the normalization condition, $t_{i,j} = 2\pi r$, *r* represents the random number between $(0,1)$, $i = 1,2,3\cdots k$, $j = 1,2,3\cdots n$, *k* is the population size, and *n* is the quantum number.

B. Qubit Update Strategy

The chromosome is updated by changing the probability amplitude of quantum bit coding to achieve population evolution, and the updates are as follows:

$$U(\theta_i) = \begin{bmatrix}\cos t_{ij}\\ \sin t_{ij}\end{bmatrix} = \begin{bmatrix}\cos(t_{ij}+\theta_i)\\ \sin(t_{ij}+\theta_i)\end{bmatrix} \tag{20}$$

Where, *U* represents the quantum revolving gate; θ represents the quantum rotation angle.

The quantum rotation angle θ affect the population convergence rate and too large leads to precocious maturity. The quantum rotation angle θ is generally: 0.001π~0.005π, in order to make the population convergence rate more gentle, adaptive adjustment θ is designed:

$$\theta_i = \frac{f_{\max} - f_{cur}}{f_{\max}} \times (\theta_{\max} - \theta_{\min}) \tag{21}$$

Where, f_{cur} represents the fitness of the individual that needs to be updated; $f_{\min}$ represents the minimum fitness values in the population; $f_{\max}$ represents the maximum fitness values in the population; $\theta_{\max}$ represents the maximum values in the interval; $\theta_{\min}$ represents the minimum values over the interval.

C. Algorithm Steps

To ensure the diversity of the population, adopted the strategy of single-point mutation for chromosome mutation. Based on the above analysis, the algorithm steps are as follows.

Step 1: The initial population Q_t was randomly generated to select the trip path and trip mode.

Step 2: Update by quantum bits, crossover, and mutation to produce offspring population P_t.

Step 3: The parent population and offspring population are merged into a new population $I_t = Q_t \cap P_t$.

Step 4: The non-dominated sorting of It generates a non-inferior solution set and calculates the crowding degree.

Step 5: According to the crowding degree comparison operator, suitable individuals are selected to enter the next generation until the number of new populations is equal to the number of the initial population.

Step 6: Let $t = t+1$ to determine whether the iteration termination condition is met. If it is, the iteration will end. Otherwise, the offspring population P_{t+1} will be generated through quantum bits update, crossover and mutation, and go to step 3.

The algorithm flow is shown in Fig. 3:

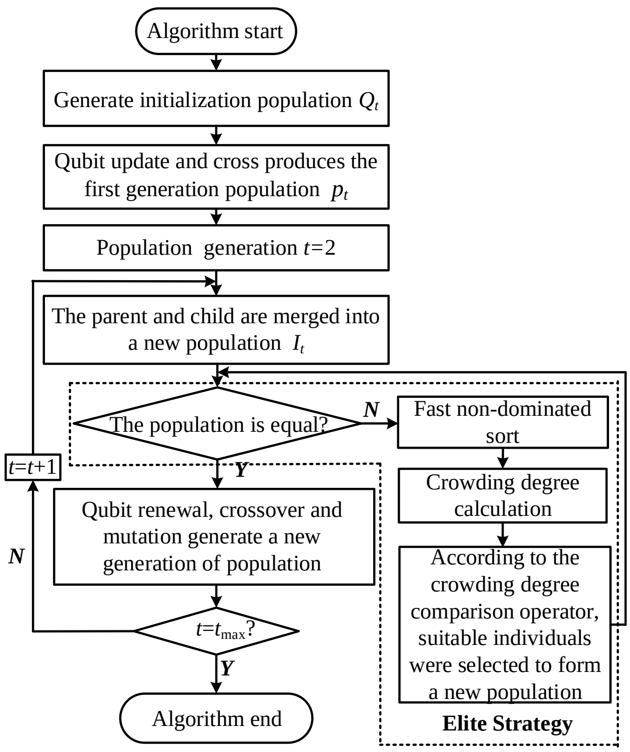

Fig. 3. Algorithm flow chart Examples analysis

V. Case Study

Suppose the traveler starts from node 1 of city O to node 35 of city J. There are interchangeable transportation modes between any two neighboring cities. The transportation network is shown in Fig. 4.

The corresponding distance and time of each transportation path are shown in Table II, and per unit distance transport costs and per unit distance transport speeds are shown in Table III.

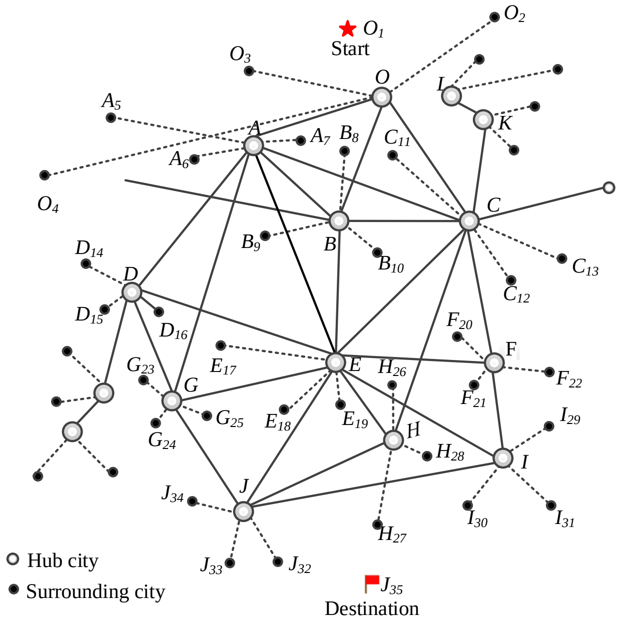

Fig. 4. Virtual transport network

TABLE III
Unit Transportation Cost And Speed

Serial Number	Mode of Transportation	Unit Transport Cost (yuan/km)	Transportation Speed(km/h)
1	Highway	0.2394	100
2	Railway	0.3100	250
3	Aviation	0.5569	800
4	Subway	0.5000	80
5	Bus	0.1000	35
6	Taxi	1.3000	60

TABLE II
The Distance Of Transport Path
(a)

