The study of City Circle's interval traffic forecast based on volume spatial contact model

Fu Junming\textsuperscript{a,b} Yan Taowei\textsuperscript{b} Yuan Erpu\textsuperscript{b}

\textsuperscript{a}School of CML Engineering, Wuhan University; No 8 Donghanan Street, Wuchang District, Wuhan Hubei 430072
\textsuperscript{b}Hubei Communication Planning Design Institute; No 7 Longyang Street, Hanyang District, Wuhan Hubei 430051

Abstract

Based on the analysis of passenger and cargo exchange model and the characteristics of traffic distribution in City Circle, this article sums up three volume spatial contact model of China, proposes the parameter calibration method for spatial interaction model, and analyzes the model usability. Finally, by taking the traffic forecast on Xiaogan to Xiantao section of Wuhan City Circle’s expressway loop link as an example, the process of trips forecasting is analyzed to verify the feasibility of traffic volume spatial model.

In the motivating of the City Circle integration development, the economic contact between the different regions of City Circle will no longer maintain the existing situation. And the transportation will appear in the “external traffic internal trend”, that is, the characteristics of travel scale and distribution between the groups or cities will come closer to the characteristics of the internal trips in a city or metropolitan area. Therefore, the general prediction methods of traffic volume, such as trend extrapolation and time series method, can't meet the accuracy requirements in this regional development state. In the full consideration of city circle interval trip distribution characteristics, this article proposes the forecast method of City Circle’s interval travel based on the volume spatial contact model.

1. Model mechanism

1.1 Traveler exchange mode

Travelers exchange in transportation corridor is a complex social and economic phenomenon. It is closely related to regional socio-economic, levels of management, social culture and customs, and many other factors. The exchange of travelers is also accompanied with the exchange of information, technologies and cultures. Because of the widely affected area and the long transport routes of transportation corridor, the different regional transportation relations have a variety of forms on account of different socio-economic background. According to its purpose and function, passenger traffic can be divided into following categories:

(1) Collaborative passenger traffic formed by the communication of regional economic cooperation, trade contact and information link of different levels;
(2) Inherited passenger traffic caused by visiting friends or relatives.
(3) Labor passenger traffic to work or apply for a job
(4) Entertainment passenger traffic in the purpose of tourism and entertainment.

According to Regional correlation characteristics result from traveler exchange, the corridor passenger communication is a connection with multi-center and production type, as shown in Figure 1.

![Figure 1. passenger contact in transportation corridor](image-url)
1.2 Cargo exchange mode

The exchange of goods between regions depends on the potential strength of the regional differences and inter-regional interdependence. Differences in traffic between location and transportation corridors' capacity lead to different modes of communication, which is generally divided into complementary exchange, competitive exchange, relay exchange. Complementary exchange is the exchange of goods caused by the complementary regional economic systems. It plays an important role in transport system, and the regional division level of labor directly determines the strength of the complementary. The competitive exchange depends on the supply of the regional economic system, the technical level of the region, the development of transportation and other factors. The existence and development of competitive exchange base on the formation of a unified market. Relay exchange is an indirectly relation between starting point and terminal point, and it is done in the transit area or the distribution area, which actually is formed by a regional complementary contact.

1.3 Traffic distribution law

The traffic volumes’ spatial distribution and dynamic changes abide by the following laws:
1) The distribution of traffic volume is direct ratio of regional economic level, the distribution of population, the city level, and the development of the transport network.
2) The distribution of traffic volume showed dynamic changes, and it’s gradually counterpoised by the economic development.
3) Because of a large number of outside traffic volume taken by passage, the distributed percentage of regional cycle is greater than the distributed percentage of transport amount.
4) Differences between traffic volume and freight volume are mainly distributed in a high level of economic region, moreover related to regional industrial structure and the degree of industrialization.

2 Volume spatial contact model

Volume spatial contact model is an important component of the transportation planning, aimed at measuring traffic volume in every traffic zone. Domestic and foreign research institutes propose spatial interacted model of transport distribution can be divided into three types: spatial interaction model, systemic balance, general shift model.

