The Research on Coordination for Regional Comprehensive Transportation Corridor Based on Multi-objective Genetic Algorithm

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ABSTRACT: At present, the studies of regional integrated transport corridor mainly focus on the planning and construction of transport corridor. Fewer studies investigate harmonious operations among different modes of transport after the completion of transport corridor construction. Regional comprehensive corridor takes on the characteristics of heavy transport demand, supply and travel modes. Meanwhile, competition is severe among different travel modes. In order to avoid vicious competition among different travel modes that negatively impact the transportation market, multi-objective and nonlinear programming model is established with the purpose to maximize the unity of traveler. The objective of this model is to realize mutual adaptation between transport demand volume and supply volume. Tournament selection is applied to weeding out the inferior solution with the concept of non-inferior solutions. The solution that does not meet the nonlinear constraints is obsoleted in the selection process by using the penalty function. Solutions that do not meet the linear and boundary constraints after crossover and mutation process are transferred to feasible solution space via repair algorithm. Pareto optimal solution set is obtained through continuous selection, crossover and mutation. At last, a numeric example demonstrates validity and feasibility of the model.

INTRODUCTION

Regional integrated transport corridor is the artery of the comprehensive transportation system. Plenty of researches on the planning and construction of the regional comprehensive transport corridor have achieved remarkable results. For example; Liu Qiang, Lu Huapu, Wang Qingyun\cite{1} use uncertain planning theory and random utility theory to realize a rational allocation of regional transportation corridor traffic modes in the established selection based on using equilibrium traffic modes in the three layers of nested Logit model. Yao Ming, Hu Ji, and Tang Lin\cite{2} believe that traffic network planning is an important component of the regional transportation construction. The authors use the sector rotation method to identify the importance of nodes and the dynamic clustering analysis to evaluate the regional transportation corridor planning. Zhao Hang, He ShiWei, and Song Rui\cite{3} use discrete optimization method to study network optimization design problem of transport corridor between each group in the area. Liu Qiang, Lu Huapu, and Wang Qingyun\cite{4} take into account construction investment cost, environmental capacity and energy consumption as constraints. At the same time, they consider the corridor level of any
mode of transport line technology and the influence of space layout on corridor layout scheme, establishing a three-layer model of the regional transport corridor planning layout optimization.

At present, studies on regional integrated transport corridor pay much attention to the planning and construction of transport corridor and there is a lack of researches on various modes of transport operations after the completion of transport corridor coordination. In the context of new urbanization construction and considering the operations of all kinds of transportation, the paper studies area transportation in the comprehensive transportation system in the corridor coordination of all kinds of passenger transportation.

ESTABLISHMENT OF MODEL

Travel by the regional comprehensive transportation corridor belongs to short-distance travels. Travel distance is limited by the size and scope of urban agglomeration, which is generally less than 500 km, the average travel distance is between 200km and 300km. In addition to self-driving, public transport can be divided into two parts: the main mode of transportation and connection mode of transportation. The main mode of transportation refers to the transportation between different stations in two towns, such as inter-city buses, intercity rail and ordinary railway. The connection mode of transportation refers to the transportation with which passengers travel leave from the departure city station for the destination city station. The convenience of the connection mode of transportation has a great impact on passengers’ choice of transportation. If the station is too far away from the city and the public transport between stations and cities is underdeveloped, it will seriously affect passengers’ choices of the means of travel. The travel process in the regional transport corridor is shown in Figure 1.

![Figure 1. Trip Process of Regional Trip.](image)

The safety, speed, economy, convenience and other factors all matter in passengers’ choice of travel modes. Safety is the most important factor for passengers, so the transportation department should make unremitting efforts to improve this index, regardless of the number of passengers. All parties involved in the traffic should care for safety, so that the impact of safety is not considered in this paper. Economy mainly refers to the cost of a trip paid by passengers. Speed refers to the travel time from the departure location to the destination. Convenience refers to the feeling and experience of passengers during the transportation. Considering a group of transport corridors within a city, there are a variety of travel modes (e.g.: ordinary roads,
highways, ordinary railway, intercity railway, etc.) for travelers to choose and their choices are usually calculated by the Logit model[6, 7]. Suppose the fare of the i-th main mode of transportation between the two towns is $F_i$, the running time is $T_i$, the average connection time at both ends of the station is $t_i$. According to the Multinomial Logit model, i-th main mode of transportation is selected for:

$$P_i = \frac{\exp(\theta_i^1 \cdot F_i + \theta_i^2 \cdot t_i + \theta_i^3 \cdot T_i)}{\sum_{j=1}^{N} \exp(\theta_j^1 \cdot F_j + \theta_j^2 \cdot t_j + \theta_j^3 \cdot T_j)}$$  (1)

Where: $P_i$ is the probability of selecting the i-th mode of transportation, $\theta_i^1, \theta_i^2, \theta_i^3$, $\theta_i^4$ is the regression parameters of the i-th mode of transportation. Fare $F_i$ reflects economy, the running time $T_i$ of the i-th main mode reflects speed, and the average time of $t_i$ reflects the level of convenience.

Take the total transport demand in the two towns as $R$, the probability of choosing i-th mode of transportation is $P_i$, so the number of selecting i-th mode of transportation is $P_i \cdot R$. If the supply of i-th mode of transportation is $S_i$, the actual ability of using i-th mode of transportation is $P_i \cdot R / S_i$. If the ability to use the ideal coefficient of using i-th mode of transportation is $A$, the difference between the actual and ideal capacity utilization factor is:

$$F_i = \frac{P_i \cdot R}{S_i} - A \quad (i = 1 \ldots N)$$  (2)

Considering the value of the characteristic symbols, the objective function can be expressed as:

$$\min f_i = \left( \frac{P_i \cdot R}{S_i} - A \right)^2 \quad (i = 1 \ldots N)$$  (3)

The demand of the i-th trip mode should be no greater than the supply. If it is not so, this kind of trip mode will generate congestion. So that Safety and efficiency will be lower. $P_i \cdot R \leq S_i \quad (i = 1, 2 \ldots N)$  (4)

At the same time, taking into account the actual circumstances of each trip, the trip characteristics of parameters need to meet the upper and lower threshold value and the model can be established as follows:

$$\min f_i = \left( \frac{P_i \cdot R}{S_i} - A \right)^2 \quad (i = 1 \ldots N)$$  (5)
The formula (5) (6) shows that there is more than one means of travel and that the objective function and constraints are nonlinear. Therefore, the model established in this paper is the multi-objective nonlinear programming model. The decision variables are $t_i$, $F_i$ and $T_i$.

**MODEL SOLUTION**

The above model is multi-objective nonlinear programming, which aims to find an optimal solution $x_{opt}$ to maximize the value of the objective function. It can be expressed as:

$$\text{opt. } (f_1(x_{opt}), f_2(x_{opt}), \ldots, f_N(x_{opt}))$$

subject to $x_{opt} \in U$.

In the formula, $U$ is feasible domain. $x_{opt}$ that maximizes the performance cannot be established because of the contradiction between the various objective functions. Can only be obtained Pareto optimal solution $X$, making all the target the following inequalities are established:

$$f_i(x') \leq f_i(x)$$

Furthermore, there is at least one $i$, $f_i(x') \neq f_i(x)$

Multi-objective planning is to find the appropriate Pareto solution by adopting the concept of inferior solution. The so-called inferior solution to the problem an $x \in U$ that establishes all of the following inequalities:

$$f_i(x) \leq f_i(x'')$$

Furthermore, there is at least one $i$, such that.

$$f_i(x'') \neq f_i(x)$$

There are various definitions for Pareto solution. A solution set consists of multiple solutions, namely front Pareto. According to their own preferences, the decision maker chooses one or more of them from multiple Pareto optimal solutions as the basis for decision-making. According to the characteristics of Pareto solutions,
genetic algorithm can be used to solve. GA can handle more than one solution and use the concept of inferior solutions to eliminate inferior solutions. Crossover and mutation can finally get Pareto front by multiple selections.