Node	t_{ij} / h	d_{ij}^m / km	Node	t_{ij} / h	d_{ij}^m / km	Node	t_{ij} / h	d_{ij}^m / km	Node	t_{ij} / h	d_{ij}^m / km
(O_1, O_2)	0.52	22	(A_6, B_{10})	3.36	335	(B_9, F_{21})	3.63	363	(D_{14}, G_{24})	2.93	293
(O_1, O_3)	0.68	27	(A_6, D_{14})	2.63	268	(B_9, F_{22})	3.78	378	(D_{14}, G_{25})	3.27	327
(O_1, O_4)	0.35	29	(A_6, D_{15})	2.76	272	(B_{10}, C_{11})	2.65	285	(D_{14}, H_{26})	3.72	372
(O_2, A_5)	3.25	255	(A_6, D_{16})	2.99	299	(B_{10}, C_{12})	2.85	294	(D_{14}, H_{27})	3.81	381
(O_2, A_6)	2.64	281	(A_6, E_{17})	3.57	357	(B_{10}, C_{13})	3.59	306	(D_{14}, H_{28})	3.93	393
(O_2, A_7)	2.86	299	(A_6, E_{18})	3.65	365	(B_{10}, D_{14})	3.76	327	(D_{14}, I_{29})	4.87	487
(O_2, B_8)	2.45	237	(A_6, E_{19})	3.95	395	(B_{10}, D_{15})	4.36	359	(D_{14}, I_{30})	5.32	532
(O_2, B_9)	2.95	212	(A_6, F_{20})	4.68	468	(B_{10}, D_{16})	3.71	371	(D_{14}, I_{31})	5.48	548
(O_2, B_{10})	3.14	232	(A_6, F_{21})	4.98	498	(B_{10}, E_{17})	2.70	270	(D_{15}, D_{16})	0.32	12
(O_2, C_{11})	2.93	275	(A_6, F_{22})	5.21	521	(B_{10}, E_{18})	2.99	299	(D_{15}, E_{17})	3.37	337
(O_2, C_{12})	2.68	289	(A_7, B_8)	3.25	319	(B_{10}, E_{19})	3.23	323	(D_{15}, E_{18})	3.49	349
(O_2, C_{13})	3.24	301	(A_7, B_9)	3.35	332	(B_{10}, F_{20})	3.20	320	(D_{15}, E_{19})	3.63	363
(O_3, A_5)	1.86	273	(A_7, B_{10})	2.79	345	(B_{10}, F_{21})	3.56	356	(D_{15}, G_{20})	2.81	281
(O_3, A_6)	3.26	291	(A_7, D_{14})	2.57	259	(B_{10}, F_{22})	3.75	375	(D_{15}, G_{20})	3.01	301
(O_3, A_7)	3.15	301	(A_7, D_{15})	2.78	265	(C_{11}, C_{12})	0.57	19	(D_{15}, G_{22})	3.42	342
(O_3, B_8)	3.55	257	(A_7, D_{16})	2.89	289	(C_{11}, C_{13})	0.43	17	(D_{15}, G_{23})	3.85	385
(O_3, B_9)	3.25	279	(A_7, E_{17})	3.49	349	(C_{11}, D_{14})	5.35	489	(D_{15}, G_{24})	3.87	387
(O_3, B_{10})	2.63	286	(A_7, E_{18})	3.58	358	(C_{11}, D_{15})	5.37	531	(D_{15}, G_{25})	3.97	397
(O_3, C_{11})	3.37	287	(A_7, E_{19})	3.79	379	(C_{11}, D_{16})	5.58	558	(D_{15}, I_{29})	4.93	493
(O_3, C_{12})	2.75	299	(A_7, F_{20})	4.47	447	(C_{11}, E_{17})	3.52	352	(D_{15}, I_{30})	5.49	549
(O_3, C_{13})	3.68	325	(A_7, F_{21})	4.86	486	(C_{11}, E_{18})	3.69	369	(D_{15}, I_{31})	5.65	565
(O_4, A_5)	1.57	301	(A_7, F_{22})	5.03	503	(C_{11}, E_{19})	3.77	377	(D_{16}, E_{17})	0.50	15
(O_4, A_6)	3.35	337	(B_8, B_9)	0.45	21	(C_{11}, F_{20})	2.79	279	(D_{16}, E_{18})	3.53	353
(O_4, A_7)	2.57	357	(B_8, B_{10})	0.43	23	(C_{11}, F_{21})	2.97	297	(D_{16}, E_{19})	362	362
(O_4, B_8)	2.87	275	(B_8, C_{11})	2.24	267	(C_{11}, F_{22})	3.29	329	(D_{16}, G_{20})	2.69	269
(O_4, B_9)	2.75	287	(B_8, C_{12})	3.35	289	(C_{12}, C_{13})	0.65	21	(D_{16}, G_{21})	2.79	279
(O_4, B_{10})	2.85	299	(B_8, C_{13})	3.67	305	(C_{12}, D_{14})	5.79	509	(D_{16}, G_{22})	2.97	297
(O_4, C_{11})	3.32	282	(B_8, D_{14})	3.15	333	(C_{12}, D_{15})	5.76	542	(D_{16}, H_{26})	3.73	373
(O_4, C_{12})	3.16	306	(B_8, D_{15})	3.58	371	(C_{12}, D_{16})	5.79	579	(D_{16}, H_{27})	3.81	381
(O_4, C_{13})	3.56	358	(B_8, D_{16})	3.65	365	(C_{12}, E_{17})	3.42	342	(D_{16}, H_{28})	3.89	389
(A_5, A_6)	0.47	17	(B_8, E_{17})	2.75	275	(C_{12}, E_{18})	3.59	359	(D_{16}, J_{29})	4.83	483
(A_5, A_7)	0.47	21	(B_8, E_{18})	2.96	296	(C_{12}, E_{19})	3.73	373	(D_{16}, J_{30})	5.38	538
(A_5, B_8)	2.75	279	(B_8, E_{19})	3.19	319	(C_{12}, F_{20})	2.76	276	(D_{16}, J_{31})	5.79	579
(A_5, B_9)	3.65	296	(B_8, F_{20})	3.37	337	(C_{12}, F_{21})	2.98	298	(E_{17}, E_{18})	0.35	15
(A_5, B_{10})	3.53	327	(B_8, F_{21})	3.68	368	(C_{12}, F_{22})	3.33	333	(E_{17}, E_{19})	0.47	21
(A_5, D_{14})	2.36	287	(B_8, F_{22})	3.86	386	(C_{13}, D_{14})	5.45	545	(E_{17}, F_{20})	2.56	256
(A_5, D_{15})	3.15	302	(B_9, B_{10})	0.56	27	(C_{13}, D_{15})	5.74	574	(E_{17}, F_{21})	2.75	275
(A_5, D_{16})	3.37	337	(B_9, C_{11})	2.34	275	(C_{13}, D_{16})	5.99	599	(E_{17}, F_{22})	2.89	289
(A_5, E_{17})	3.61	361	(B_9, C_{12})	2.96	287	(C_{13}, E_{17})	3.58	358	(E_{17}, G_{23})	3.26	326
(A_5, E_{18})	3.73	373	(B_9, C_{13})	2.95	298	(C_{13}, E_{18})	3.47	347	(E_{17}, G_{24})	3.15	315
(A_5, E_{19})	3.81	381	(B_9, D_{14})	3.87	362	(C_{13}, E_{19})	3.62	362	(E_{17}, G_{25})	3.47	347
(A_5, F_{20})	4.56	456	(B_9, D_{15})	4.15	375	(C_{13}, F_{20})	2.59	259	(E_{17}, H_{26})	2.73	273
(A_5, F_{21})	4.84	484	(B_9, D_{16})	3.81	381	(C_{13}, F_{21})	2.84	284	(E_{17}, H_{27})	2.95	295
(A_5, F_{22})	5.05	505	(B_9, E_{17})	2.81	281	(C_{13}, F_{22})	3.25	325	(E_{17}, I_{29})	3.56	356
(A_6, B_8)	3.33	307	(B_9, E_{19})	3.25	325	(D_{14}, D_{16})	0.33	13	(E_{17}, I_{30})	3.69	369
(A_6, B_9)	3.57	312	(B_9, F_{20})	3.36	336	(D_{14}, E_{17})	3.12	312	(E_{18}, E_{19})	0.51	17
(D_{14}, E_{18})	3.27	327	(E_{18}, F_{22})	3.03	303	(G_{24}, H_{27})	3.35	335	(E_{18}, G_{25})	3.39	339