2.1 Spatial interaction model

Spatial interaction model is one of the widely used distribution models in spatial association analysis. Its theoretical basis is derived from the assumption that the production of passenger and cargo communication is influenced by external factors. The spatial interaction model and Newtonian gravitation Theorem has the similar form. Studies suggest that inter-regional passenger and cargo flow is proportional to regional flow, and is inversely proportional to the inter-regional distance. The basic form of this model is:

\[ X_{ij} = k \cdot O_i \cdot D_j \cdot f(T_{ij}) \]

\[ X_{ij} \] — passenger and cargo flow between region i and region j;
\[ O_i \] — the amount of passenger and cargo sent from region i;
\[ D_j \] — the amount of passenger and cargo sent from region j;
\[ T_{ij} \] — the travel time between region i and region j;
\[ f(T_{ij}) \] has such forms:

1) Power function:
   \[ f(T_{ij}) = \frac{1}{T_{ij}^a} \]
2) The exponential function:
   \[ f(T_{ij}) = e^{-\beta T_{ij}} \]
3) Gamma function:
   \[ f(T_{ij}) = (aT_{ij} + b)^{-\gamma} \]
4) Polynomial function:
   \[ f(T_{ij}) = a_0 + a_1T_{ij} + a_2T_{ij}^2 + a_3T_{ij}^3 + \ldots \]

\[ k, a, b, \alpha, \beta, r \] are constants.
According to Constraint conditions of Proportion adjustment coefficient $k$, when $a \approx b \approx 1.0$, the modified space interaction model can be divided into single constraint model and fully constrained models, respectively, as follows:

1. **Single constraint model**
   \[
   X_{ij} = \frac{O_i a D_j a f(T_{ij})}{\sum_{j=1}^{n} D_j f(T_{ij})}.
   \]

2. **Fully constrained model**
   \[
   X_{ij} = k_i k_j a O_i a D_j a f(T_{ij})
   \]

where $k_i$ and $k_j$ represent the scale factor of dispatch point $i$ and arrival point $j$. The letters of the above two modified model is the same meaning as before.

### 2.2 System balance method

System balance model assumes that there is a balance between the transport distribution of freight and traffic section impedance. Each traffic area is in different position in the system, and its distribution pattern is also different, calculated as follows:

\[
X_{ij} = \frac{O_i a D_j a f(T_{ij})}{\sum_{j=1}^{n} D_j f(T_{ij})}, \quad \alpha = \frac{1}{k_i}, \quad \beta = \frac{1}{k_j},
\]

\[
\alpha_i = \text{Undetermined coefficients of Traffic i};
\]

\[
k_{ij} = \text{Premeditated adjustment coefficient of nonequilibrium factor, generally take 1, the other symbols are the same as before.}
\]

The characteristics of System equilibrium model isn't the base of modeling existing transport of freight OD, but base on system balancing. When the system is a balance, that is $k_{ij} = 1$, it can directly calculate the distribution of passenger and freight flow by traffic generation and transport impedance.

### 2.3 General shift model

The General shift model is proposed by American scholar W. Alonso in 1970s, which is A set of analytic model of economic interacted activity, the model formula:

\[
X_{ij} = A_i a V_i a B_j a W_j a t_{ij}, \quad O_i = A_i a V_i
\]

\[
D_j = B_j a W_j, \quad A_i = \sum_{j=1}^{n} B_j a W_j a t_{ij}
\]

\[
B_j = \sum_{i=1}^{n} A_i a V_i a t_{ij}
\]

\[
X_{ij} - \text{Passenger and freight flow volume of region i sent to region j}
\]

\[
O_i, D_j - \text{Respectively stand for total amount of passenger and freight traffic sent from region i and reaches at region j}
\]

\[
V_i - \text{Aggregate numbers To cause the inflow of passengers and cargo in region i}
\]

\[
W_j - \text{Aggregate numbers To cause the outflow of passengers and cargo in region j}
\]

\[
A_i - \text{Tension strength to outflow of passenger and cargo in region i for the overall system}
\]
Thrust strength to inflow of passenger and cargo in region j for the overall system;

\[ B_j \]

Intensity constant coefficient;

\[ \alpha, \beta \]

Correlation Factor between region i and region j.

The model has a good versatility. When the intensity coefficient \( \alpha = \beta = 1 \), it is the same as space in each model completely constraint model; When \( \alpha = \beta = 0 \), it is similar to spatial interactive models, at this time, model factor \( k_i \) of intensity constant coefficient and model factor \( k_j \) of spatial interaction have a certain reciprocal relation.

