Definition of the Logistics Park Hinterland Based on the Analysis of Spatial Medium Effect Applying to Weighted Voronoi Diagram

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ABSTRACT: Accurately defining the logistics park hinterland is the basis of the rational planning of the logistics park as well as further improving the logistics efficiency. However, currently, the parameters of the methods and models for defining the logistics park hinterland are still not perfect, which lead those reasonableness and accuracy are also not ideal. Subsequently, based on the Voronoi diagram basic theory in computational geometry which reflects the advantage of the continuity of space division as well as by introducing both the ‘scale’ parameter of the space object in the breaking-point model and the heterogeneity of the spatial medium caused by both the transportation network and the regional comprehensive strength factors into Voronoi diagram, the model based on the analysis of spatial medium effect applying to weighted Voronoi diagram to define the logistics park hinterland was built. Then the plug-in used in GIS software was programmed. Finally, this model and plug-in were practically applied to the planning example of Xinjin logistics park in Sichuan Province. Practice has proved that this model overcome the defects existing in the conventional space division theories and the ordinary Voronoi diagram theory, which makes the definition of the logistics park hinterland more reasonable and scientific.

Keywords: logistics park; Hinterland; Voronoi diagram; GIS

1 INTRODUCTION

Hinterland was especially referred to the material distribution area around the harbor at first (Kong, 2007). Then, with the widely development the research content of economic geography, the concept of hinterland gradually was introduced into the layout research of the various economic center of the inland cities as well as the urban functional areas or facilities, so some scholars began to call it radiation scope, a ttracting scope or influencing scope. Due to the increasingly prominent role the logistics park played in regional economic development, the study of the definition of its hinterland was also increased and, Zhang (2011) firstly defined the hinterland of the logistics park in his study. As the accurate definition the hinterland of the logistics park provided the direct decision making basis for the precise prediction of the logistics volume in the logistics park and the reasonable layout of function settings and scientific design for the profit model, it was crucial for the rational, scientific and accurate planning of the entire logistics park project. With the advent of the information age, the technology that using GIS made spatial data analysis was developed and being applied, thus more and more scholars began using Voronoi diagram theory in computational geometry which had the advantage of the precise continuity space division to define hinterland. Wang et al. (2002) firstly applied the Voronoi diagram theory to divide the urban influencing scope. Some subsequent scholars (Zhang et al., 2000, Wang, 2006 and Feng, 2010) extended its application to the influencing scope division of the urban public facilities and functional areas. Many scholars (Duan, 2010, and Huang et al., 1990) had combined the Voronoi diagram theory with the breaking-point model to create weighted Voronoi diagram theory which had more practical value and was tested well. However, the existing Voronoi diagram theory failed to fully reflect the impact of heterogeneity caused by the spatial medium on defining the hinterland. Therefore, based on the basic Voronoi diagram theory as well as fully con-
sidering the effect of the space object scale and the heterogeneity of the spatial medium caused by both the transportation network and the regional comprehensive strength factors, the new method that weighted Voronoi diagram based on the analysis of spatial medium effect which was applied to defining the logistics medium was proposed.

2 VORONOI DIAGRAM BASIC THEORY

In 1908, Voronoi diagram theory proposed by Russian mathematician M.G. Voronoi was used to divide spatial plane. In this theory, in any convex, Voronoi polygon the distance that any point within some convex polygon from the space object within the convex polygon is less than any point from any other space objects in the spatial plane. Therefore, an important property of the Voronoi diagram is that the distance that each point within the Voronoi grid from the occurrence point in the grid is less than that from any occurrence point in other Voronoi grids. Definition (1) represents the Voronoi diagram.

\[ p^*_i = \{X|d(x, p_i) \leq d(x, p_j), p_i, p_j \in P, i \neq j}\] (1)

Where \( p^*_i \) is the Voronoi diagram area of the space object \( p_i \); \( x \) is the set of space object stands for any point in the space; \( d \) is the Euclidean distance function.

Thereafter, since the Voronoi diagram had the advantages of precise continuity in space division, many scholars gradually developed this theory. For example, both the variables such as the scale of the space object and traffic network that caused the heterogeneity of the spatial medium were respectively introduced into the Voronoi diagram theory to form weighted Voronoi diagram theory (Duan, 2010) and Voronoi diagram theory based on spatial network analysis (Lan, 2010); in addition, the two variables were simultaneously introduced into the Voronoi diagram theory to form the weighted Voronoi diagram theory based on spatial network analysis (Zhang, 2011). These theories had been applied to solving practical problems and achieved good results.