TABLE II
THE DISTANCE OF TRANSPORT PATH
(b)

Node	t_{ij} / h	d_{ij}^m / km	Node	t_{ij} / h	d_{ij}^m / km	Node	t_{ij} / h	d_{ij}^m / km	Node	t_{ij} / h	d_{ij}^m / km
(E_{18}, H_{28})	3.26	326	(F_{20}, H_{27})	3.52	352	(G_{24}, J_{33})	3.64	364	(H_{27}, J_{34})	3.27	327
(E_{18}, I_{29})	3.64	364	(F_{20}, H_{28})	3.73	373	(G_{24}, J_{34})	3.71	371	(H_{28}, I_{29})	2.69	269
(E_{18}, I_{30})	3.73	373	(F_{20}, I_{29})	2.63	263	(G_{25}, H_{26})	2.75	275	(H_{28}, I_{30})	2.73	273
(E_{18}, I_{31})	3.94	394	(F_{20}, I_{30})	2.76	276	(G_{25}, H_{27})	2.97	297	(H_{28}, I_{31})	2.58	258
(E_{19}, F_{20})	2.87	287	(F_{20}, I_{31})	2.89	289	(G_{25}, H_{28})	3.24	324	(H_{28}, J_{32})	3.24	324
(E_{19}, F_{21})	2.99	299	(F_{21}, F_{22})	0.39	19	(G_{25}, J_{32})	3.14	314	(H_{28}, J_{33})	3.42	342
(E_{19}, F_{22})	2.84	284	(F_{21}, G_{23})	5.47	547	(G_{25}, J_{33})	3.59	359	(H_{28}, J_{34})	3.17	317
(E_{19}, G_{23})	3.52	352	(F_{21}, G_{24})	5.58	558	(G_{25}, J_{34})	3.83	383	(I_{29}, I_{30})	0.43	13
(E_{19}, G_{24})	3.43	343	(F_{21}, G_{25})	5.28	528	(H_{26}, H_{27})	0.41	21	(I_{29}, I_{31})	0.51	21
(E_{19}, G_{25})	3.57	357	(F_{21}, H_{26})	3.78	378	(H_{26}, H_{28})	0.52	22	(I_{29}, J_{32})	3.72	372
(E_{19}, H_{26})	2.65	265	(F_{21}, H_{27})	3.63	363	(H_{26}, I_{29})	2.65	265	(I_{29}, J_{33})	3.81	381
(E_{19}, H_{27})	2.78	278	(F_{21}, H_{28})	3.86	386	(H_{26}, I_{30})	2.74	274	(I_{29}, J_{34})	3.65	365
(E_{19}, H_{28})	3.11	311	(F_{21}, I_{29})	2.71	271	(H_{26}, I_{31})	2.93	293	(I_{30}, I_{31})	0.48	18
(E_{19}, I_{29})	3.47	347	(F_{21}, I_{30})	2.79	279	(H_{26}, J_{32})	2.92	292	(I_{30}, J_{32})	3.59	359
(E_{19}, I_{30})	3.59	359	(F_{21}, I_{31})	2.87	287	(H_{26}, J_{33})	3.26	326	(I_{30}, J_{33})	3.68	368
(E_{19}, I_{31})	3.72	372	(G_{23}, G_{24})	0.37	17	(H_{26}, J_{34})	3.46	346	(I_{30}, J_{34})	3.71	371
(F_{20}, F_{21})	0.5	22	(G_{23}, G_{25})	0.49	19	(H_{27}, H_{28})	0.38	18	(I_{31}, J_{32})	3.74	374
(F_{20}, F_{22})	0.42	24	(G_{23}, H_{26})	2.87	287	(H_{27}, I_{29})	2.45	245	(I_{31}, J_{33})	3.83	383
(F_{20}, G_{23})	5.63	563	(G_{23}, H_{28})	3.14	314	(H_{27}, I_{30})	2.69	269	(I_{31}, J_{34})	3.65	365
(F_{20}, G_{24})	5.25	525	(G_{23}, J_{32})	*3.25*	*325*	(H_{27}, J_{31})	2.87	287	(I_{32}, J_{35})	0.55	21
(F_{20}, G_{25})	5.11	511	(G_{23}, J_{34})	3.94	394	(H_{27}, J_{32})	2.68	268	(I_{33}, J_{35})	0.75	16
(F_{20}, H_{26})	3.61	361	(F_{20}, H_{27})	3.52	352	(H_{27}, J_{33})	2.98	298	(E_{18}, F_{20})	2.74	274

Considering that the subway is not affected by external factors, the weather reduction factor of the subway is always 1.00, the weather reduction factor of aviation is set to 0.80, and the weather reduction factor of road traffic is set to 0.75. The road crowding coefficient mainly affects traffic, such as highways and buses, so the congestion crowding is set to 0.79.

The pareto solution and the iteration number of the algorithm judge the convergence performance of the algorithm. The results are shown in Fig. 5 and Fig. 6.

