Hindawi
Wireless Communications and Mobile Computing
Volume 2022, Article ID 3355883, 9 pages
https://doi.org/10.1155/2022/3355883

WILEY | Hindawi

Research Article

Routes Choice in the International Intermodal Networks under the Soft Time Window

Hong Xiao,[1] **Hengjuan Gong**,[1] **Xiaokun Wang**,[2,3] **and Bo Hang**[4]

[1]*School of Economics and Management, Chongqing Jiaotong University, Chongqing 400074, China*
[2]*School of Economics and Management, Dalian Jiaotong University, Dalian 116028, China*
[3]*Research Institute of the Belt and Road, Dalian Jiaotong University, Dalian 116028, China*
[4]*Computer School, Hubei University of Arts and Science, Xiangyang 441053, China*

Correspondence should be addressed to Xiaokun Wang; wxk@djtu.edu.cn and Bo Hang; bohang@163.com

Received 6 January 2022; Accepted 4 March 2022; Published 6 April 2022

Academic Editor: Kalidoss Rajakani

Copyright © 2022 Hong Xiao et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

There are many transportation nodes in multimodal transport. It is more in line with the actual transportation situation to reasonably select the transportation mode from the perspective of the elastic constraint of arrival time. Considering the elastic constraint of arrival time, the soft time window factor is brought into the research of multimodal transport route optimization, the route optimization model is established, and the appropriate genetic algorithm is selected and designed to deal with it. So as to obtain the optimal transportation scheme of multimodal transport, multimodal transport system optimization involves many factors such as multimodal transport organization, policy, process, responsibility, coordination, and environment.

1. Introduction

Intermodal transport is the use of at least two different modes of transport to move goods from origin to destination in a single transport unit like an ocean container, without handling the goods themselves [1]. It plays a crucial role in global trade and inland goods transportation. Multimodal transport can improve the efficiency, security, and flexibility compared to a single mode of transport while meeting the requirements of shippers. Multimodal transport improves the ongoing operational efficiency of the logistics system. Both improvements are achieved by integrating different modes of transport into a single transport network that exploits the comparative advantages of the different modes. In today's globalized marketplace, the suppliers are more likely to need to reach the customers over great distances [2, 3]. The demand for intermodal freight transportation is increasing and is expected to continue to do so. The rapid development of China's economy has pushed the rapid growth of China's port cargo throughput. The container throughput of Shanghai Port, Shenzhen Port, and Ningbo Port in 2019 was 43.3 million TEU, 27.53 million TEU, and 25.77 million TEU, respectively, ranking the first, the third, and the fourth in the global container throughput. The European Commission (EC) has recognized that shifting freight flows from road to more sustainable modes of transport, such as rail, inland waterways, and maritime transport, is a key policy strategy to "create a sustainable transport system that meets society's economic, social and environmental needs" [4–6].

The majority of long-distance transport demand in the USA and the rest of the world is met by road transport–like trucks. However, road transport also causes significant environmental and congestion problems due to the economic benefits of this mode of transport and the resulting level of service provided to customers. So, it is useful to select the best routes to substantially decrease logistics costs in international intermodal networks [7, 8].

2. Literature Review

There is a rich literature on the vehicle routing problem and how to choose the optimal path for multimodal carriers in multimodal networks. In fact, an intermodal network usually has several nodes from origin to destination. Previous mathematical formulas for intermodal network design have many variables and decision constraints, making them difficult to formulate for large networks, even when other decisions are not taken into account. To solve this problem and incorporate tactical decisions into network design problems, Ghane-Ezabadi [9] developed a combinatorial variable formulation where the entire path of a packet from source to destination is treated as a single combinatorial variable in the mixed integer linear programming (MILP) problem formulation. They developed a form of mixed integer linear programming (MILP) in which the entire path of a packet from source to destination is treated as a single variable. They affect transport costs and the cost of goods in circulation when planning the transport and logistics network. Xiong [10] proposed a two-stage multiobjective Taguchi genetic algorithm to solve a multimodel routing problem with time windows. A mathematical model was constructed with two ideal destinations, different available transport modes and different required delivery times. Rosyida [11] developed an intermodal transportation model that extends to the VRP model and its recovery model and used the metaheuristics, namely, genetic algorithm and simulated annealing, for the NP-hard problem.

Nearly all of the consulted studies concluded that prices or costs of freight transport are the most important performance. Confetera [12] notes that the reliability is somewhat more important in the freight management phase, while Cardebring [13] observes that for intermodal users, the most important thing is the best price. Quality is of paramount importance to road transport users. Most of the studies reviewed concluded that the reliability over time was the most important outcome, receiving a grade of Cardebring [13], Confetera [12], Beuthe [14], or Vandaele [15], and was more important than the journey time. De [16] found that in the case of road transport, a 10% increase in travel time is more reliable than a 10% decrease. This result also applies to a subset of the study, namely, road transport of containers by mode. Ekki [17] modelled the transport network and the associated data with a multilabel graph on travel time minimizing networks to find the shortest path in intermodal transport networks. The developed pathfinding algorithm is presented, in particular by describing a label correction method that updates certain labels associated with nodes in the graph. Wang [18] identified and extended the link between the reduction of total operating costs for carriers and hub operators in the context of a general route choice model for combined carriers. He proposed two methods to solve this problem, one providing a heuristic solution and the other generating a global optimal solution.