3 MODELING

3.1 Weighted Voronoi diagram based on the analysis of spatial medium effect

Although the weighted Voronoi diagram theory based on spatial network analysis improved the Voronoi diagram theory from the perspective of both the scale of the space object and traffic network that caused the heterogeneity of the spatial medium, it was still insufficient in analyzing the factors caused the heterogeneity of the spatial medium, namely, the differences between existent different regions which caused the heterogeneity of the spatial medium were not taken into account. Therefore, the differences between existent different regions were introduced into the factors that caused the heterogeneity of the spatial medium, and then weighted Voronoi diagram based on the analysis of spatial medium effect was proposed in this study.

Suppose \( D = \{P_1, P_2, P_3, \ldots, P_n\} \) is the set of the points on plane \( L \). The network \( R = \{l_1, l_2, l_3, \ldots, l_n\} \) is composed of a variety of curve on plane \( L \); \( R \) is an open network, namely, it can get free access to network \( R \) at any point; \( J = \{G_1, G_2, G_3, \ldots, G_n\} \) is a set of the different regions on plane \( L \), and Definition (2) is the weighted Voronoi diagram based on the analysis of spatial medium effect.

\[ S_i(p, \lambda_i) = \bigcap_{i=1}^{n} \left\{ p | d_o(x, p_i) \leq d_o(x, p_j) \right\} (i = 1, 2, \ldots, n) \] (2)

Where \( S_i(p, \lambda_i) \) is the Voronoi diagram of space \( p_i \); \( P \) is the set of objectives; \( d_{o_i} \) is the distance or time functions of objective \( p_i \) based on the heterogeneity of the spatial medium caused by both the regional network and the regional comprehensive strength factors; \( t \) is the regional network factor; \( r \) is the existent regional differences factor; \( x \) is any point of space; \( \lambda_i \) is the weight of objective \( p_i \).

Definition (2) was introduced into the definition of logistics park hinterland to obtain Definition (3).

\[ S_i(p, C_i) = \bigcap_{i=1}^{n} \left\{ p | d_o(x, p_i) \leq d_o(x, p_j) \right\} (i = 1, 2, \ldots, n) \] (3)

Where \( S_i(p, C_i) \) is the Voronoi diagram of logistics park \( p_i \); \( P \) is the set of logistics parks; \( d_{o_i} \) is the distance or time functions of logistics park \( p_i \) based on the heterogeneity of the spatial medium caused by both the transport network and the regional comprehensive strength factors; \( t \) is the transport network factor, which is determined by the relative speed of the different kinds or levels of roads compared with the non-transport network areas, as shown in Table 1; \( r \) is the existent regional differences factor, which is evaluated by index system established in Part 3.3; \( x \) is any point of space; \( C_i \) is the central strength of the logistics park \( p_i \), which is evaluated by index system established in Part 3.2.

3.2 Index system of evaluating the logistics park centrality

On the basis of the principles such as Macroscopic, comprehensiveness, operation and dynamic, the index system of evaluating the logistics park centrality was established in this study, as shown in Table 2.
3.3 Index system of evaluating the regional comprehensive strength

The regional comprehensive strength was also known as regional comprehensive competitiveness.

In this study, the comprehensive strength of the region was illustrated by two aspects such as the scale of the economy and the quality of the economy, as shown in Table 3.

4 EXAMPLE

The method proposed in this study was used in this example to define the hinterland of Xinjin Logistics Park which was the key construction project of regional planning in Chengdu-Chongqing economic zone.

Based on the analysis of the existing logistics parks in Sichuan Province, the four logistics parks around and of the same level and type as Xinjin Logistics Park, namely, Jiazhou Logistics Park, Ya’an Logistics Park, Qingbaijiang Logistics Park and Western China Modern Logistics Park, as shown in Figure 1.

![Figure 1. Location of the logistics parks, transport network and regions.](image)
4.1 Evaluation of the logistics park centrality

According to the index system of evaluating the logistics park centrality established in Table 1, the relevant original data was queried in statistics or obtained the experts grading, as shown in Table 4.

Table 4. Relevant original data of the index evaluating the regional comprehensive strength of the five logistics park.

(A)

<table>
<thead>
<tr>
<th>Logistics parks</th>
<th>Index</th>
<th>(X_i (10^7) million Yuan)</th>
<th>(X_i (10^7) million Yuan/mu)</th>
<th>(X_i )</th>
<th>(X_i )</th>
<th>(X_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>200</td>
<td>0.005</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>60</td>
<td>0.004</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>233</td>
<td>0.005</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>25</td>
<td>0.01</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>500</td>
<td>0.01</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Then the principal component analysis was utilized to evaluate the original data by SPSS software. According to the total variance explained table shown in Table 5 and based on the principle eigenvalues that are greater than 1 and the cumulative contribution rate which is more than 85%, the three main ingredients were determined.