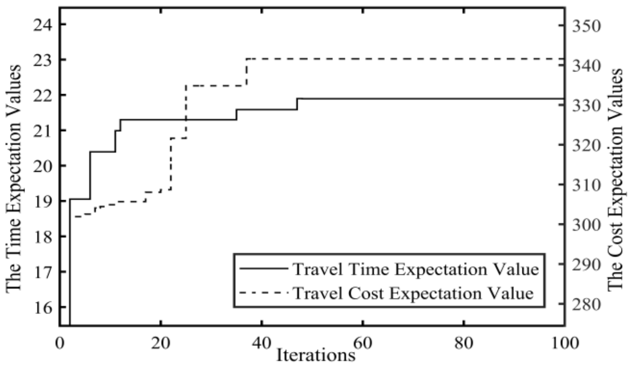

Fig. 5. Algorithm Iteration Graph

The changes in iteration times for travel time expectation and travel cost expectation are shown in Fig. 5. It can find that when the number of iterations is about 50, the time expectation values converge. The cost expectation values converge when the number of iterations is about 40. This further shows that the algorithm has excellent convergence performance.

TABLE IV
SCHEME FOR THREE SPECIAL SOLUTIONS

	P_1	P_2	Travel plan
1	13.8	341.6	$O_1 \xrightarrow{5} O_4 \xrightarrow{2} B_{10} \xrightarrow{2} D_{16} \xrightarrow{2} F_{22} \xrightarrow{2} H_{28} \xrightarrow{1} J_{32} \xrightarrow{5} J_{35}$
2	20.2	321.6	$O_1 \xrightarrow{5} O_4 \xrightarrow{1} C_{13} \xrightarrow{1} D_{16} \xrightarrow{1} G_{35} \xrightarrow{1} J_{34} \xrightarrow{5} J_{35}$
3	21.9	301.9	$O_1 \xrightarrow{4} O_4 \xrightarrow{2} B_{10} \xrightarrow{2} D_{16} \xrightarrow{2} F_{22} \xrightarrow{2} I_{31} \xrightarrow{2} J_{34} \xrightarrow{4} J_{35}$

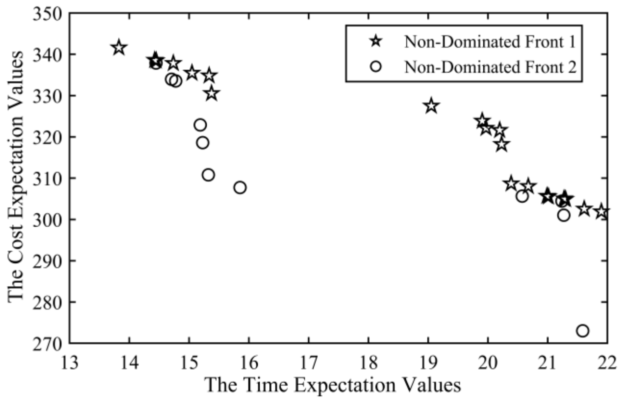

Fig. 6. Pareto front

It can see from Fig.6 that the result obtained is non-dominant, and the algorithm is feasible. Time expectation is negatively related to cost expectation: with increased time expectation, cost expectation decreases.

The pareto solution set satisfying the requirements of transportation time and transportation cost is obtained iteratively. The two solutions in the pareto solution set correspond to the solution with the most significant prospect values of transportation time and cost. Since there are many alternative solutions, this paper takes three special solutions for analysis, as shown in Table IV.

It can be seen from Table IV that the number of transfers between scheme 1 and scheme 3 is relatively large, and there is little difference between scheme 1 and scheme 3. There is a large difference in the travel between scheme 2 and the other two schemes. Considering the feasibility of travelers' travel plans, it means that the range of time expectation value is $[13.8, 21.9]$, and the range of cost prospect value is $[301.9, 341.6]$.

VI. DISCUSSION AND ANALYSIS

A. Parametric Analysis of the Time Expectation Values

The time expectation values are mainly affected by risk attitude parameters (the gain sensitivity coefficient and the loss sensitivity coefficient) and perceived probability parameters (the weight benefit coefficient and the weight loss coefficient). In order to analyze the sensitivity of time expectation values and the time expectation values of the three schemes that were taken as the research object, the impact of parameters on time expectation values are shown in Fig. 7 to Fig. 9.

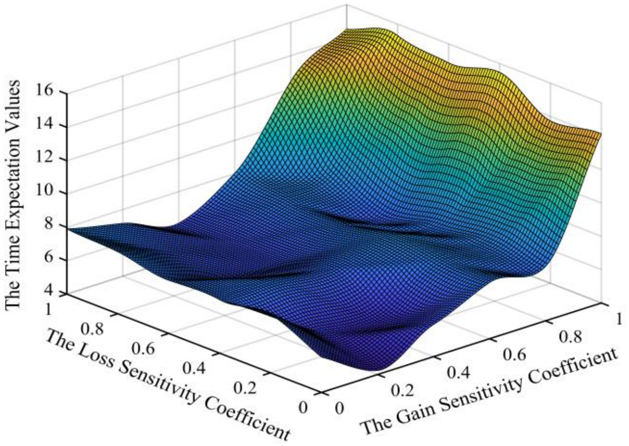

Fig. 7. The effect of the parameter α, β on the time expectation values of scheme 1

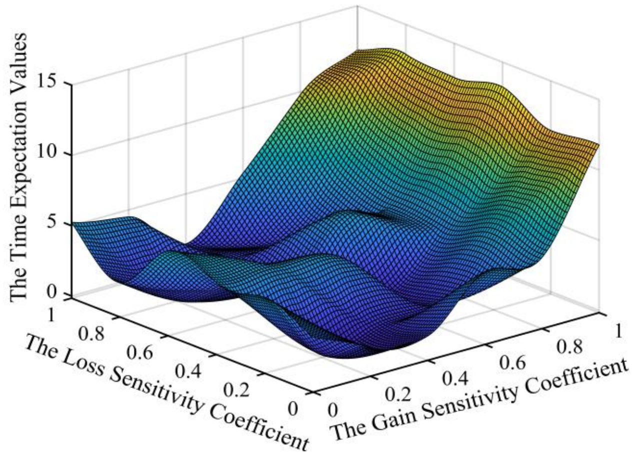

Fig. 8. The effect of the parameter α, β on the time expectation values of scheme 2

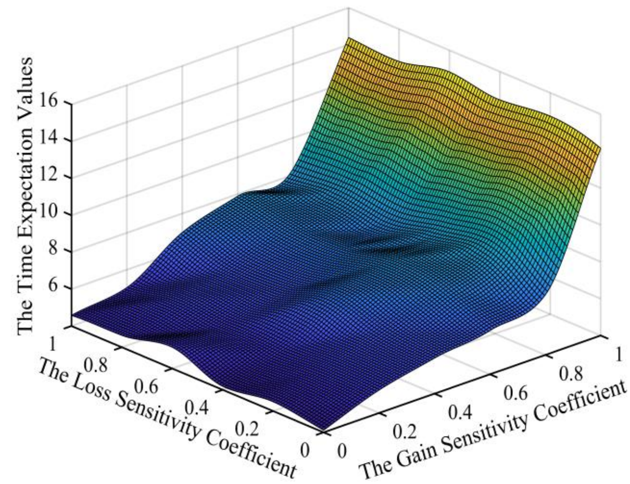

Fig. 9. The effect of the parameter α, β on the time expectation values of scheme 3

As can be seen from Fig. 7 to Fig. 9, both the gain and loss sensitivity coefficients affect the time expectation values. Still, the influence of the gain sensitivity coefficient on the time expectation values are much more significant than that of the loss sensitivity coefficient. Considering the travelers' perception of travel time under the three scenarios, the above phenomenon shows that: when travelers pay more attention to travel time, they pursue gains while avoiding risks.