Leblanc [19] used a branch-and-bound algorithm to solve a binary programming model for urban transport network planning, which solved the sub-boundary problem assuming deterministic path utility and user equilibrium principle. Meng [20] studied the capacity planning problem for a continuous urban transport network based on the principle of user equilibrium and solved it with an extended Lagrange algorithm. Yamada [21] presented a two-stage scheduling model for freight network planning, in which the problem set is a multiclass problem involving several classes of user traffic assignment problems with deterministic routing. Several heuristic approaches have been tested on real networks, including a genetic algorithm and procedures based on a Tabu search method. As mentioned above, Meng [22] presents the problem of planning an intermodal freight network using deterministic routing services and solves it using a hybrid genetic algorithm. Wang [23] proposed a global optimization algorithm to solve the discrete transportation network planning problem using the relationship between user equilibrium models and the optimal traffic assignment scheme. The study by Min [24] addresses various objectives and requirements for point management. He has developed a finite probability planning model that minimizes costs and risks while meeting the various requirements of point management. The problem for international multimodal transport companies is to find the optimal route for shipments in an international multimodal transport network with time windows and costs [25–27].

In the process of multimodal transport, it will be affected by weather, traffic conditions, and other factors. In practice, customers think that the transportation time is within an elastic range, so they will consider how to minimize the delivery time of the goods, that is, the path optimization under the soft time window. In the research of route problem under soft time window constraints, Wei [28] studied the influence of vehicle speed fluctuation on vehicle route planning with soft time window, introduced the average vehicle speed distribution function, established the route optimization model based on the lowest distribution cost, and designed an improved genetic algorithm. Chen [29] summarized the types of soft time window penalty functions, researched models and solution algorithms, and considered that it is very important to improve distribution satisfaction of how to optimize the soft time window route. Bao [30] considered soft time window, multitype vehicle, and other factors; aimed at minimizing vehicle fixed cost, transportation cost, and waiting time penalty cost; established a multitype vehicle distribution route optimization model under soft time window constraints; and introduced an adaptive competitive strategy and an adaptive competitive genetic algorithm for multitype vehicle selection. Karoonsoontawong [31] studied the multitrip time-varying vehicle route problem with soft time windows and timeout constraints and proposed improving recursive multiobjective planning and equivalent single-objective planning. Bouchra [32] proposed an improved multiobjective local search algorithm based on a hybrid approach in order to optimize multiple mutually opposing objectives simultaneously. Zare-Reisabadi [33] proposed a local search ant colony algorithm and forbidden search algorithm. Iqbal [34] built a soft time window multiobjective route optimization model and solved it using a hybrid metaheuristic technique. Beheshti [35] constructed a model for the soft time window route problem and designed a hybrid generative metaheuristic.

From the above literature reviews, the scholars have made many views in the multimodal path optimization. There are numerous national and international scholars who bring the time factor into the analysis of multimodal transport route optimization and study the optimization of transportation route by solving the shortest transportation time. Multimodal transport has the characteristics of long distance and various uncertain factors in practice, so the operators often consider the route optimization problem with the minimum total cost under the constraint of soft time window. At present, the research on route optimization of soft time window is mainly from the perspective of urban distribution, which only involves one mode of transportation. The research content is relatively simple. In this paper, the soft time window constraint model is applied to the route optimization of freight multimodal transport. The total time of multimodal transport is set as an elastic time range. The route selection optimization model with the goal of minimizing the total cost of multimodal transport under the constraint of soft time window is constructed. The genetic algorithm is designed. The example is calculated and solved by matlab2012a software. And the effectiveness of the model and solution algorithm is verified.

2.1. Establishment of Optimization Multimodal Transport Model under Soft Time Window Problem Description. If a shipment of goods will be transported from "O" (the origin) to "D" (the destination), there are N nodes (including "O" and "D") on the way of transportation, and there are M modes of transport between each pair of nodes. Each mode of transportation between nodes has corresponding transportation distance, cost, and time, and different costs and time are generated by the transit of goods between different transportation modes at the midway nodes. In practice, the goods are required to arrive the destination within a time range. Detention charges will be incurred in case of early delivery, and penalty charges will be incurred in case of late delivery. How to choose an optimization transport route and the corresponding internode transport mode to minimize the total transport costs?