Multi-objective genetic algorithm widely used in all walks of life[8, 9], so we adopt multi-objective genetic algorithm to solve the problem.

1. Coding

The model uses floating-point encoding, so that individual is expressed as:

$$X_j = x_1 \ x_2 \ x_3 \ \cdots \ x_n$$  \hspace{1cm} (12)

2. Selecting

This paper adopts the tournament selection, which means choosing the highest fitness of an individual among k individuals to the next generation of genetic population. As follows: (1) randomly selected k individuals to compares the adaptation of the size, and to select the Pareto genetic for the next generation; (2) the process is repeated m times, so the next group of m individuals can be reached.

3. Cross

In this paper, the model uses arithmetic crossover. Arithmetic crossover refers to a linear combination of two individuals to form two new individuals. Suppose that the two individuals are \( X_1 \) and \( X_2 \), after crossing the new individual is \( X' \).

$$X' = rand \cdot X_1 + (1 - rand) \cdot X_2$$  \hspace{1cm} (13)

\( rand \) is subject to uniform distribution of the random number in \([0, 1]\).

4. Variation

The model uses uniform mutation, which can be divided into two steps. In turn, assign each gene in individual code string as a variation point. Each variation point with the mutation probability of p replaces the original from the corresponding gene values range in a random number. If the individual is \( X = x_1 x_2 \cdots x_k \cdots x_m \), variation point is \( x_k \). \( x_k' \) range is \([B_{\min}^k, B_{\max}^k]\). The new value of mutation point is:

$$x_k' = B_{\min}^k + rand \cdot (B_{\max}^k - B_{\min}^k)$$  \hspace{1cm} (14)

\( rand \) is subject to the random number and distribution of both \([0,1]\).
5. Constraints processing

Constraints can be processed by four methods: limit the feasible region strategy; repair strategy; rejection policies and penalty function. In this paper, the model includes both linear and nonlinear constraints.

\[
f_i(x_j) = \begin{cases} 
  f(X_j) & X_j \in U \\
  f(X_j) + P(X_j) & X_j \notin U 
\end{cases}
\]

(15)

In the formula, \( P(X) = \max(0, C) \), \( C \) is a sufficiently large number. \( U \) is a feasible region. Repair strategies are used for linear constraints and boundary constraints. The individual does not satisfy linear constraints or boundary conditions, which is converted to the feasible region by the next model.

\[
f(x) = \|X - \bar{X}\|^2
\]

(16)

\[
AX \leq B
\]

(17)

\[
LB \leq X \leq UB
\]

(18)

EXAMPLES

Considering a regional comprehensive transportation corridor, there are two central cities A and B. Between the two cities there are three travel modes - highways, ordinary roads, intercity railways. By the RP and SP survey data, this paper gets coefficient of the multinomial Logit model after calibrating model parameter of the three kinds of trip mode. As shown in Table 1, the total passenger demand in AB corridor within two points is \( R = 40000/\text{day} \). The supply and the ideal capacity utilization coefficient of the three kinds of trip mode are shown in table 2. At the same time, according to the specific characteristics of each travel mode, the threshold value of the variable is shown in table 3.

<table>
<thead>
<tr>
<th>Trip Mode</th>
<th>( \theta_1^i )</th>
<th>( \theta_2^i )</th>
<th>( \theta_3^i )</th>
<th>( \theta_4^i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercity rail ((i=1))</td>
<td>0.18</td>
<td>-0.007</td>
<td>-0.006</td>
<td>-0.005</td>
</tr>
<tr>
<td>Ordinary road ((i=2))</td>
<td>0.01</td>
<td>-0.035</td>
<td>-0.011</td>
<td>-0.013</td>
</tr>
<tr>
<td>highway ((i=3))</td>
<td>0.08</td>
<td>-0.018</td>
<td>-0.017</td>
<td>-0.0026</td>
</tr>
</tbody>
</table>
Table 2. Supply Characteristic Data of Trip Mode.

<table>
<thead>
<tr>
<th>Trip Mode</th>
<th>Capacity Utilization</th>
<th>Supply Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercity rail</td>
<td>0.8</td>
<td>32000</td>
</tr>
<tr>
<td>Ordinary road</td>
<td>0.85</td>
<td>6000</td>
</tr>
<tr>
<td>highway</td>
<td>0.75</td>
<td>10000</td>
</tr>
</tbody>
</table>

Table 3. Parameters Threshold of Trip Mode.

<table>
<thead>
<tr>
<th>i</th>
<th>$t_{i,min}$</th>
<th>$t_{i,max}$</th>
<th>$p_{*,min}$</th>
<th>$p_{*,max}$</th>
<th>$T_{i,min}$</th>
<th>$T_{i,max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>65</td>
<td>80</td>
<td>120</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>140</td>
<td>10</td>
<td>40</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>100</td>
<td>40</td>
<td>80</td>
<td>20</td>
<td>40</td>
</tr>
</tbody>
</table>

Use Multi-objective genetic algorithm above to program by Matlab. The population size is 200. The probability of crossover is 0.8. The probability of mutation is 0.05. The maximum number of iterations is 200. The results are shown in Table 4 (excerpt 10 solutions).
Table 4. Pareto Optimal Solutions.

<table>
<thead>
<tr>
<th>The Objective Function</th>
<th>Decision Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3</td>
</tr>
<tr>
<td>0.019 0.001 0.000</td>
<td>95 49 44 22 9 52 80 68 0</td>
</tr>
<tr>
<td>0.017 0.000 0.001</td>
<td>95 52 40 23 0 52 79 70 0</td>
</tr>
<tr>
<td>0.007 0.018 0.062</td>
<td>96 55 41 23 0 51 80 68 1</td>
</tr>
<tr>
<td>0.010 0.007 0.031</td>
<td>96 53 42 23 0 51 79 69 1</td>
</tr>
<tr>
<td>0.018 0.000 0.000</td>
<td>95 49 43 22 9 52 80 68 0</td>
</tr>
<tr>
<td>0.007 0.017 0.062</td>
<td>96 54 41 23 0 51 80 68 1</td>
</tr>
<tr>
<td>0.007 0.020 0.061</td>
<td>96 54 41 23 0 51 80 68 1</td>
</tr>
<tr>
<td>0.016 0.000 0.003</td>
<td>96 51 41 22 0 52 80 69 1</td>
</tr>
<tr>
<td>0.007 0.022 0.057</td>
<td>96 54 40 22 1 51 79 68 1</td>
</tr>
<tr>
<td>0.007 0.021 0.054</td>
<td>96 54 41 23 0 51 80 68 1</td>
</tr>
</tbody>
</table>

Figure 2. The diversity of genetic algorithm.
Figure 2 shows the algorithm stops iteration to 150 generations. The average distance between each Pareto optimal solution is 5.

Figure 3. Distribution Pareto solutions (20 the optimal solution in all).

Figure 3 shows the top 20 solutions of Pareto front in accordance with the distribution of the objective function. Figure 4 shows the distribution of solutions after grouping all solutions in the Pareto front based on the size factore. Figure 5 shows the objective function 1 and the objective function 2 in the Pareto front.

Figure 4. Distribution of Grouping of Objective Function Value in Pareto Front.

Figure 5. Pareto Front of Objective Function 1,2.

CONCLUSIONS

This paper investigates the huge transport supply and demand in the regional comprehensive transportation corridor and the fierce competition for each travel mode. In order to avoid vicious competition among various travel modes and to alleviate the disruptions in the normal order of the transportation market, the paper establishes a mathematical model of regional integrated transport corridor coordination. The multi-objective genetic algorithm is designed to provide solutions to the model. This paper also provides a quantitative viewpoint for decision-making when the transportation departments coordinate the development of travel mode.
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REFERENCES