The time expectation values of the three schemes were taken as the research object for analysis. Fig. 10 to Fig. 12 show the influence of parameters (the weight benefit coefficient and the weight loss coefficient) on the time expectation values.

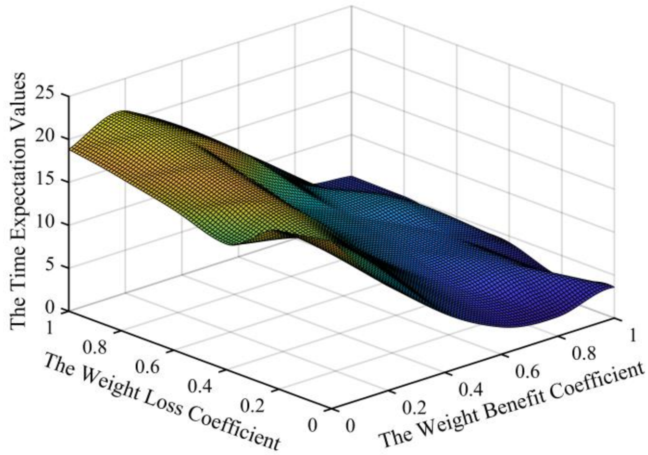

Fig. 10. The effect of the parameter on the time expectation values of scheme 1

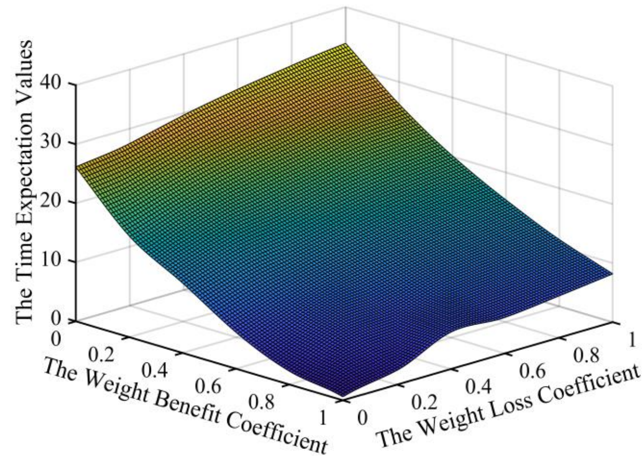

Fig. 11. The effect of the parameter on the time expectation values of scheme 2

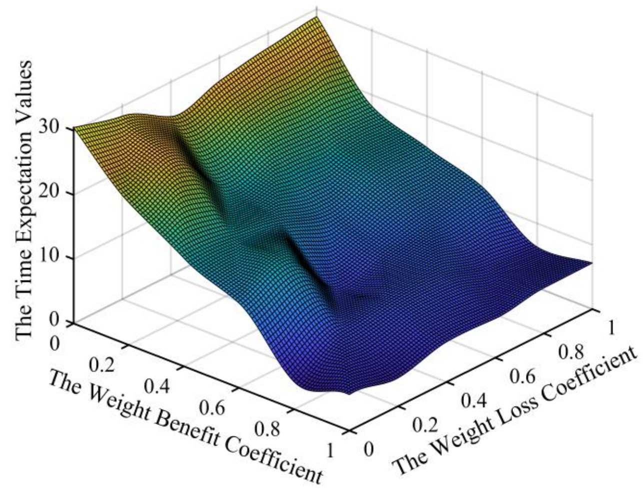

Fig. 12. The effect of the parameter on the time expectation values of scheme 3

As can be seen from Fig. 10 to Fig. 12, the weight loss coefficient and the weight benefit coefficient jointly affect the time expectation values, and the time expectation values are negatively correlated with the weight benefit coefficient. The increase in the weight loss coefficient has no significant impact on time expectation values, but as the weight benefit coefficient decrease, time expectation values gradually increase. Among the three schemes, the effect of the weight benefit coefficient on time expectation values are more sensitive than the impact of the weight loss coefficient on time expectation values.

B. Parametric Analysis of the Cost Expectation Values

Cost expectation values are mainly affected by risk attitude parameters (the gain and the loss sensitivity coefficients) and perceived probability parameters (the weight benefit and weight loss coefficients). In order to analyze the sensitivity of cost expectation values to the gain sensitivity coefficient, the loss sensitivity coefficient, the weight benefit coefficient and the weight loss coefficient, and the cost expectation values of the three schemes were taken as the research object, and the influence of parameters the gain sensitivity coefficient and the loss sensitivity coefficient on cost expected values are shown in Fig. 13 to Fig. 15.