2.2. Model Assumes. In order to make the study of multimodal transport path optimization more consistent with the actual situation, the following assumptions are made:

(1) Containers are used as carriers of transport during the carriage of goods, and the volume of cargo remains constant during transport

(2) The goods transfer only occurs at the nodes. In addition, the number of transits at a certain node shall not more than one

(3) The carriage of goods between nodes can only rely on a certain kind of transporter mode

(4) The impact of cargo damage, weather, and other factors on transportation shall not be considered

(5) The arrival of goods in advance will incur detention charges

(6) The late arrival of the goods will incur penalty charges

2.3. Model Establishment. Based on the lowest-cost model for multimodal transport paths is set under the soft time window, for example:

$$\min Z = \sum_{i\in N}\sum_{j\in N}\sum_{k\in m} c_{ij}^k \cdot d_{ij}^k \cdot y_{ij}^k \cdot q + \sum_{i\in N}\sum_{(k,l)\in m} c_i^{kl} \cdot x_i^{kl} \cdot q + p_1 \max(a - t_D, 0) + p_2 \max(t_D - b, 0) \quad (1)$$

$$s.t. \sum_{k\in m} y_{ij}^k = 1, (i,j) \in N, i \neq j, \forall i, j, k \quad (2)$$

$$\sum_{(k,l)\in m} x_i^{kl} = 1, \forall i \quad (3)$$

$$q \leq Q_{ij}^k, \forall i, j, k \quad (4)$$

$$t_j = \sum_{(k,l)\in m}\sum_{i\in N}\left(t_i^k + \overline{t_i^{kl}} + t_{ij}^l\right), \forall i, j, k, l \quad (5)$$

$$f = p_1 \max(a - t_D, 0) = \begin{cases} p_1(a - t_D), t_D \langle a \\ 0, t_D \geq a \end{cases} \quad (6)$$

$$g = p_2 \max(t_D - b, 0) = \begin{cases} 0, t_D \leq b \\ p_2(t_D - b), t_D \rangle b \end{cases} \quad (7)$$

$$y_{i-1,i}^k + y_{i,i+1}^l \geq 2x_i^{kl}, \forall i, k, l \quad (8)$$

$$y_{ij}^k, x_{ij}^k \in \{0, 1\} \quad (9)$$

Among them, q is the freight volume (unit: t); node i and node j have k modes of transport, and the distance between each node and modes is d_{ij}^k; the unit transportation distance cost of the unit cargo between node i and node j in k modes of transport is c_{ij}^k; in node i, the unit case transfer cost generated from the k modes of transport to the l modes of transport is c_i^{kl}. If the transportation mode before and after the node is the same, $c_i^{kl} = 0$; the cargo transportation time from node i to node j in k transport modes is t_{ij}^k; if the k modes of transport are adopted from node i to node j, then $y_{ij}^k = 1$, or $y_{ij}^k = 0$; if the k modes of transport are changed to the l modes of transport at node i, then $x_i^{kl} = 1, (k \neq l)$; otherwise, $x_i^{kl} = 0$. In node i, the transit time generated from the k modes of transport to the l modes of transport is $\overline{t_i^{kl}}$. If the transportation mode before and after the node is the same, $\overline{t_i^{kl}} = 0$; t_i^k refers to the time when the goods transport operation reaches node i by the k modes of transport; t_D refers to the time when the goods transport operation reaches the destination; Q_{ij}^k refers to the limitation of load capacity from node i to node j using k transport modes; The transportation time range stipulated in the transportation contract is $[a, b]$; p_1 is the unit time detention cost of goods waiting at the destination ahead of time; p_2 is the unit time penalty cost of goods arriving at the destination after the specified time.

Equation (1) is a measure of the total cost of freight transport. It is made up of four parts, which are the freight transportation cost $\sum_{i\in N}\sum_{j\in N}\sum_{k\in m} c_{ij}^k \cdot d_{ij}^k \cdot y_{ij}^k \cdot q$; the freight transfer cost $\sum_{i\in N}\sum_{(k,l)\in m} c_i^{kl} \cdot x_i^{kl} \cdot q$; the detention cost caused by the early arrival of the cargo $p_1 \max(a - t_D, 0)$; and the penalty caused by the late arrival of the cargo $p_2 \max(t_D - b, 0)$.

Constraint (2) indicates that only one mode of transportation between nodes can be used; Constraint (3) indicates that goods between nodes can only be transferred once; Constraint (4) indicates that during the transportation, the total weight of the transported goods shall not exceed the maximum load capacity of the transportation method k between nodes; Constraint (5) indicates that the total transportation time from node i to node j equals to the time from the k modes of transport to node i plus the time from the k modes of transport to the l modes of transport at node i and plus the time from node i to node j using l transport modes; Constraint (6) f is the early arrival detention cost function; Constraint (7) g is the delay penalty cost function; Constraint (8) shows the continuity of the movement of goods at transport nodes; Constraint (9) indicates that y_{ij}^k, x_{ij}^k are both 0-1 variables.

3. Algorithm Implementation

3.1. Algorithm Choice. The network optimization problem in this paper belongs to the category of network paths, and network optimization itself belongs to a combinatorial optimization problem, which is also a NP problem. There are many literatures that have proposed to solve the transportation network optimization problems, and a lot of new methods for solving such problems have emerged in computer technology. We summarized the network optimization problems into two categories: deterministic algorithms and random search algorithms.