3 spatial contact model calibration

Before using above Model predictive method, it must calibrate parameters in the effective form to ensure the applicability of the model.

The main purpose of the spatial interacted model calibration is obtained space distance impedance function \( f(T_{ij}) \) in the present passenger and freight distribution and each parameter in function relation of travel distance (or time, cost). The strict calibration test every different impedance function, but in fact is selected one of four calibrations Under the condition of master data.

There are 3 methods of calculating distance impedance function \( r_{ij} \) in every traffic area: one is determined by analogy to similar areas; the second is determined in regression analysis method through the sampling survey; the third is using The method of simulation approach to extract \( r_{ij} \) under the condition of known average capacity.

Strength coefficient of general shift model can be selected according to the regional economic development. When \( \alpha = \beta = 1 \), its Model form is same as spatial interacted model. The model regional relations coefficient \( t_{ij} \) can be used as an endogenous variable, calculated by the system, can also be regarded as the spatial distance impedance function, determined in the same method as spatial interacted model.

The adjustment factor of system balance method can be determined by the present distribution of passenger and freight survey, usually taken for 1.

4 model practicality analysis

In order to better reflect the distance (or time) factors on passenger and freight traffic, Spatial interacted models are always determined different forms of traffic impedance function according to the actual problem. And it has certain practical significance in that \( k_i \), \( k_j \) of the model reflect the regional passenger and freight attracted by other district and attract other areas of strength and ability. The main advantage of the spatial interacted model in specific applications including:

- more sensitive to changes in reaction of the regional transport time;
- the structure of the model is simple and easy to understand, and good applicability;
- The model can consider the impact of land use on traffic generation and attraction.

The advantage of the universal displacement model economic model considers many factors, and thus the model may be more accord with the actual economic space connection. Besides, generic displacement model can be converted to the other model by selecting Correlation Coefficient for meet more analysis needs. So it has strong generalization ability and versatility. Its shortage is the complicate form and difficult calculation.

5 Case Study

Take the traffic forecast on Xiaogan to Xiantao section of Wuhan City Circle’s expressway loop link as an example. According to the wuhan city circle's overall development plan, Wuhan city circle will form the four industries - towns groups, East Wing – WEH(Wuhan, Ezhou and Huangshi), the Northwest wing – XYA(Xiaogan, Yingcheng and Anlu), the West Wing – XQT(Xiantao, Qianjiang and Tianmen), and South Wing – XCI(Xianning, Chibi and Jiayu). In the driven of city circle integration development process, the economic ties between groups will no longer maintain the existing situation.

Travel contact will also appear in the internalization of external traffic trend. That's the Travel size and distribution characteristics of groups or cities will increasingly approach in internal travel characteristics of cities or metropolitan areas. In the following days, three development areas will be developed to many multiple industry chains in the direct impact of the project. Therefore, it can be
expected interval transport scale of three major development areas will break through the current development pattern, improved significantly.

Figure 2 Three major development area location

Obviously, it's inappropriate to predict transport scale among the future three major development area by trend growth of status survey data. It can’t reflect the future development trend. So we calculate the transport volume between the three major development areas in spatial interaction model of volume spatial model.

1) model parameter calibration

Table 1. The Pearl River Delta city group comparison with the Wuhan city circle

<table>
<thead>
<tr>
<th></th>
<th>Population (million)</th>
<th>Area (000 square kilometers)</th>
<th>Spatial structure</th>
<th>GDP (billion)</th>
<th>Per capita GDP (Yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wuhan city circle</td>
<td>3141</td>
<td>5.8</td>
<td>Center (Wuhan)</td>
<td>5557</td>
<td>18601</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A sub-center (Huangshi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Pearl River Delta</td>
<td>3370</td>
<td>5.5</td>
<td>Center (Guangzhou)</td>
<td>18059</td>
<td>53588</td>
</tr>
<tr>
<td>city group</td>
<td></td>
<td></td>
<td>Two vice Center</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Shenzhen, Zhuhai)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Transport characteristics of city circle groups will tend to outflow characteristics of Cities or metropolitan area internal groups In Wuhan city circle industry - town group and integration, specifically when transport infrastructure network of city circle is basically formed. In the View of the Wuhan city circle still in its infancy, and the lack of parameter standardized data, therefore, we select a more developed urban group or city circle as analog object, grasp the future developmental model of Wuhan city circle and trend according to development process of the analog object, and standard
model parameters according to transport infrastructure data of the analog object. According to the investigation of the land area, population, urban circle space structure layout, we select the Pearl River Delta city group as analog object.