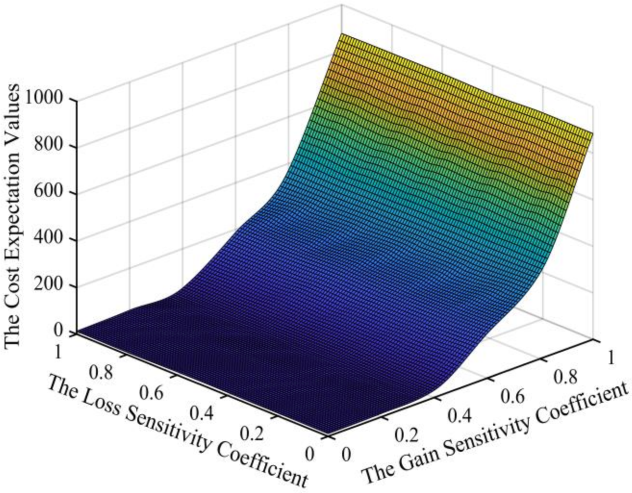

Fig. 13. The effect of the parameter on the cost expectation values of scheme 1

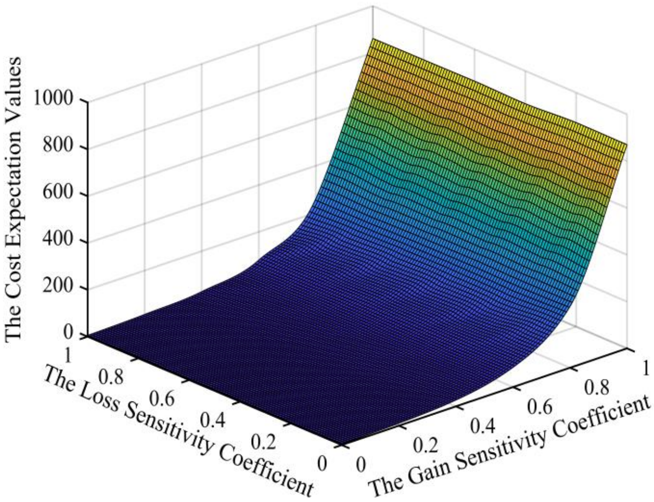

Fig. 14. The effect of the parameter on the cost expectation values of scheme 2

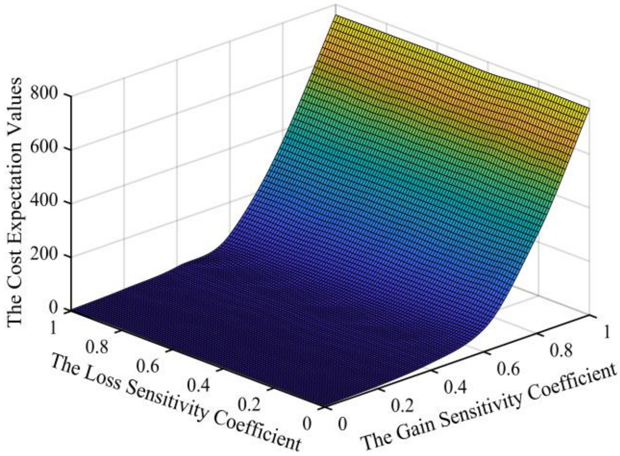

Fig. 15. The effect of the parameter on the cost expectation values of scheme 3

As can be seen from Fig.13 to Fig.15, the cost expectation values increase with the increase of the gain sensitivity coefficient and are not affected by the loss sensitivity coefficient. All three schemes were more sensitive to the gain sensitivity coefficient, suggesting that travelers would be more inclined to avoid risks to preserve the current gain.

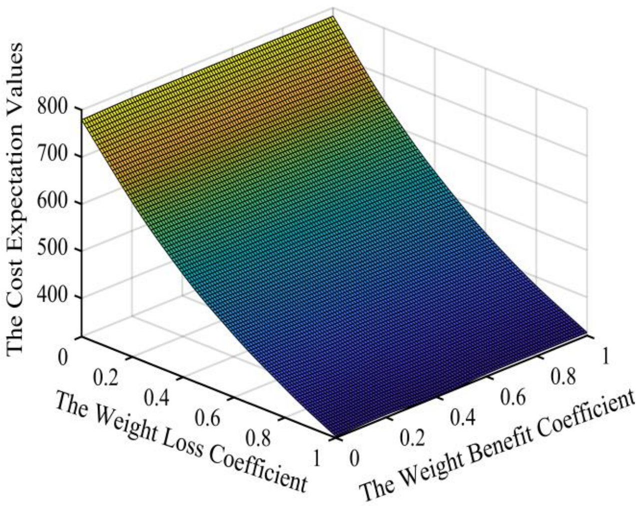

Fig. 16. The effect of the parameter on the cost expectation values of scheme 1

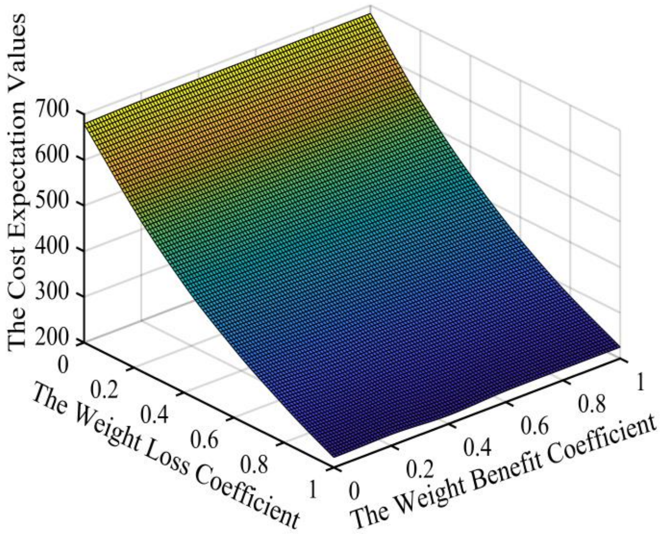

Fig. 17. The effect of the parameter on the cost expectation values of scheme2

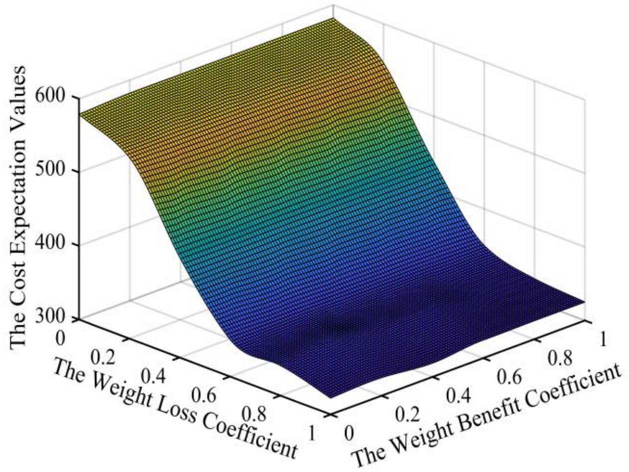

Fig. 18. The effect of the parameter on the cost expectation values of scheme 3

Fig. 16 to Fig. 18 show that the weight loss coefficient is more sensitive than the weight benefit coefficient. The cost expectation values decrease with the increase of the weight loss coefficient and growth with the rise of the weight gain coefficient. This shows that the weight loss coefficient affects the cost expectation values.

When travelers are more concerned about travel costs, the travel time changes relatively gently, indicating that travelers are more inclined to retain the current gains and avoid risks; when travelers consider two objective functions at the same time, they tend to pursue gains and avoid risks; when travelers pay more attention to travel time, they pursue gains while avoiding risks.

Using scheme 2 as an example, both the crowding coefficient and the weather reduction coefficient affect the time expectation values and the cost expectation values.

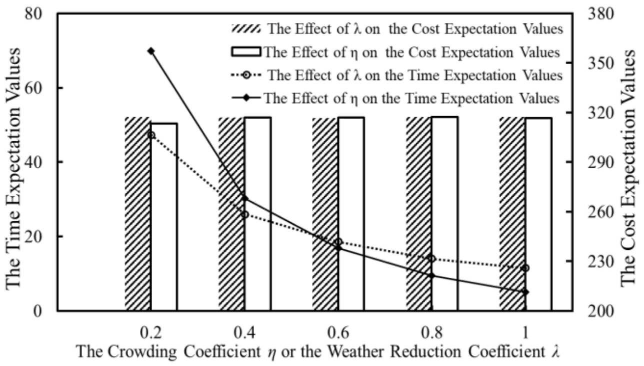

Fig. 19. The effect of reduction coefficient on the target values

As seen in Fig. 19, the crowding and weather reduction coefficients significantly impact the time expectation values. The impact is most significant when the crowding coefficient is 0.2, and the weather reduction coefficient is 0.2. The road traffic conditions are poor, and the weather conditions need to be improved. With the continuous increase of the crowding coefficient and the weather reduction coefficient, the road surface conditions gradually improve, and the prospect values gradually become smaller but stabilize progressively. However, the crowding and weather reduction coefficients have little effect on the cost expectation values. Under bounded rationality, travelers make reasonable judgments on route selection based on limited cognition and information.

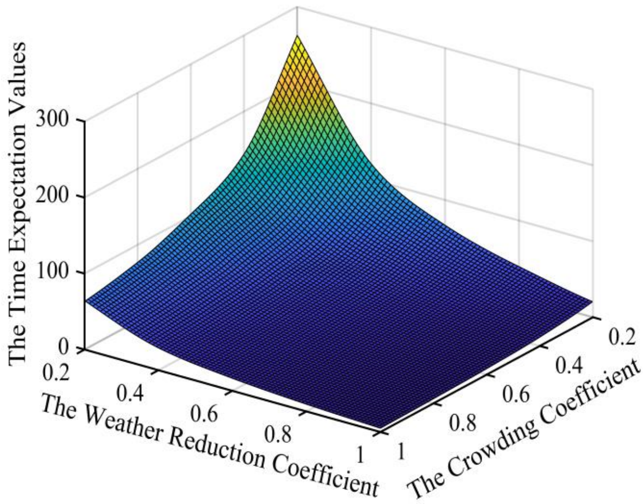

Fig. 20. The effect of the reduction factor on the time expectation values

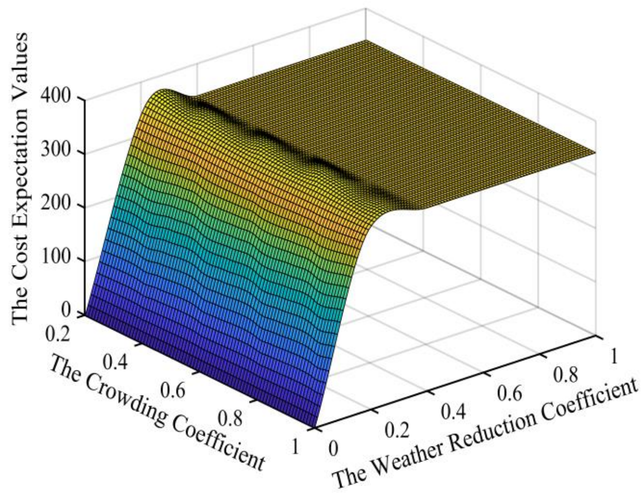

Fig. 21. The effect of the reduction factor on the cost expectation values

As can be seen from Fig.20, when the crowding coefficient is 0.2222, the weather reduction coefficient is 0.2222, the crowding coefficient and the weather reduction coefficient have the greatest influence on the time expectation values, with the continuous increase of the crowding coefficient and the weather reduction coefficient, the road traffic is gradually smooth, the weather is gradually better, and the time expectation values gradually tends to be stable. As shown in Fig. 21, both the crowding coefficient and the weather reduction coefficient have certain effects on the cost expectation values. When the crowding coefficient is 0.2525, the weather reduction coefficient is 0.2424, the maximum the cost expectation values of objective function is 384.2, but the crowding coefficient and the weather reduction coefficient have little influence on the cost expectation values. Both the time expectation values and the cost expectation values are greater than 0, indicating that the travelers' perception of time and cost is beneficial under the condition that the crowding coefficient and the weather reduction coefficient change.

VII. Conclusion

By considering the bounded rational behavior of travelers, this paper establishes a travelers' intermodal transport optimization model and designs a multi-objective hybrid quantum evolutionary algorithm to solve the model. Find three special solutions from the pareto solution set and analyze the influence of various parameters on the travelers' decisions. The simulation results are as follows:

(1) The multi-objective hybrid quantum evolution algorithm not only improves the diversity of the population but also improves the computational efficiency of the algorithm, which can ensure the uniform distribution of non-inferior solutions.

(2) The crowding and weather reduction coefficients have significant effects on the time expectation values but have little impact on the cost expectation values.

(3) The gain and loss sensitivity coefficients affect the time expectation values. Still, the effect of the gain sensitivity coefficient on time expectation values is much greater than the loss sensitivity coefficient.

In future research, it is necessary to investigate the situation where travelers have multiple trips and prior experience.

REFERENCES

[1] M. Yang, H. W. Li, Y. F. Ren, C. W. Zhang, "Road-rail intermodal travel recommendations based on a passenger heterogeneity profile," *J Tsinghua Univ* (*Sci & Technol*), vol.62, no.7, pp.1220-1227, 2022.

[2] L. Chen, E. J. Yao, Y. Yang, and T. Y. Lu, "Modeling of transfer behavior between urban hubs of intermodal passengers," *Journal of Bei Jing JiaoTong University*, vol.45, no.4, pp.79-88, 2021.

[3] R. R. Clewlow, J. M. Sussman, and H. Balakrishnan, "Interaction of High-Speed Rail and Aviation," *Transportation Research Record: Journal of the Transportation Research Board*, vol.2266, no.1, pp.1-10, 2012.

[4] X. Y. Li, C. M. Jiang, K. Wang, J. Ma, "Determinants of partnership levels in air-rail cooperation," *Journal of Air Transport Management*, vol.71, pp.88-96, 2018.

[5] Y. Qiu, Y. M. Yang, and H. P. Zhou, "The optimization research for intermodal tourist transport network design between high-speed rail and highway," *Journal of Changsha University of Science & Technology* (*Natural Science*), vol.12, no.4, pp.17-23, 2015.

[6] W. Y. Zhang, X. F. Wang, and K. Yang, "Uncertain multi-objective optimization for the water-rail-road intermodal transport system with consideration of hub operation process using a memetic algorithm," *Soft Computing*, vol.24, no.5, pp.3695-3709, 2020.

[7] G. Ren, Z. P. Zhou, and H. R. Zhang, "Application of discrete choice model in trip mode structure forecast: a case study of Bengbu," *Journal of Southeast University* (*English Edition*), vol.27, no.1, pp.83-87, 2011.

[8] C. Domarchi, A. Tudela, and A. González., "Effect of Attitudes, Habit and Affective Appraisal on Mode Choice: an Application to University Workers," *Transportation*, vol.35, no.5, pp.585-599, 2008.

[9] Z. H. Zhang, H. Z. Guan, H. M. Qin, and Y. Q. Xue, "A traffic mode choice model for the bus user groups based on SP and RP data," *Procedia-Social and Behavioral Sciences*, vol.96, no.6, pp.382-389, 2013.

[10] M. Paulssen, D. Temme, A. Vij, and J.L. Walker, "Values, Attitudes and Travel Behavior: A Hierarchical Latent Variable Mixed Logit Model of Travel Mode Choice," *Transportation*, vol.41, no.4, pp.873-888, 2014.

[11] E. Cherchi, C. Cirillo, and J. de Dios Ortúzar, "Modelling correlation patterns in mode choice models estimated on multiday travel data," *Transportation Research Part A: Policy and Practice*, vol.96, pp.146-153, 2017.

[12] C. Thrane, "Examining tourists' long-distance transportation mode choices using a multinomial logit regression model," *Tourism Management Perspectives*, vol.15, pp.115-121, 2015.

[13] K. Liu and J. Zhou, "Study on the mixed user equilibrium model under the influence of traffic guidance information," *Syst. Eng. Theory Pract*, vol.40, no.2, pp. 415-425, 2020.

[14] S. Nurlaela, and C. Curtis, "Modeling household residential location choice and travel behavior and its relationship with public transport accessibility," *Procedia-Social and Behavioral Sciences*, vol.54, no.4, pp.56-64, 2012.

[15] E. Fernández, J. De Cea, M. Florian, and E. Cabrera, "Network equilibrium models with combined modes," *Transportation Science*, vol.28, no.3, pp.182-192, 1994.

[16] R. D. Connors and A. Sumalee, "A network equilibrium model with travelers' perception of stochastic travel times," *Transportation Research Part B: Methodological*, vol.43, no.6, pp.614-624, 2009.

[17] Z. Zhi, X. F. Pan, L. X. Wang, T. Feng, "Stochastic traffic-assignment with multi-modes based on bounded rationality," *International Symposium for Intelligent Transportation and Smart City, Springer, Singapore*, pp.49-62, 2019.

[18] X. J. Zhang, H. Z. Guan, L. Zhao, and B. Fang, "Nested Logit Model on Travel Mode Choice under Bounderby Rational View," *Journal of Transportation Systems Engineering and Information Technology*, vol.18, no.6, pp.110-116, 2018.

[19] L. J. Tian, Q. Yang, H. J. Huang, C. R. Lu, "The cumulative prospect theory-based travel mode choice model and its empirical verification," *Systems Engineering-theory Practice*, vol.36, no.7, pp.1778-1785, 2016.

[20] B. Li and D. A. Hensher, "Risky weighting in discrete choice," *Transportation Research Part B: Methodological*, vol.102, pp.1-21, 2017.

[21] X. Q. Long, J. Q. Song, J. J. Wang, and H. Z. Guan, "Study on traveler's behavior for bounded-rational decision-making," *Highway Transp. Res. Dev*, vol.33, no.5, pp.105-110, 2016.

[22] Mahmassani and S. Hani, "Dynamic network traffic assignment and simulation methodology for advanced system management applications," *Networks and Spatial Economics*, vol.1, no.3, pp.267-292, 2001.

[23] C. Sun, L. Cheng, and J. Ma, "Travel time reliability with boundedly rational travelers," *Transport Metrical A Transp*, vol.14, no.3, pp.210-229, 2018.

[24] A. Tversky and D. Kahneman, "Advances in prospect the ory: Cumulative representation of uncertainty," *Journal of Risk and Uncertainty*, vol.5, no.4, pp.297-323, 1992.

[25] X. F. Pan, Z. Zuo, and S. C. Zhao, "Improved Multi-Path Assignment Model Based on Prospect Theory," *Journal of Transportation Systems Engineering and Information Technology*, vol.14, no.2, pp.162-167, 2014.

[26] H. L. Xu, Y. Y. Lou, Y. F. Yin, and J. Zhou, "A prospect-based user equilibrium model with endogenous reference points and its application in congestion pricing," *Transportation Research Part B: Methodological*, vol.45, no.2, pp.311-328, 2011.

[27] H. J. Guo, X. F. Yang, and C. X. Ma, "A Study of travel mode choice of transport corridor based on prospect theory," *Journal of Transport Information and Safety*, vol.37, no.4, pp.120-127, 2019.

[28] S. N. Liu, C. F. Zhu, Y. H. Zheng, and Q. R. Wang, "Research on Bi-level Game Scheduling for Emergency Rescue Workers under the Condition of Limited Rationality," *Engineering Letters*, vol.28, no.4, pp.1338-1347, 2020.

[29] X. J. Li and L. Z. Liu, "Route Choice Model for Commuters Based on Cumulative Prospect Theory," *Journal of Transportation Systems Engineering and Information Technology*, vol.15, no.1, pp.173-178, 2015.

[30] J. J. Xia, Z. C. Juan, and J. X. Gao, "Travel Routing Behaviors Based on Prospect Theory," *Journal of Highway and Transportation Research and Development*, vol.29, no.4, pp.126-131, 2012.

[31] S. N. Wu, "Study on route choice of public transportation based on m ixed logit-cumulative prospect theory," *Xi'an University of Architect ure and Technology*, 2021. DOI:10.27393/d.cnki.gxazu.2021.000326.

[32] W. Zhang and R. C. He, "Residents travel mode choice based on prospect theory," *Journal of Computer Applications*, vol.34, no.3, pp.749-753, 2014.

[33] X. L. Shi, "Travel Mode Choice Based on Prospect Theory and Fuzzy Comprehensive Evaluation," *Journal of Transportation Engineering and Information*, vol.16, no.3, pp.119-124, 2018.

[34] W. Wang and H. J. Sun, "Pricing Models in a Highway with Bottleneck Based on reference-dependent Theory," *Journal of Transportation Systems Engineering and Information Technology*, vol.14, no.1, pp.180-186, 2014.

[35] T. Schwanen and D.F. Ettema, "Coping with unreliable transportation when collecting children: Examining parents' behavior with cumulative prospect theory," *Transportation Research Part A*, vol.43, no.5, pp.511-525, 2009.

[36] B. Ma, C.F. Zhu, Y.B. Zhang, Q.R. Wang, "Research on Evolutionary Game of Emergency Material Allocation under Bounded Rationality," *Engineering Letters*, vol.29, no.4, pp.1524-1534, 2021.