

Optimization of multimodal transportation path selection under low-carbon and time-schedule situation

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Abstract. Multimodal transportation has improved the effectiveness and efficiency of the transport and logistics industry. Unifying a transport unit and selecting a reasonable transport plan dramatically save both time and cost of delivery. Considering that time schedules exist in marine and airline logistics, more and more focus on the sustainability of the transport industry and the special need time-sensitivities cargos, this paper will establish an optimization model with the goal of minimizing the total cost of transportation, which is the combination of transport cost, time efficiency and consideration of carbon emission. The genetic algorithm will be used to solve the problem in this article. The effectiveness of this model is proved to be effective through the application of the case study, and the study results can provide support in decisioning a multimodal transport plan.

Keywords: Multimodal transport, Low carbon emission, Time schedule.

1. Introduction

1.1 Background

Nowadays, multimodal transport has brought convenience to the transport and logistics industries. Compared with traditional single-mode transportation, multimodal transport performs longer-distance transportation by making a connection between various transportation modes, such as road, railway, and marine. And this transportation method uses a united transport unit to provide a faster speed, lower price, and safer process in the delivery of cargo.

However, in recent years, there are raising concerns about excessive greenhouse emission problems, especially in the transportation industry. Due to the highly dependent on fossil fuels, approximately 37% of carbon emissions are produced by the transportation industry. Therefore, reducing carbon emissions in the transportation industry could help society to achieve the goal of energy conversation, and help the industry to achieve sustainable transportation.

What's more, time is also an important value in the transportation industry. For one thing, delivery time will directly have an impact on the price of time-sensitive products, the other reason is that delivery on time is the restriction and basic standard in the transportation industry, otherwise, the delay penalty fee will be paid.

Thus, this paper aims to study multimodal transport under the background of low-carbon emission and time restriction, and finally find out the best path that has minimize total cost.

1.2 Literature review

In 2022, Wong et al describe the concept and advantages of multimodal transport in their paper, according to the statement, multimodal transport is connecting various transportation modes into a whole transport process based on the same transport unit, and multimodal transport will save delivery time and the total cost [1]. Zheng et al used the knowledge of mathematics, linear planning method, and use of algorithms to optimize the multimodal transport path [2]. The linear planning method is broadly used in optimizing multimodal transport roads that pursue the minimization of the total cost. Liang et al used data to perform a linear planning method aligned with an improved genetic algorithm, and in his paper, the total was divided into various parts including transportation cost, transit cost, and carbon emission cost [3].

Transportation cost is necessary for path optimization problems, in Zhao's paper, transportation cost is related to the data of transport distance, speed, volume, and unit transport cost [4]. Furthermore,

Hu used a time schedule method to improve the objective of the analysis result, and his paper is based on the background of sea-rail multimodal transport. And this paper introduced a transit cost to achieve the facticity of the transit process in multi-modal transport [5]. In addition, since time is also an important factor in transport problems, Jiang used a waiting cost to restrict the time that cargo is detained in the transit station or port [2], and other studies also used the method of the fulfillment of customers to improve the time efficiency, in Song's paper, a concept of time penalty cost was also introduced to improve the timer efficiency, in this method a coefficient was used, and the whole cargo was viewed as an entirety when calculating this cost [6].

With the introduction of a new concept of sustainability, there are several new approaches in linear planning methods to achieve the goal of green transportation, and in Feng's paper, he used the method of the carbon tax, which switches the abstract carbon emission to a specific cost and add it into the whole linear planning model to achieve a minimization of the total cost [7]. Okyere et al created an SMFTLS model based on Ghana's geographic background. This model also included the carbon emission cost to achieve sustainable logistics, an assumed unit carbon emission cost, and delivery speed and distance used to calculate the carbon emission cost [8].

And except for the various components of costs, the modes of multimodal transport are different. Xu et al mainly focus on the optimization of expressway logistics based on the multimodal transport mode, this kind of transportation mode can effectively reduce the transport cost through the advantages of flexibility and convenience [9]. Jiang points out that it should have a schedule related to marine and rail transport, and in his paper, he introduces a new time calculation method that includes wait time based on the time schedule in transit stations and ports [10].

Recently, more and more innovative and improved algorithms were created to solve the path selection problem. Ge used the ant Colony Algorithm to minimize the total transport cost based on no time schedule limitation, and he point out that the advantages of compatibility and modifiability of this algorithm will produce a high-quality result in solving path selection problems [11]. In Jiang's paper, he used a genetic algorithm to optimize the path selection based on a time schedule limitation, and he create three parts of the population in his improved algorithm, and a correction operator is used to create and modify feasible results [10].

1.3 Objective

This paper is to study the optimization of multimodal path selection based on the improvement of lower carbon emission and shorter delivery time. Lower carbon emission refers to the use of carbon cost and the minimization of total cost; shorter delivery time refers to the use of port time window and time penalty cost. Compared with other multimodal transport optimization papers, which solely focus on sustainability or time value and rarely consider airline transport, this paper will make a connection between multimodal transport path selection, sustainable transportation, and time schedule, and provide an airline selection in the final transport step. From the micro level, the experiment result will provide the best transport path with the lowest cost. On the macro level, the study result will contribute to achieving the goal of sustainable transport and energy saving.

2. Method

2.1 Case description

There is a batch of cargoes in the origin city O, and these cargoes are needed to be transported to the destination city D. During transportation, there are 5 cities in the middle of the delivery process, and figure.1 shows the whole transportation path of this transport mission. In the figure, it is obvious that only the city A, B, and C have accessibility to origin city O, and only city E and F has accessibility to destination city D. In addition, only marine or airline transport is available between the city E, F and destination D, and before that delivery, all other paths are finished by road or train transportation.

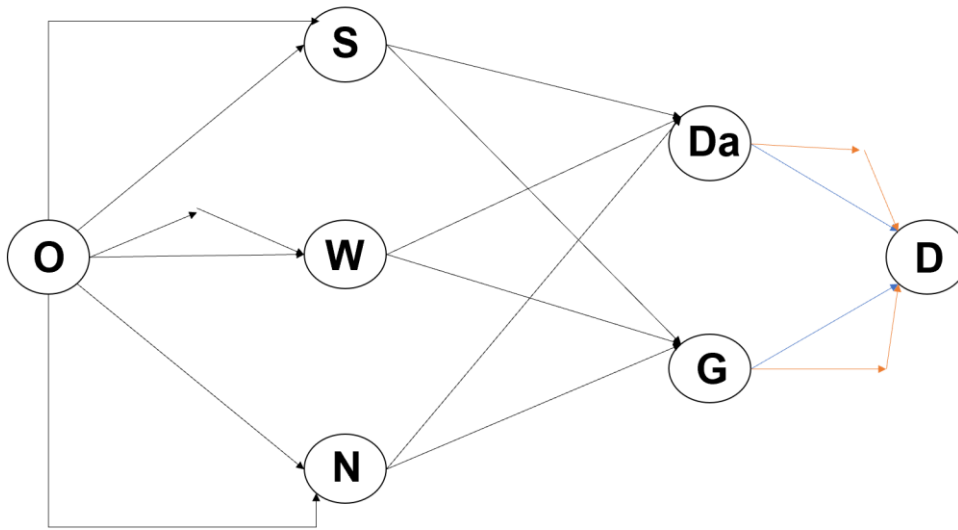


Figure 1. The path between origin and destination

When it comes to the time window of transportation mode, road and train transportation can start delivering directly. However, there is a fixed working time window for marine and airline transportation, and the departure time is restricted by this fixed time window. And the transport speed and unit price of the same transportation mode remains the same among every 2 cities.

During the delivery, cargoes are treated as a whole part, which cannot be separated, and the transshipment operation can be started immediately after the cargoes reach the cities. Therefore, a linear programming model is created to achieve the goal of minimizing the total cost.

2.2 Optimization model

2.2.1 Objective function

Transportation cost

$$C_1 = \sum_{i \in I} \sum_{j \in J} \sum_{m \in M} Q * C_{ij}^m * D_{ij}^m * X_{ij}^m + \sum_{a \in A} \sum_{b \in B} \sum_{n \in N} Q * C_{ab}^n * D_{ab}^n * X_{ab}^n \quad (1)$$

Fixed cost

$$C_2 = \sum_{i \in I} \sum_{j \in J} \sum_{m \in M} Q * C_{ij}^{mf} * X_{ij}^m + \sum_{a \in A} \sum_{b \in B} \sum_{n \in N} Q * C_{ab}^{nf} * X_{ab}^n \quad (2)$$

Transshipment cost

$$C_3 = \sum_{i \in I} \sum_{j \in J} Q * C_i^s * X_i^s + \sum_{a \in A} \sum_{b \in B} Q * C_a^s * X_a^s \quad (3)$$

Carbon emission cost

$$C_4 = \sum_{i \in I} \sum_{j \in J} \sum_{m \in M} Q * C_e * E_{ij}^m * D_{ij}^m * X_{ij}^m + \sum_{a \in A} \sum_{b \in B} \sum_{n \in N} Q * C_e * E_{ab}^n * D_{ab}^n * X_{ab}^n \quad (4)$$

Time penalty cost

$$C_5 = \mu * Q * (T - T_s) \quad (5)$$

Total cost

$$C_T = \text{Min} (C_1 + C_2 + C_3 + C_4 + C_5) \quad (6)$$

2.2.2 Description of variables

Q – Quantity of order(TEU)

m – Transportation mode(Road, Railway; A – E,F)

n– Transportation mode1(Airline, Marine; E,F- G)

i, j – Transportation node(i belongs to I = {1, 2, 3, 4}; j belongs to J = {2, 3, 4, 5, 6})

a,b - Transportation node(a belongs to A = {5, 6}; b belongs to B = {7})

- C_{ij}^{mf} – From node i to node j, the fixed cost through transportation mode m
 C_{ij}^m – From node i to node j, the transportation cost through transportation mode m (yuan/TEU)
 C_{ab}^n – From node a to node b, the transportation cost through transportation mode n
 C_i^s – Transshipment cost in the node i(per TEU)
 C_a^s – Transshipment cost in the node a(TEU)
 D_{ij}^m – The distance from node i to node j
 D_{ab}^n – The distance from node a to node b
 V_{ij}^m – From node i to node j, the speed of transportation mode m
 V_{ab}^n – From node a to node b, the speed of transportation mode n
 C_e – Unit carbon emission cost(yuan/TEU)
 E_{ab}^n – Unit carbon emission quantity from node a to node b(/TEU*KM)
 E_{ij}^m –Unit carbon emission quantity from node I to node j(/TEU*KM)
 T_0 – Departure time of this transport mission
 t_i^s – Transshipment time in node i
 t_a^s – Transshipment time in node a
 t_{ij}^m – Transportation time from node I to node j
 t_{ab}^n - Transportation time from node I to node j
 X_{ij}^m – Dummy variable, use transportation mode m from node i to node j
 X_{ab}^n – Dummy variable, use transportation mode n from node a to node b
 X_i^s – Dummy variable, whether do transshipment at node i
 X_a^s – Dummy variable, whether make a transshipment at node a

2.2.3 Constraints

Transportation time:

$$t_{ij}^m = \sum_{i \in I} \sum_{j \in J} \sum_{m \in M} D_{ij}^m / V_{ij}^m \quad (7)$$

$$t_{ab}^n = \sum_{a \in A} \sum_{b \in B} \sum_{n \in N} D_{ab}^n / V_{ab}^n \quad (8)$$

The arriving time of cargo at node a:

$$t_{ia} = T_0 + \sum_{i \in I} \sum_{j \in J} \sum_{m \in M} t_{ij}^m + t_i^s * X_i^s \quad (6)$$

Only one transportation mode is available from node i to node j

$$\sum_{m \in M} X_{ij}^m = 1 \quad (9)$$

Only one transshipment operation is available at each node i

$$X_i^s \leq 1 \quad (10)$$

Only one transportation mode is available from node a to node b

$$\sum_{n \in N} X_{ab}^n = 1 \quad (11)$$

Only one transshipment operation is available at each node a

$$X_a^s \leq 1 \quad (12)$$

Prevent the conflict of the selection of transportation mode, in case transshipment variable is 1 when no transshipment happen

$$X_{i-1i}^T + X_{ii+1}^R \geq 2X_i^s \quad (13)$$

Prevent the conflict of the selection of transportation mode, in case transshipment variable is still 0 when transshipment happen

$$X_{ii+1}^R * X_{i-1i}^T \leq X_i^s \quad (14)$$

Prevent the conflict of the selection of transportation mod, ensure that the pervious path and next path share a same node.

$$\sum_{m \in M} X_{jj+1}^m - \sum_{m \in M} X_{ij}^m \leq 0 \tag{15}$$

Waiting time at port

$$t_{wa} = \begin{cases} a_{i1} - t_{ia}, & t_{ia} < a_{i1} \\ 0, & a_{i1} < t_{ia} < t_{ia} + t_a^s < b_{i1} \\ a_{i2} - t_{ia}, & b_{i1} < t_{ia} + t_a^s \end{cases} \tag{16}$$

Total transportation time

$$T = T_0 + \sum_{i \in I} \sum_{j \in J} \sum_{m \in M} (t_{ij}^m + t_i^s * X_i^s) + \sum_{a \in A} \sum_{b \in B} \sum_{n \in N} (t_{ab}^n + t_a^s * X_a^s) + t_{wa} \tag{17}$$

2.3 Genetic algorithm

In this experiment, the genetic algorithm is used to solve the regression model. Genetic algorithm is suitable to solve the path optimization problems, the algorithm will calculate an accurate result through various steps, which are original population, encoding and decoding, variation, and fitness calculation. In this algorithm, original population will process a fitness calculation, and then create a new generation through selection, crossing and variation process. It will keep produce new generation till the best solution is found. And in this study, roulette method is used to manipulate selection, crossing and variation steps.

3. Case and Results analysis

3.1 Information description

In this case, there are 20 TEU of cargo needed to be transported from origin city O to destination city D in 22 days, and the transportation tools used in this case is container. The distance between each city will be shown in table.1. Working time window of ports and airports will be 8:00 am to 17:00 pm in each day, and the departure time of origin was set as 0 (T0). The cost, speed, and time information are shown as follow tables.

Table 1. Distance between cities

	O-S	O-W	O-N	S-Da	S-G	W-Da	W-G	N-Da	N-G
Road	686	1172	1022	394	2285	1938	979	924	1377
Railway	786	1229	1023	397	3021	2076	1069	1759	1581

Table 2. Information of road and railway transportation

	Road	Railway
V_{ij}^m / V_{ab}^n (KM/h)	60	70
C_{ij}^{mf} (yuan/TEU)	0	149.5
C_{ij}^m / C_{ab}^n (yuan/TEU*KM)	27	16
E_{ij}^m / E_{ab}^n (Kg/TEU*KM)	2.120	0.216

Table 3. Information of marine and airline transport

	Marine	Airline
t_{ab}^n (h) – 5	516	72
t_{ab}^n (h) - 6	480	48
C_{ij}^{mf} (yuan/TEU)	6970	38000
C_{ij}^m/C_{ab}^n (yuan/TEU*KM)	0	0
E_{ij}^m/E_{ab}^n (Kg/TEU)	762	6975

Table 4. Information of transit

	Road/Railway	Marine/Airline
C_i^s/C_a^s (yuan/TEU)	100	200
t_i^s/t_a^s	3	5

3.2 Study result

After solved the problem, an optimized path is produced (In figure 3). In this case, the transportation path is using rail transportation from origin to node S, and then deliver to node Da and still using rail transportation, and finally transport to destination using marine transportation, and the μ is 100. The cost and time information are shown in table 3.5, in this table, it is obvious that the total cost this transportation is 1762485, which include approximate 203505 carbon cost, and the total time of this study is 534 hour(22.25 Days).

However, in another assumption, if the cargo delivered are time sensitive product with less quantity, for example 3 TEU cargo needed to be transport in 15 days, and the μ is 250. After solving the problem, a new optimized path is provided. Different with the original path, this new pat will use airline transport between node Da and destination, while others keep the same. In such way, it will complete the transport mission on time and only uses 89 hours, however, perform a very high cost, which is 78090; and the carbon emission cost is also more than the original plan, which is 216915.8. Therefore, this optimized path only recommended under the situation that cargos need to be transported in a short period of time, or cargo’s value have strong relationship with time, otherwise, this path perform a high cost and environmental damage.

Table 5. The information of optimized path

	Path	Mode	Time	Total cost	Carbon emission cost
20 TEU	O-S-Da-D	Rail/Rail/Marine	534	737400	203505
3 TEU	O-S-Da-D	Rail/Rail/Airline	89	789090	216915.8

4. Limitation & Future Outlook

4.1 Limitation

In this study, there are still some limitations and parts can be improved to make the analysis results more accurate.

From the aspect of regression model, it consider the cost of transport, transshipment, carbon emission, and time. However, the impact of bad weather conditions and traffic congestions, which may lead to the delay of cargo transport and the increase of total cost, are ignored. Therefore, the study result is actually based on a perfect condition, incidents that happen in real transportation are not consider enough.

From the cargo aspects, this research only explore the optimization of multimodal transportation through 20ft (TEU) container, however, cargos that need a refrigeration during the transportation or

hazardous cargos are not appropriate to use the study result, since the transportation price of these kind of cargo are different. Therefore, this study only focus on transportation of general cargo.

From the path aspects, the path model of this study has limitations. The transportation nodes and paths are only examples, there will be more selection of paths in the real life, and the optimized path may different, however, it can all use the regression model to solve. In addition, in this case, marine ports and airports are share a same node, however, there will be a distance between two nodes in the real transportation

4.2 Future Outlook

In the future, the model will be improved to making an analysis, which is closer to the real transportation.

Firstly, there will be a broader selection of transportation paths and nodes, and the destination will be various. In such improvement, the study result and model can apply to various of transportation plan in the real world, and the increments of more port nodes can provide a more accurate study results.

Secondly, the study can introduce more kinds of cargos in the transportation plan. Except the general cargo, refrigerated cargo, hazardous cargo, 40ft container cargo, and so on. Due to the difference in the cargo or container type, the relative cargo handling cost and time will be different, and the unit transport price will also increase with more caution needed on the cargo during transport process. And thus, the study result may be different, for example, cargo that need a flexible transport may prefer the option of road transportation.

5. Conclusion

An optimized multimodal transport route is the key to expert the advantages of saving cost and time of multimodal transport. And in this paper, since the introduce of time schedule, time penalty cost, and carbon emission cost, the study result will be practical, effective, and environment-friendly. After the design of model, the total cost are aimed to achieve a minimization, and the transport path will not the emerge conflicts through the build of constraints. Finally, the best solutions are provided by the genetic algorithm. The study result can be applied to the real transportation plan, and provide a optimized path that are environmental friendly and considering the time constraints. However, this article still have limitations, for example, the study result can only apply to the general cargos, and the quantity of transportation nodes can increasing. In addition, the weather, weekend and holiday influence in time schedule should also be considered. These will be improved in further in research in the future.

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