Currently, there are many unique algorithms for solving network path optimization problems, and each has its own advantages and disadvantages in solving the problem of adaptation. The network path problem itself is a combinatorial optimization problem, often with more local extreme points, and the local extreme points are not the global optimal solution to the problem. Moreover, for some large-scale problems, the search space of the solution is relatively large, and the difficulty of solving is also increased. As one of the species of random search algorithms, the genetic algorithm has good performance in dealing with such problems. Therefore, this paper mainly applies the genetic algorithm to the analysis of path optimization problems.

The genetic algorithm selects all individuals in the population according to the relevant principles, calculates the selection probability based on the fitness function, forms new individuals through a series of individual crossovers and variations, and finally converges to get the optimal solution. The operation of genetic algorithm is a typical search iteration process. Aiming at the problem of multimodal transport route optimization in this paper, the operation steps of genetic algorithm can be described as follows, and the solution flow is shown in Figure 1.

(1) Identify the relevant parameters of the problem

(2) Code the parameters

(3) Initialization of groups

(4) Calculate the value of the objective function and determine the fitness function

(5) Select the corresponding genetic strategies to generate a new population

(6) Judge whether the population meets the convergence condition, and if not, return to Step 6 by modifying the corresponding genetic strategy or parameters

3.2. Multimodal Transport Network Description. A shipment of goods will be transported from "O" (the origin city 1) to "D" (the destination city 11). And there are nine node cities for transportation operation as shown in Figure 2. It is known that the weight of the goods is 10 t and it is planned to use two transportations of 20 ft containers. This chapter selects the hub cities with more developed transportation and multiple transportation modes as the nodal cities. The transportation operation requires the transportation carriers to select a reasonable transportation path and transportation mode to reach the destination within the time range specified by the customer in the transportation contract and minimize the total transportation cost. There are three modes of transport between nodal cities: highway, waterway, and railway, which can be selected. Moreover, different modes of transportation can also be exchanged between node cities. The calculation formula for transportation cost is transportation cost = transportation base price × transportation distance × freight volume.

3.3. Data Statistics. The travel distance and time of different transport modes between each node from "O" to "D" are shown in Table 1 and Table 2, respectively.

In practice, there are some differences between the inflow point and the transfer station of multimodal transportation for the urban traffic conditions when the goods at the nodes are transferred. For example, in node cities, railway transportation needs to be converted into waterway transportation; if the distance between ports and railway stations is relatively farther away, then the transit of goods needs to be connected by road transportation, which will indirectly increase the cost and time of the whole cargo transportation.

So, we consider various situations and assumed that the transfer process is carried out under ideal conditions. That means that the transfer process of two nodes does not require other ways of transportation as the transfer connection and there are no other costs generated except the transfer cost. Detailed freight transfers cost and transit times are, respectively, shown in Table 3 and Table 4.

3.4. Parameter Explain. According to the data of basic transportation price, this paper assumes that the unit distance price of road transportation is 0.6 yuan/ton·km, the unit distance price of waterway transportation is 0.2 yuan/ton·km, and the unit distance price of railway transportation is 0.4 yuan/ton·km. The cost of a container, which is closely related to the number of times it is used, is mainly

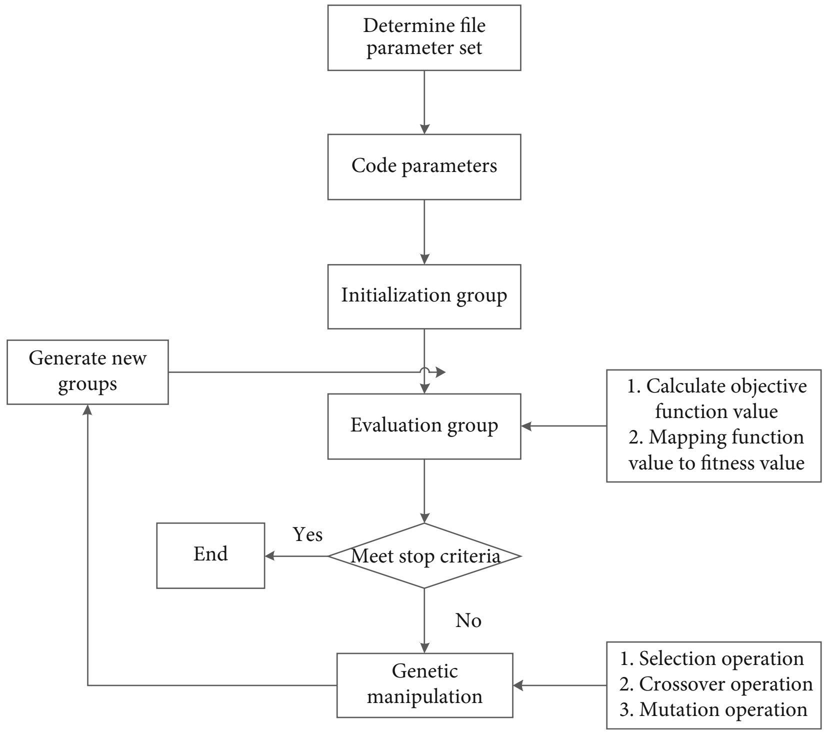

Figure 1: Genetic algorithm solution flow.

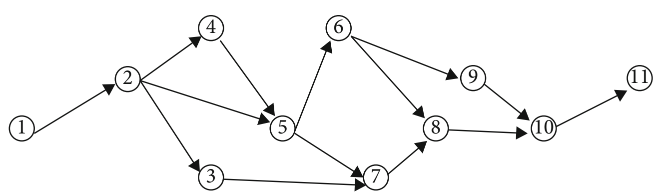

Figure 2: Cargo transportation network.

Table 1: Transport distance parameters between node cities.

Serial number	City node	Transportation distance (unit: km) Railway	Waterway	Highway
1	1-2	—	—	28
2	2-3	26	28	28
3	2-4	31	—	26
4	2-5	27	—	29
5	3-7	—	60	50
6	4-5	30	—	—
7	5-6	30	42	22
8	5-7	—	—	38
9	6-8	45	—	48
10	6-9	32	—	40
11	7-8	—	55	45
12	8-10	35	43	—
13	9-10	—	37	30
14	10-11	—	—	26

Note: "—" means there is no such transportation mode at the node.

considered in the process of cargo transshipment and does not involve transportation costs.

For this cargo transportation, the delivery time range required by the customer is (35, 40) (unit: h); the unit time detention cost caused by the early arrival of the cargo p_1 is 200 yuan/hour; and the unit time penalty cost caused by the delayed arrival p_2 is 200 yuan/hour. The population size is 100; chromosome length is 19; crossover probability p_c is 0.7; mutation probability p_m is 0.1; and iteration times are 100.

3.5. Construction Diagram of Virtual Transportation Network. There are three modes of transportation: highway, railway, and waterway. According to the optional modes of transportation, each node city is now expanded into three virtual nodes (i.e., three inflow points and three outflow points). The modes of transportation at the expansion nodes are represented by corresponding graphs, as shown in Figure 3. If the virtual transport network between the nodes has an appropriate mode of transport, the county line indicates that the goods can be delivered by that mode of transport. According to the given data, the specific virtual

Table 2: Transport time parameters between node cities.

Serial number	City node	Transportation time (unit: hours)		
		Railway	Waterway	Highway
1	1-2	—	—	4.5
2	2-3	6	9	4
3	2-4	6.5	—	5
4	2-5	11.5	—	8
5	3-7	—	17	14
6	4-5	6	—	—
7	5-6	10	6	4.5
8	5-7	—	—	5
9	6-8	4	—	3
10	6-9	5	—	3
11	7-8	—	10	7
12	8-10	4	6.5	—
13	9-10	—	6	4.5
14	10-11	—	—	3

Note: "—" means there is no such transportation mode at the node.

Table 3: Transit costs of various modes of transportation.

Type of shipping	Transfer cost (unit: yuan/box)		
	Railway	Waterway	Highway
Railway	0	45	25
Waterway	45	0	25
Highway	25	25	0

Table 4: Transit time of each mode of transportation.

Type of shipping	Transit time (unit: hours)		
	Railway	Waterway	Highway
Railway	0	2.2	1.5
Waterway	2.2	0	1.5
Highway	1.5	1.5	0

network for multimodal transport of goods can be obtained, as shown in Figure 4.

From Figure 4, it can be seen that from city 1 to city 2, the goods can only be delivered by highway. Therefore, there is only the connection with highway points between node cities 1 and 2. The goods from city 2 to city 3 can be transported by highway, waterway, and railway and to city 4 can be transported by highway or railway. Therefore, from city 2 to the next city, there are two situations: one is continuous transportation mode (still using same transportation mode) and the other is different transfer mode (transferring by other transportation mode), that is, from city 2 to the next node city, still using highways or transferring by railway or waterway.

3.6. Calculation and Analysis. The network path problem itself is a combinatorial optimization problem that often has a high number of local maximum points and is not the optimal solution of the whole situation to the problem. Moreover, for some large-scale problems, the search space of the solution is also relatively large, and the difficulty of solving them also increases. As one of the types of random search algorithms, the genetic algorithm often has good performance in dealing with such problems.

Because the network path problem belongs to the NP-hard problem, it often has more local optimal values, but not the global optimal value. Moreover, the search space for some problems is very large, and the difficulty of solving them also increases. The genetic algorithm is a heuristic algorithm with good global search capabilities, so it is often good at dealing with such problems.

Therefore, this paper mainly applies genetic algorithm to analyze the path optimization problems. Based on the designed genetic algorithm, the author uses MATLAB2012a software to simulate the problem. The running environment of computer is as follows: AMD A6-7310 processor; 4GB memory; and 500G hard disk. By substituting the data, we can get the optimal path of goods transportation: 1 → highway → 2 → railway → 5 → railway → 6 → railway → 8 → railway → 10 → highway → 11. The total transportation cost is 1372 yuan, and the total transportation time is 37 hours. The specific optimal solution iterative process is shown in Figure 5.

At the same time, the optimal path of cargo transportation without considering the time window limitation is calculated as follows: 1 → highway → 2 → highway → 5 → highway → 6 → highway → 9 → highway → 10 → highway → 11. The total transportation cost is 1050 yuan, and the total transportation time is 27.5 hours. It can be seen that the time window constraint still has a certain impact on the calculation results. The path optimization without considering the time window constraint is simply the path of the shortest transportation time and the lowest transportation cost. If the transportation time of the above routes is restricted, the goods will have a detention cost of 1500 yuan due to early arrival, and the final comprehensive cost of goods transportation will be 2550 yuan. In addition, we also note that the railway transportation accounts for a large proportion of the optimal path, which shows that the railway plays a positive role in reducing costs and increasing efficiency. Therefore, China should vigorously explore the development space of railway in the process of developing multimodal transport.

In this thesis, other algorithms are used to test how efficiently they solve problems. The specific results are shown in Table 5.

As can be seen from the comparison of the above results, the transportation route obtained by the genetic algorithm is optimal under the constraint of the time window, which not only ensures the arrival within the specified time range, but also makes the total transportation cost minimum. Compared with Dijkstra heuristic algorithm and greedy algorithm, genetic algorithm improves the transportation time by 2.6% and 3.9%, respectively; and improves the transportation cost by 9.85% and 27.63%, respectively.

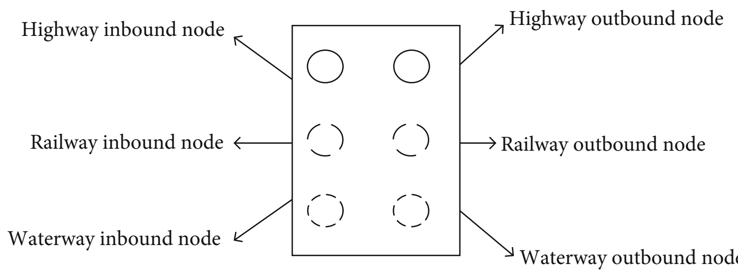

Figure 3: Transportation mode after node expansion.

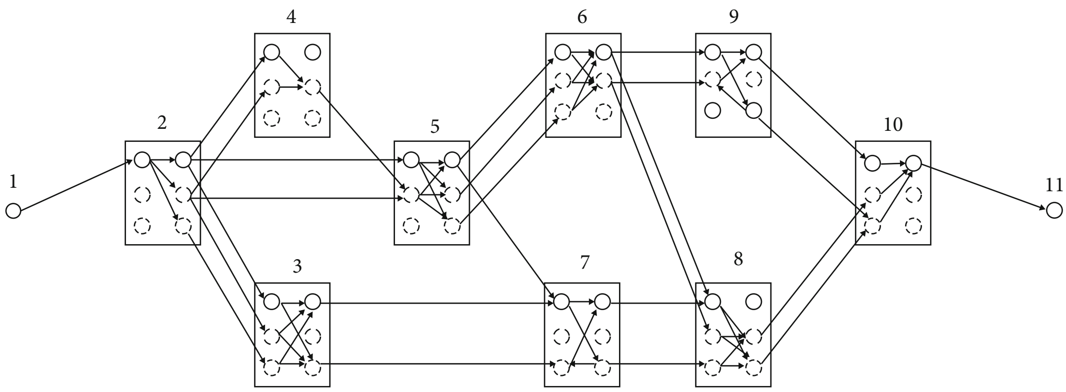

Figure 4: Virtual network of multimodal transport of goods.

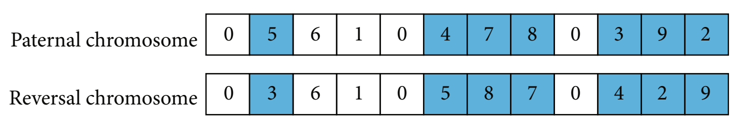

Figure 5: The results of optimal solution.

Table 5: Comparison of algorithm results.

	Optimal path	Transportation cost (unit: yuan)	Transportation time (unit: hours)
Dijkstra heuristic algorithm	1 → highway →2 → highway → 5 → highway → 7 → waterway → 8 → waterway → 10 → highway → 11	1622	38
Greedy algorithm	1 → highway → 2 → railway→ 4 → railway → 5 → railway → 6 → railway → 9 → highway → 10 → highway → 11	1896	38.5
Genetic algorithm	1 → highway → 2 → railway → 5 → railway → 6 → railway → 8 → railway → 10 → highway → 11	1372	37

4. Innovation Points

The current researches on path optimization under soft time window are mainly majored in the urban distribution, problems which involve only one transportation mode, and it is relatively simple. In this paper, we use the soft time window factor for multimodal transportation route optimization research. In the case of many transportation nodes, we choose transportation vehicles reasonably and organize transportation routes from the perspective of time elasticity, which is more efficient and complex than previous research.

5. Conclusion

The summary of this paper are as follows:

(1) Multimodal transport is a complex integrated system, and the system optimization involves many aspects such as multimodal transport policy, transportation specific process, the responsibilities of carriers, transportation modes, and transportation path selection. So, it is more in line with the actual transportation situation to reasonably select the

transportation mode from the perspective of elastic constraint of arrival time, and then we construct a multimodal transportation path optimization model under soft time windows

(2) This paper mainly applies genetic algorithm to analyze path optimization problems. Based on the designed genetic algorithm, we use MATLAB2012a software to simulate the problem. The computer running environment is as follows: AMD A6-7310 processor; 4GB memory; and 500G hard disk. By substituting the data, we can get the optimal path of goods transportation: 1 → highway → 2 → railway → 5 → railway → 6 → railway → 8 → railway → 10 → highway → 11. The transportation route obtained by the genetic algorithm is optimal under the constraint of the time window, which not only ensures the arrival within the specified time range, but also makes the total transportation cost minimum

In this paper, we only studied the optimization of multimodal transportation paths under time windows. We hope that these areas will be improved in the future with possible extensions such as the following:

(1) In considering the time window constraint, each lot transportation time is different due to the difference of transportation modes and the distance, so how to consider the time window constraint for each lot needs to be further studied

(2) In this paper, we study multimodal transportation optimization problems applied the soft time window constraint model only considering cost and time factors; we could also need to consider other factors such as environment in the future research

Data Availability

Data on the results of this study can be obtained from the corresponding authors upon reasonable request.

Conflicts of Interest

The authors say there is no conflict of interest in publishing this paper.

Acknowledgments

The authors wish to thank the Chongqing Municipal Education Commission of China, for its support of the project (No. 21SKGH088); we wish to thank the Science and Technology Development Program of Central Guide to Local Government of China (No. 2019ZYYD043) and Xiangyang Science and Technology Project.

References

[1] C. Macharis and Y. Bontekoning, "Opportunities for OR in intermodal freight transport research: a review," *European Journal of Operational Research*, vol. 153, no. 2, pp. 400–416, 2004.

[2] W. Zhou, L. Yu, Y. Zhou, W. Qiu, M. Wu, and T. Luo, "Local and global feature learning for blind quality evaluation of screen content and natural scene images," *IEEE Transactions on Image Processing*, vol. 27, no. 5, pp. 2086–2095, 2018.

[3] Z. Lv and H. Song, "Mobile internet of things under data physical fusion technology," *IEEE Internet of Things Journal*, vol. 7, no. 5, pp. 4616–4624, 2020.

[4] CEC, "Communication from the commission: keep Europe moving – sustainable mobility for our continent. Mid-term review of the European Commission's 2001," in *Transport White Paper*, Commission of the European Communities, Brussels, 2006.

[5] CEC, *Communication from the Commission: A Sustainable Future for Transport: Towards an Integrated*, Technology-led and user Friendly System Commission of the European Communities, Brussels, 2009.

[6] CEC, *WHITW PAPER: European Transport Policy for 2010: Time to Decide*, European Commission, Luxembourg, 2001.

[7] Y. Jiang and X. Li, "*Broadband Cancellation Method in an Adaptive Co-site Interference Cancellation System*," *International Journal of Electronics*, pp. 1–21, 2021.

[8] Z. Lv and L. Qiao, "Analysis of healthcare big data," *Future Generation Computer Systems*, vol. 109, pp. 103–110, 2020.

[9] M. Ghane-Ezabadi and H. A. Vergara, "Decomposition approach for integrated intermodal logistics network design," *Transportation Research*, vol. 89, pp. 53–69, 2016.

[10] G. X. Xiong and Y. Wang, "Best routes selection in multimodal networks using multi-objective genetic algorithm," *Journal of Combinatorial Optimization*, vol. 28, no. 3, pp. 655–673, 2014.

[11] E. E. Rosyida, B. Budi Santosa, I. N. Pujawan, and J. Guo, "Freight route planning in intermodal transportation network to deal with combinational disruptions," *Cogent Engineering*, vol. 7, no. 1, p. 1805156, 2020.

[12] Confetera, *Il mercato dei servizi logistici e di trasporto negli anni'90*, Rome Presented in SPIN, 1997.

[13] P. W. Cardebring, R. Fiedler, C. Reynauld, and P. Weaver, "Summary of the IQ project," in *Analysing Intermodal Quality; a Key Step Towards Enhancing Intermodal Performance and Market Share in Europe*, Hamburg and Paris, 2000.

[14] M. Beuthe, C. Bouffioux, J. Maeyer, G. Santamaria, M. Vandresse, and E. Vandaele, "*A Multicriteria Analysis of Stated Preferences among Freight Transport Alternatives*," in *In: Proceedings of the 7th NECTAR Conference. A New Millennium. Are things the same?*, Umea, 2003.

[15] E. Vandaele and F. Witlox, *Kwaliteitsattributen in het goederenvervoer gemeten: een "stated preference" benadering*, Vervoerslogistieke werkdagen, Connekt, Delft, 2003.

[16] G. De Jong, S. Bakker, and M. Pieters, *Hoofdonderzoek naar de reistijdwaardering in het goederenvervoer, Rand Europe*, Adviesdienst Verkeer en Vervoer (AVV), Leiden, 2004.

[17] D. K. Ekki, "Distance and time in intermodal goods transport networks in Europe: a generic approach," *Transportation Research*, vol. 42, no. 7, pp. 973–993, 2008.

[18] X. C. Wang and Q. Meng, "Discrete intermodal freight transportation network design with route choice behavior of intermodal operators," *Transportation Research*, vol. 95, pp. 76–104, 2017.

[19] L. J. Leblanc, "An algorithm for the discrete network design problem," *Transportation Science*, vol. 9, no. 3, pp. 83–199, 1975.

[20] Q. Meng and X. Wang, "Intermodal hub-and-spoke network design: incorporating multiple stakeholders and multi-type containers," *Transportation Research Part B Methodological*, vol. 45, no. 4, pp. 724–742, 2011.

[21] T. Yamada, B. F. Russ, J. Castro, and E. Taniguchi, "Designing multimodal freight transportation networks: a heuristic approach and applications," *Transportation Science*, vol. 43, no. 2, pp. 129–143, 2009.

[22] Q. Meng, H. Yang, and M. G. H. Bell, "An equivalent continuously differentiable model and a locally convergent algorithm for the continuous network design problem," *Transportation Research Part B Methodological*, vol. 35, no. 1, pp. 83–105, 2001.

[23] S. Wang, Q. Meng, and H. Yang, "Global optimization methods for the discrete network design problem," *Transportation Research Part B Methodological*, vol. 50, pp. 42–60, 2013.

[24] H. Min, "International intermodal choices via chance-constrained goal programming," *Transportation Research*, vol. 25, no. 6, pp. 351–362, 1991.

[25] J. Chen, Y. Liu, Y. Xiang, and K. Sood, "RPPTD: robust privacy-preserving truth discovery scheme," *IEEE Systems Journal*, pp. 1–8, 2021.

[26] B. Li, G. Xiao, R. Lu, R. Deng, and H. Bao, "On feasibility and limitations of detecting false data injection attacks on power grid state estimation using D-FACTS devices," *IEEE Transactions on Industrial Informatics*, vol. 16, no. 2, pp. 854–864, 2020.

[27] T. Wang, X. Wei, J. Wang et al., "A weighted corrective fuzzy reasoning spiking neural P system for fault diagnosis in power systems with variable topologies," *Engineering Applications of Artificial Intelligence*, vol. 92, article 103680, 2020.

[28] D. Q. Wei and X. Zhao, "Research on vehicle routing problem with soft time window under speed fluctuation influence," *Logistics Technology*, vol. 39, no. 5, p. 69-76+98, 2020.

[29] T. Chen, "Review of penalty function for vehicle routing optimization with soft time windows," *Technology Wind*, vol. 12, pp. 230-231, 2020.

[30] W. Bao, J. M. Jia, X. S. Li, and Q. H. Zhou, "Optimization of multi vehicle distribution path with soft time-window," *Logistics Sci-Tech*, vol. 43, no. 10, pp. 76–82, 2020.

[31] A. Karoonsoontawong, P. Punyim, W. Nueangnitnaraporn, and V. Ratanavaraha, "Multi-trip time-dependent vehicle routing problem with soft time windows and overtime constraints," *Networks and Spatial Economics*, vol. 20, no. 2, pp. 549–598, 2020.

[32] B. Bouchra, D. Btissam, and C. Mohammad, "Multiobjective local search based hybrid algorithm for vehicle routing problem with soft time windows," *Communications in Computer and Information Science*, vol. 872, pp. 312–325, 2018.

[33] E. Zare-Reisabadi and S. H. Mirmohammadi, "Site dependent vehicle routing problem with soft time window: modeling and solution approach," *Computers & Industrial Engineering*, vol. 90, pp. 177–185, 2015.

[34] S. Iqbal, M. Kaykobad, and M. S. Rahman, "Solving the multi-objective vehicle routing problem with soft time windows with the help of bees," *Swarm and Evolutionary Computation*, vol. 24, pp. 50–64, 2015.

[35] A. K. Beheshti and S. R. Hejazi, "A novel hybrid column generation-metaheuristic approach for the vehicle routing problem with general soft time window," *Information Sciences*, vol. 316, pp. 598–615, 2015.