Table 5. Total variance explained.

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial Eigenvalues</th>
<th>% of Variance</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.515</td>
<td>50.140</td>
<td>50.140</td>
</tr>
<tr>
<td>2</td>
<td>2.967</td>
<td>26.971</td>
<td>77.111</td>
</tr>
<tr>
<td>3</td>
<td>2.028</td>
<td>19.433</td>
<td>95.544</td>
</tr>
<tr>
<td>4</td>
<td>.940</td>
<td>4.456</td>
<td>100.000</td>
</tr>
</tbody>
</table>

Then the scores of the principal components multiplied the proportion that the corresponding eigenvalues for each principal component accounted for the sum of all the principal components to get the comprehensive evaluation scores. As the comprehensive evaluation scores of some logistics parks calculated by SPSS were negative which could not be directly used in the model proposed in this study, Min-Max Normalization method as shown in Equation (4) was used to make the linear transformation of the original data which was mapped to the new data range \((1, 8.885)\) to form the new data column, so the centrality of the logistics parks was obtained, as shown in Table 6.

\[
V' = \frac{V - \min A}{\max A - \min A} (new_{\max A} - new_{\min A}) + new_{\min A}
\]

Where \(V'\) is the data after normalization, \(V\) is the original data; \(\max A\) and \(\min B\) are respectively the maximum data and minimum data in original data column; \(new_{\max A}\) and \(new_{\min A}\) are respectively the maximum data and minimum data in new data column.

4.2 Evaluation of the comprehensive strength of the regions

According to the index system of evaluating the regional comprehensive strength established in Table 2, the relevant original data was queried in statistics, as shown in Table 7. Then the principal component analysis was utilized to evaluate the original data by SPSS software. According to the total variance explained table shown in Table 8 and based on the principle eigenvalues that are greater than 1 and the cumulative contribution rate which is more than 85%, the main ingredients were determined. Then the scores of the principal components multiplied the proportion that the corresponding eigenvalues for each principal component accounted for the sum of all the principal components to get the comprehensive evaluation scores. As the comprehensive evaluation scores of some regions calculated by SPSS was negative which could not be directly used in the model proposed in this study, Min-Max Normalization method was used to make the linear transformation of the original data which was mapped to the new data range \((1, 8.885)\) to form the new data column, so the centrality of the logistics parks was obtained, as shown in Table 9.

Table 6. Comprehensive strengths of the five logistics parks.

<table>
<thead>
<tr>
<th>Logistics parks</th>
<th>Comprehensive scores</th>
<th>Comprehensive strength (C_i) calculated by the minimum-maximum standardized method</th>
<th>Weights ((\lambda_i \sqrt{C_i}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.735</td>
<td>4.04</td>
<td>2.01</td>
</tr>
<tr>
<td>B</td>
<td>-2.305</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>0.476</td>
<td>3.781</td>
<td>1.944</td>
</tr>
<tr>
<td>D</td>
<td>0.61</td>
<td>3.915</td>
<td>1.979</td>
</tr>
<tr>
<td>E</td>
<td>0.483</td>
<td>3.788</td>
<td>1.946</td>
</tr>
</tbody>
</table>

Table 7. Relevant original data of the index evaluating the regional comprehensive strength of the five logistics parks.

(A)

<table>
<thead>
<tr>
<th>Cities</th>
<th>(Y_1 (10^7) million Yuan)</th>
<th>(Y_2 (10^7) Yuan)</th>
<th>(Y_3 (10^4) thousand dollars)</th>
<th>(Y_4) (Yuan)</th>
<th>(Y_5) (Yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>5551.33</td>
<td>24288296</td>
<td>2467759</td>
<td>41253</td>
<td>30515</td>
</tr>
<tr>
<td>P</td>
<td>921.27</td>
<td>3055028</td>
<td>223195</td>
<td>25335</td>
<td>28355</td>
</tr>
<tr>
<td>Q</td>
<td>960.22</td>
<td>4263018</td>
<td>159752</td>
<td>20053</td>
<td>26347</td>
</tr>
<tr>
<td>R</td>
<td>495.23</td>
<td>2084908</td>
<td>28150</td>
<td>14498</td>
<td>22621</td>
</tr>
<tr>
<td>S</td>
<td>657.90</td>
<td>2130041</td>
<td>15669</td>
<td>16644</td>
<td>24224</td>
</tr>
<tr>
<td>T</td>
<td>552.25</td>
<td>1885569</td>
<td>9985</td>
<td>18586</td>
<td>22897</td>
</tr>
<tr>
<td>U</td>
<td>286.54</td>
<td>1046540</td>
<td>1333</td>
<td>18881</td>
<td>23065</td>
</tr>
<tr>
<td>V</td>
<td>743.92</td>
<td>2840917</td>
<td>97630</td>
<td>22490</td>
<td>23865</td>
</tr>
</tbody>
</table>
Table 8. Total variance explained.

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial Eigenvalues</th>
<th>Total</th>
<th>% of Variance</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.415</td>
<td>9.415</td>
<td>85.595</td>
<td>85.595</td>
</tr>
<tr>
<td>2</td>
<td>1.062</td>
<td>1.062</td>
<td>9.651</td>
<td>95.247</td>
</tr>
<tr>
<td>3</td>
<td>.308</td>
<td>.308</td>
<td>2.802</td>
<td>98.048</td>
</tr>
<tr>
<td>4</td>
<td>.158</td>
<td>.158</td>
<td>1.436</td>
<td>99.484</td>
</tr>
<tr>
<td>5</td>
<td>.051</td>
<td>.051</td>
<td>.466</td>
<td>99.950</td>
</tr>
<tr>
<td>6</td>
<td>.004</td>
<td>.004</td>
<td>.033</td>
<td>99.982</td>
</tr>
<tr>
<td>7</td>
<td>.002</td>
<td>.002</td>
<td>.018</td>
<td>100.000</td>
</tr>
</tbody>
</table>

Table 9. Regional comprehensive strength of the cities.

<table>
<thead>
<tr>
<th>Cities</th>
<th>Comprehensive scores</th>
<th>Comprehensive strength ((r_i)) calculated by the minimum-maximum standardized method</th>
<th>Weights ((\sqrt{r_i}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chengdu(O)</td>
<td>6.289</td>
<td>8.885</td>
<td>2.981</td>
</tr>
<tr>
<td>Deyang(P)</td>
<td>0.237</td>
<td>2.833</td>
<td>1.683</td>
</tr>
<tr>
<td>Mianyang(Q)</td>
<td>-0.103</td>
<td>1.651</td>
<td>1.285</td>
</tr>
<tr>
<td>Suining(R)</td>
<td>-1.576</td>
<td>1.225</td>
<td>1.107</td>
</tr>
<tr>
<td>Ziyang(S)</td>
<td>-0.935</td>
<td>2.493</td>
<td>1.579</td>
</tr>
<tr>
<td>Meishan(T)</td>
<td>-1.371</td>
<td>1.02</td>
<td>1.01</td>
</tr>
<tr>
<td>Ya’an(U)</td>
<td>-1.596</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Leshan(V)</td>
<td>-0.945</td>
<td>1.661</td>
<td>1.289</td>
</tr>
</tbody>
</table>

4.3 Definition of the hinterland of Xinjin Logistics Park

On the basis of the crystal growth algorithm, by using ArcObjects development tools and C# programming software to implement the secondary development, the plug-in of weighted Voronoi diagram based on the analysis of spatial medium effect that could be directly installed into ArcMap for operation was generated, as shown in Figure 2. In addition, this plug-in had the characteristics of simple operation and universality, because it can load the file with precise location information including Shape and Dwg format as well as directly import the relevant parameters from Excel.

With this plug-in, the related layers were loaded into Arcmap. Meanwhile, the parameters calculated in Parts 4.1 and 4.2 were also imported to obtain the definition result, which showed the hinterland of Xinjin Logistics Park covered the western and southern region of Chengdu City, the southwestern and central region of Meishan City, the northern region of Ya’an City and the northeastern region of Leshan, as shown in Figure 3. Finally, “Calculate Geometry” tool in Arcmap was used to calculate the area of the hinterland of Xinjin Logistics Park which was 10,885.46 square kilometers.

5 CONCLUSION

Currently, since the definition of the hinterland based on the traditional space division model as well as the literature about the definition of the logistics park hinterland was limited, the weighted Voronoi diagram based on the analysis of spatial medium effect was established in view of its own characteristics of the logistics park, which provides a more scientific and rational basis for accurately defining the logistics park hinterland. At the same time, the GIS plug-in by programming further verified the feasibility of this method. However, this method also needs further improvement. For instance, first, the index system used for evaluating the logistics park centrality and the comprehensive strength of the region was still not perfect and comprehensive; second, when using this
method to define the logistics park hinterland, the dividing line was put in the first place, so when the Voronoi diagram formed was not a completely closed space, this method was also subject to certain limitations. In a word, these deficiencies need to be further studied in the future.

REFERENCES