Currently, the Pearl River Delta city group has not yet established peripheral intercity transport statistic data, only parts of the transport planning related to the data. Railway Fourth Survey and Design Institute and other units study Shenhui city circle traffic in its railway planning research. Because of OD TABLE of inter-city transport completely contained the data of outlying towns transport, so we standard spatial interacted model parameter with the inter-city transport OD data of this region in 2005.

After calibration, in spatial interaction model \( X_{ij} = k \cdot D_i \cdot D_j \cdot f(T_{ij}) \), when \( k = 1.1 \), \( a = 0.9 \), \( b = 0.9 \) impedance function \( f(T_{ij}) = e^{-\beta T_{ij}} \), \( \beta = 10.6466 \).

2) Interval travel amount forecast

Considering the difficulty of collecting every transport enterprise production quota, furthermore, using analysis and prediction of transport volume method in the analysis of transport demand, so assumed three development areas passenger and freight transport are in oversupply or balance, that is the demand for passenger and freight transport the same as the generation of passenger and freight transport. Regression model was established based on three major development area traffic statistics, such as GDP, population, industrial and agricultural output value, sales of consumer goods, total retail sales and transport volume. the prediction of future passenger and freight transport volume in the three development areas are shown in Table 2. The passenger and freight occurred and attract volume is converted for automobile traffic volume according to vehicles carrying coefficient of the OD survey.

<table>
<thead>
<tr>
<th>Area</th>
<th>2015</th>
<th>2020</th>
<th>2030</th>
<th>2034</th>
</tr>
</thead>
<tbody>
<tr>
<td>XYA</td>
<td>Passenger Traffic (million)</td>
<td>15673</td>
<td>23575</td>
<td>42832</td>
</tr>
<tr>
<td></td>
<td>Cargo Volume (million tons)</td>
<td>12125</td>
<td>18332</td>
<td>33990</td>
</tr>
<tr>
<td>XQT</td>
<td>Passenger Traffic (million)</td>
<td>11902</td>
<td>17828</td>
<td>32868</td>
</tr>
<tr>
<td></td>
<td>Cargo Volume (tons)</td>
<td>4402</td>
<td>6553</td>
<td>11967</td>
</tr>
<tr>
<td>XCJ</td>
<td>Passenger Traffic (million)</td>
<td>12777</td>
<td>19121</td>
<td>34885</td>
</tr>
<tr>
<td></td>
<td>Cargo Volume (tons)</td>
<td>4875</td>
<td>7262</td>
<td>13554</td>
</tr>
</tbody>
</table>

3) Interval transport distribution forecast

Take the data of the passenger and freight occurred and attract volume into the Calibration good prediction model to calculate the transport volume of future three major development areas. The predicted results of inter value transport volume are separated by the district population, GDP and other key economic indicators of three major development areas as the important factors, for subsequent analysis and conforming to the actual situation. And then merge the results with OD table of feature years, which is calculated from OD table of base year using Fratar Method. Finally we can get the OD table of the future year. The traffic forecasted results divided in administrative areas are shown in Table 3.

<table>
<thead>
<tr>
<th>Sections</th>
<th>2015</th>
<th>2020</th>
<th>2030</th>
<th>2034</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section of Xiaogan City</td>
<td>8355</td>
<td>13345</td>
<td>27964</td>
<td>36416</td>
</tr>
<tr>
<td>Section of Xiantao City</td>
<td>10462</td>
<td>16774</td>
<td>35737</td>
<td>46861</td>
</tr>
<tr>
<td>Section of Xianning City</td>
<td>9961</td>
<td>16155</td>
<td>34704</td>
<td>45686</td>
</tr>
</tbody>
</table>

6. Conclusion

Based on the analysis of passenger and cargo exchange model and the characteristics of traffic distribution in City Circle, this article propose a forecasting method of interval traffic in City Circle based on spatial contact model. This method can reflect the actual development and changes of the City
Circle’s interval transport volume much better. However, the spatial contact model is used to describe and analyze different regional economic ties, such as population movements, passenger and freight volume. Since the objective existing economic ties are formed by a complex variety of factors, we should establish different regional forecast models on the basis of research in regional geographical and economic conditions.

References: