

Research on an Optimization Model for Coordination Transportation Based on Low-Carbon

De-zhi Zhang^{1,2,3*}, Shuangyan Li¹

¹ School of Transportation Engineering, Central South University, Changsha Hunan 410075

² School of Management, Huazhong University of Science and Technology, Wuhan 430074

³ Logistics Center Department of Wasion Group, Changsha Hunan 401205

*EMAIL: dzzhang126@163.com

Abstract: Based on the analysis of the technical and economical characteristics of transportation modes (such as speed, cost and transport capacity), this paper presents a fuzzy planning optimization model for multi-modal transportation coordination, in which the factors including the transportation cost, CO2 emission of transport tool, transportation time and transfer time with uncertainty, transfer conditions and time-window demanded by customer are considered. According to the characteristic of the optimization model, the genetic algorithm is investigated to solve the proposed model. In the end, a numerical example is provided to validate the model and algorithm. The influence of the optimization solution with the time-windows parameter change is analyzed. Meanwhile, the comparison among the given genetic algorithm (GA) and other methods is presented on search capability for optimization solution. The simulation result shows that genetic algorithm is valid and effective to solve the optimization model for coordination transportation based on low-carbon under uncertain environment.

Keywords: Coordination Transportation, CO2 Emission, Fuzzy Planning, Genetic Algorithm

I. Introduction

With the further push of economic globalization, some large logistics enterprises not only carry out the short distance freight distribution, but also the long one. It may not be the best choice to only involve a single transport tool in the course of a whole trip because each transport tool has its own technical and economic superiority and perhaps the combined mode, namely unified use of multimode in a trip, is a better alternative to bring more benefits. So it is worthy to discuss the problem, i.e., how to make an optimal one from all feasible transport decisions in order to reduce the transport cost and improve the service level. The choice of an appropriate transport mode is extremely important for logistics decision-makers in a global industrial process. The theory and practice application research is focused by many scholars.

So far, there are some literatures about this subject. Gelders and Printelton have presented the outcome of surveys about Logistics decision-makers' perception on the transportation

mode choices[1]. They gave a so-called multi-criteria decision-making model based on census method, which is a qualitative analysis one. On quantitative analysis method, Kasilingam has proposed a model for intermodal choices, but he hasn't taken into account the transport time and capacity constraints [2]. Angelica Lozano investigates the feasible shortest path under multi-mode transportation [3]. Southworth has presented a optimization model on international multi-mode transportation network design problem, and given its solution [4]. Nierat has study the market problem on railway-truck terminals using spatial space theory [5]. Pierre Arnold investigates the aspects of modeling a rail/road inter-modal transportation system [6]. McKinnon gives an overall review of measurement of CO2 emissions from road freight transport using UK relative data [8]. Xiaoyu Yan and Roy J. Crookes analyzes the current status of China's road transport sector in terms of vehicles, infrastructure, energy use and emissions, and presents the comprehensive and appropriate strategies to minimise the adverse impacts of China's road vehicles on energy resources and the environment [9]. Susan Cholette investigates the relationship between energy, carbon emissions and wine distribution. And they found that supply chain configurations can result in vastly different energy and emissions' profiles, varying by up to a factor of 80, and discuss how these results could be incorporated into a winery's overall sustainability strategy [10].

In this paper, we focus on the multi-mode selection problem coordination under uncertain transport time and transfer time considering the amount of CO2 emission of transport tool. The purpose of this paper is to establish a n optimization model of combined transportation that considers both time and cost simultaneously in CO2 emissions of transportation mode, and to develop an effective algorithm to solve the proposed model.

II. Problem Descriptions

As shown in figure 1, a logistics enterprise will send freight from the origin place (O) to destination place (D) via n cities during the trip. There are several available transport tools to choose between any two adjacent cities called a city pair. The cost and time and transport capacity vary with the transport tool selected at the same city pair. During the

whole trip, the total transport time can't exceed the restrictive arrive destination time windows ([early_time, late_time]). Otherwise, some amount of penalty should be given. The transportation time and transfer time are both uncertainty stochastic variables. It is also possible that there exists the transfer between different transport modes (the combined mode trip) for those special freights such as dangerous freights, fresh and living freights. Our object is to combine the transport tools to obtain a best decision, which minimizes the transport cost and satisfies the permitting time and capacity constraints.



Figure 1. The Original Transportation Map

III. Model Formulation Assumptions

The following assumptions are utilized in this paper.

- (1) Only one mode is used for a given city pair, but there may exist mode transfer for the different city pairs so as to obtain the lowest cost alternative.
- (2) The transport costs are assumed to be a linear function of the travel distance.

Notations

J : The set of available transport tools;

I : The set of via cities;

q : The total demand of freight shipment;

M : An infinite large penalty factor;

$x_{i,i+1}^k = \{0,1\}$ The value is 1 if mode k is used to shipment goods from city i to city $i+1$; 0, otherwise;

$r_i^{kl} = \{0,1\}$ The value is 1 if the goods are transferred from mode k to mode l at city i ; 0, otherwise;

$c_{i,i+1}^k$: The unit transport cost from city i to city $i+1$ by transport tool k ;

$e_{i,i+1}^k$: The Unit CO2 emission amount from city i to city $i+1$ by transport tool k ;

$\tilde{t}_{i,i+1}^k$: The fuzzy transport time from city i to city $i+1$ by transport tool k , given the fuzzy transport time is a triangular fuzzy numbers denoted by:

$$[t_{i,i+1}^k(1), t_{i,i+1}^k(2), t_{i,i+1}^k(3)]$$

Δc_i^{kl} : The transfer cost from mode k to mode l at city i .

$\tilde{\Delta t}_i^{kl}$: The fuzzy transfer time from mode k to mode l at city i , given its value is a triangular fuzzy numbers denoted by $[\Delta t_i^{kl}(1), \Delta t_i^{kl}(2), \Delta t_i^{kl}(3)]$;

$Cap_{i,i+1}^k$: The transport capacity of the tool K between node I and $i+1$;

$\mu_i^{kl} = \{0,1\}$: The value is 1 if the transfer conditions are permitted at city i ; 0, otherwise;

$[T^E, T^L]$: The permitting time scope of arriving the destination, and T^E, T^L presenting the earlier time and later time respectively

T_1 : The total time from the origin place (O) to destination place (D)

θ_1, θ_2 : The unit penalty cost for ahead of schedule and unit penalty cost of delaying;

The model is directly formulated as follows:

Model P1:

$$\min Z1 = \sum_{i \in I} \sum_{k \in J} x_{i,i+1}^k c_{i,i+1}^k Q + \sum_{i \in I} \sum_{k \in J} \sum_{l \in J} r_i^{kl} \Delta c_i^{kl} + \sum_{i \in I} \sum_{j \in J} \sum_{l \in J} r_i^{jl} (1 - \mu_i^{kl}) M$$

$$+ \theta_1 \cdot \max[(T^E - T_1), 0] Q + \theta_2 \cdot \max[0, (T_1 - T^L)] Q$$

$$\min Z2 = \sum_{i \in I} \sum_{k \in J} x_{i,i+1}^k e_{i,i+1}^k Q$$

Subject to:

$$\sum_{k \in J} x_{i,i+1}^k = 1 \quad \forall i \in I \quad (1)$$

$$\sum_{k \in J} \sum_{l \in J} r_i^{kl} = 1 \quad \forall i \in I \quad (2)$$

$$Q \leq Cap_{i,i+1}^k \quad \forall i \in I \quad (3)$$

$$\sum_{i \in I} \sum_{k \in J} x_{i,i+1}^k \tilde{t}_{i,i+1}^k + \sum_{i \in I} \sum_{k \in J} \sum_{l \in J} r_i^{kl} \tilde{\Delta t}_i^{kl} = T_1 \quad (4)$$

$$x_{i,i+1}^k, r_i^{kl} \in \{0,1\} \quad (5)$$

This model aims to minimize the sum of the costs, which includes the transport cost, the transfer cost and the penalty cost, and minimize the total amount of CO2 emission. If the condition of transfer is not available, the penalty cost will be infinite, and thus transport plan is not available.

Constraint (1) specifies only one mode is selected for transporting goods between two cities. This ensures non-splitting of the shipment between modes. Constraint (2) implies that transfer takes place at most one time at city i . Constraint (3) represents the transport can't exceed the capacity between city i and city $i+1$ by transport tool k ; Constraint (4) indicates that the total time from the origin place (O) to destination place (D). Constraint (5) is the 0-1 constraint for the decision variables.

III. Solution Algorithm

The model P1 can be converted into the following chance constrained programming with fuzzy parameters, denoted as model P2.

Model P2:

$$\text{Min } \bar{f} \quad (6)$$

s.t.

$$\text{Pos}\{Z \leq \bar{f}\} \geq \alpha \quad (7)$$

Other constraints include the equations (1), (2), (3), (5) in the model P1. $\text{Pos}\{\cdot\}$ denotes the possibility of the event in $\{\cdot\}$. Where,

$$Z = (1 - \lambda) \left[\sum_{i \in I} \sum_{k \in J} x_{i,i+1}^k c_{i,i+1}^k Q + \sum_{i \in I} \sum_{k \in J} \sum_{l \in J} r_i^{kl} \Delta c_i^{kl} + \sum_{i \in I} \sum_{j \in J} \sum_{l \in J} r_i^{kl} (1 - \mu_i^{kl}) M \right] \\ + \theta_1 \cdot \max[(T^E - T^I), 0] Q + \theta_2 \cdot \max[0, (T^I - T^L)] Q \\ + \lambda \sum_{i \in I} \sum_{k \in J} x_{i,i+1}^K e_{i,i+1}^K Q$$

Where, $1 - \lambda$, λ are the weight of the cost object function and CO2 emission function respectively.

The model P2 aims to seek the minimum of the objective function value \bar{f} . The objective value \bar{f} reaches the minimization that objective function Z achieves with at least possibility α if and only if the following conditions are satisfied.

For the completion of this paper, we now provide the following possibility definitions and the corresponding lemma by Zhao [7].

$$\text{Pos}\{\tilde{r} \leq Z\} = \text{Sup}\{\mu_r(x) / x \in R, x \leq Z\} \quad (8)$$

$$\text{Pos}\{\tilde{r} \geq Z\} = \text{Sup}\{\mu_r(x) / x \in R, x \geq Z\} \quad (9)$$

$$\text{Pos}\{\tilde{r} = Z\} = \text{Sup}\{\mu_r(x) / x \in R, x = Z\} \quad (10)$$

where Z is the decision variable of the model.

Lemma 1 Assume that the triangular \tilde{r} is equal to (r_1, r_2, r_3) , then for any given confidence level: α ($0 \leq \alpha \leq 1$),

$$\text{Pos}\{\tilde{r} \leq Z\} \geq \alpha \text{ if and only if } Z \geq (1 - \alpha)r_1 + \alpha r_2.$$

Based on the three lemma 1, the fuzzy chance constraints (7) can be converted into the general constraints (11) as follows.

$$Z_0(\cdot) + \theta_1 \cdot \max[(T^E - t^I), 0](1 - \alpha) \cdot Q + \theta_2 \cdot \max[0, (t^I - T^L)] \cdot \alpha \cdot Q \leq \bar{f} \quad (11)$$

Where, $Z_0(\cdot) =$

$$\sum_{i \in I} \sum_{k \in J} x_{i,i+1}^k c_{i,i+1}^k Q + \sum_{i \in I} \sum_{k \in J} \sum_{l \in J} r_i^{kl} \Delta c_i^{kl} + \sum_{i \in I} \sum_{j \in J} \sum_{l \in J} r_i^{kl} (1 - \mu_i^{kl}) M$$

IV. Solution Algorithm

The method for solving the proposed fuzzy chance constraint programming models can be fallen into two classes. One is to use the solution algorithms for solving the

deterministic models based on the conversion of the chance-constrained programming models into deterministic models. The other is based on stochastic simulation-based genetic algorithms, which are effective for the solutions of the complex chance-constrained programming problems, multi objective problems and goal programming problems (Liu and Zhao, 1998; Liu and Iwamura, 2001).

In this paper, the first method is adopted to solve the proposed model. The main idea of the algorithm is that the fuzzy chance programming model is first converted into a deterministic and mixed integer programming problem, then the converted model is solved by a revised genetic algorithm.

It is very important on how to represent the solution of the investigating problem as chromosome and to design genetic operator. In general, the binary code is a good alternative. The representation of chromosome is denoted as $[u_1, u_2, \dots, u_{n-1}]$.

It indicates that the section i (i.e node i and node $i+1$) will be select the k th transport tool if u_i is equal to K . The objective value can be obtained if the tool of each section is known, which is used to calculate the fitness of the associated chromosome. Crossover operator is applied to the method of partially matched crossover (PMC).

The step-by-step hybrid genetic algorithm is outlined as follows.

Step 1 Choose the main parameters, including the probability of crossover (P_c), the probability of mutation (P_m), the size of population (Pop_size), and the maximum of evolution.

Step 2 Initialization: produce the number of Pop_size of individual by randomization as the initial population.

Step 3 Evaluate the fitness of the individual: Solve the corresponding extended transportation problem for each given chromosome, and calculate the fitness of the individual using normalization designation based on the obtained object function value.

Step 4 Selection: apply the fitness proportional method to select the better parents in order to carry out genetic operation (crossover and mutation).

Step 5 Genetic operation: produce the new population by carrying out crossover operation by the probability of P_c and mutation operation by the probability of P_m .

Step 6 Update the old population combined with the newly generated population.

Step 7 If the certain number of generation reaches the maximum evolution generation, stop; otherwise, go to Step 3.

V. A Numerical Example

The example is shown in Figure.2, on which there are six cities and four transport modes (namely, railway, highway,

air and waterway.) between any two cities. The shipment, q , is assumed to be 38 units. The arrival time restriction is $[120,140]$. The unit penalty cost for advancing and delaying is 1.5 and 2.5 respectively. Other data is shown in the table1-4.

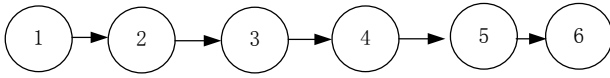


Figure2. Graph of Freight Transport

Table 1 Cost and capacity for each city pair

City pair	1--2	2--3	3---4	4---5	5---6
Railway	20(3)	30(4)	50(5)	30(3)	40(4)
Highway	18(2)	30(2)	45(5)	30(2)	40(5)
Waterway	25(3)	40(4)	60(5)	40(4)	50(5)
Air	10(1)	20(2)	30(2)	15(1)	20(2)

Notes: In table 2, the data in the bracket is variances of transport time and the other is mean value of transport time.

Table 3 Mean value and variances of transfer time

	Railway	Highway	Air	Waterway
Railway	0(0)	5(1)	4(1)	3(1.5)
Highway	5(1)	0(0)	4(1)	5(1)
Waterway	4(1)	4(1)	0(0)	4(1)
Air	6(1.5)	5(1)	4(1)	0(0)

Notes: In table 3, the data in the bracket is variances of transfer time and the other is mean value of transfer time.

Table 4 The unit of transfer cost

City pair	1--2	2--3	3---4	4---5	5---6
Railway	0	1	2	3	0
Highway	1	0	3	2	1
Waterway	2	3	0	4	2
Air	3	2	4	0	3

Table 5 The amount of CO2 emission

City pair	1--2	2--3	3---4	4---5	5---6
Railway	3	4	5	2	6
Highway	4	5	8	3	9
Waterway	2	3	4	2	4
Air	4	6	7	4	7

Suppose that the transport time and transfer time both follow the normal distribution $N(\mu_k, \sigma_k^2)$, their mean value and variances are shown in Table 2 and Table 3. And their triangle fuzzy number are denoted by $[\mu_k - 3\sigma_k, \mu_k, \mu_k + 3\sigma_k]$. Let confidence parameter $\alpha = 0.9$.

The algorithm parameters of GA are given as below, $P_c=0.8, P_m=0.1, P_{\text{popsize}}=30, \text{max_gen}=150, \text{and } \lambda = 0.4$.

According to the given data and degree of confidence, the simulation results produced by the proposed hybrid genetic algorithm coded in C++ are provided as below: total cost =1627, total transport time=137.59, solution vector=[4, 4, 4, 2, 1], which presents the transport tool of the first, second and third section is waterway, the last two selection are highway and railway respectively.

Table 5 shows the performance of the algorithm for different value of arriving time windows.

Table 6 Effect of different arriving time windows

arrive time windows		Optimization solution			
T1	T2	Total cost	Total CO2 emission	Total time	Solution vector
80	100	3382	1140	116.4	4,4,4,4,2
100	120	1824	1140	116.4	4,4,4,4,2
120	140	1672	1216	137.59	4,4,4,2,1
140	160	1330	1102	158.28	2,2,2,2,2
160	180	1216	988	178.5	1,1,2,3,1
180	200	1178	684	197.5	3,1,3,3,1
200	220	1026	646	203.53	3,3,3,3,1
220	240	2506.8	798	211.15	1,3,3,3,2
240	260	2936.3	798	211.15	1,3,3,3,2
260	360	1064	646	203.53	3,3,3,3,1

As seen from the table 6, the optimization solution seem to sensitive to the value of arriving time windows. When the early arriving time changes, the transportation tool selected at different section changes.

In order to compare the quality of optimal solutions by GA proposed in this paper with that of other algorithms, such as lingo 8.0 software package and heuristic algorithm presented in reference 3, we conducted additional computational experiments (table 7). The result of simulation shows the quality of optimal solutions obtained by GA is best. Furthermore, the computational times required by GA is acceptable. So the GA algorithm is effective and efficient for larger-size problems.

Table 7. Comparison of solutions among GA, lingo 8.0 and heuristics algorithm

$ N \times M $	Lingo 8.0		GA		Heuristics algorithm	
	CPU	Obj	CPU	Obj	CPU	Obj
6X4	12''	1627	23''	1627	6''	1635
10X6	26''	7231	37''	7231	13''	7548
20X6	2'8''	1683	1'16''	1589	56''	1699
50X8	55'12''	4235	6'9''	4169	4'29''	4467

notes: $|N|$: number of cities, $|M|$: number of transport tools

VI. Conclusion

This paper presents a fuzzy planning optimization model for multi-modal transportation, in which the factors including the transportation time and transfer time with uncertainty, transfer conditions and time-window demanded by customer are considered. The model is useful to make decisions on how to choose the optimal transport mode and path in the long distance distribution. According to the characteristic of the optimization model, the genetic algorithm is investigated to solve the proposed model. The result of the simulation shows that the GA algorithm is effective and efficient to solve the larger-size multi-modal transportation problems. In this paper, the cities are implicitly assumed to be linked in lines. The future work is to investigate the counterpart with the cities distribution in network shape.

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Background of Authors

Zhang Dezhi received the P.h.D from University of Central South University ,P.R.C, 2006, major in logistics system optimization and Supply Chain management.