Research on Regional Traffic and Economic Linkage Based on Accessibility and Gravity Model--Taking Hengyang, China as an example

WANG Zhi-yuan 1,2, CHEN Hai-ting 1, OU Yang-mei 3 *

1 School of Architecture, University of South China, Hengyang 421001, Hunan, China; 2 School of Architecture and Art, Central South University, Changsha 41007, Hunan, China; 3 Hunan Institute of Traffic Engineering, Hengyang 42100, Hunan, China E-mail: wzhiyuan2005@yeah.net

Abstract: Regional urban connection is mainly reflected in the connection between transportation and economy. Using accessibility and improved gravity model, this paper studies the traffic and economic relations and spatial pattern analysis among districts and counties in Hengyang based on the shortest travel time data and socio-economic data of 12 districts and counties in Hengyang, China. The results show that: firstly, in terms of traffic accessibility, there are 8 districts and counties in Hengyang that have higher accessibility than the average level of the city, and 4 districts and counties that have lower accessibility than the average level. Secondly, the accessibility of districts and counties in Hengyang generally presents an irregular circular distribution pattern, forming a core edge distribution feature with five districts in Hengyang as the core and gradually decreasing outward enclosure. Thirdly, from the perspective of economic connection, the 12 districts and counties in Hengyang are divided into five levels. The first level is the connection between Shigu District and Yanfeng District in the central city. The second level connection intensity is between Shigu District and Zhengxiang District in the central city and between Zhengxiang District and Hengyang County. The intensity of the three-level connection is the connection between the counties near the central urban area and the districts in the central urban area, as well as the connection between the counties near the central urban area and the neighboring counties. The fourth level connection refers to the connection between districts and counties far away from the central urban area and counties near the central urban area. The fifth level connection refers to the connection between districts and counties far away from the central urban area.

Last but not least, the economic connection of Hengyang District and county forms the center-peripheral radiation pattern which diffuses from the area with the core of Shigu District, steamed Xiang District, Yanfeng District and Zhuhui District as the core, which presents the pattern of "one core and two centers" in space.

1. Introduction

The regional connection is manifested as the interaction and connection between economic entities and regions. In the regional space, it is manifested in various forms such as people flow, logistics, capital flow and information flow. The size of the regional economic connection is the strength of the interaction. Through the quantitative study of its size, the strength and spatial orientation of the regional connection can be quantitatively discussed [1]. By quantifying the strength and spatial orientation of regional traffic accessibility and economic ties, the status and role of each city in the region can be
clarified, and the relevant theoretical basis and decision support can be provided for the rational
development and functional positioning of the cities in the region. In this study, the accessibility and
improved gravity model are used to analyze the traffic and economic relations and spatial pattern among
12 districts and counties in Hengyang, China.

2. Research area
Hengyang, located in 110°32′16″~113°16′32″E, 26°07′05″~27°28′24″N, is a prefecture level city
under the jurisdiction of Hunan Province, China. It is a sub-central city, central city of southern
Hunan in Hunan Province, and one of the important transportation hubs in Hunan Province and
Central South China. Besides, many railway trunk lines and important highways meet here. Hengyang
has jurisdiction over 5 counties of Hengnan, Hengyang, Hengshan, Hengdong and Qidong, 2 cities of
Changning and Leiyang, 5 districts of Nanyue, Yanfeng, Shigu, Zhuhui and Zhengxiang, with a total
area of 15310 square kilometers. In 2018, there were 7.2434 million permanent residents, including
3.8832 million urban residents, with a urbanization rate of 53.61%. The gross regional product reached
304.603 billion yuan.

3. Research methods and data sources
3.1. Research methods
3.1.1. Traffic accessibility analysis. The concept of accessibility was first proposed by Hansen in 1959
[2], that is, the interaction opportunity of each node in the traffic network. In the regional scope,
accessibility reflects the difficulty of spatial interaction and connection between a city or region and
other cities or regions [3-5]. Considering the influence of node scale and economic development level
on accessibility, weighted average travel time distance index is used to measure, and its expression is as
follows:

$$A_i = \frac{\sum_{j=1}^n (T_{ij} \times M_j)}{\sum_{j=1}^n M_j}$$  \hspace{1cm} (1)

In the formula, $T_{ij}$ is the shortest travel time distance from node i to node j; $M_j$ is the weight of node j,
which can be population scale or GDP, reflecting the impact of node scale on people's willingness to
move.

$$M_j = \sqrt{P_j \cdot G_j}$$  \hspace{1cm} (2)

In the formula, $P_j$ is the population scale of j area, $G_j$ is the total GDP of j area; n is the total number of
nodes except i point; $A_i$ is the weighted average travel time of node city i, which represents the
accessibility level of i point in the traffic network. The smaller the value of $A_i$ is, the better the
accessibility of node is. Otherwise, the worse the accessibility of node is.

In order to further reveal the status and changing trend of each node in the whole traffic network, the
accessibility coefficient is used to reflect the relative level of each node's accessibility level [6-7]. The
accessibility coefficient is the ratio of the node's accessibility value and the average accessibility value
of all nodes in the network, and its expression is:

$$S_i = \frac{A_i}{\left( \sum_{i=1}^n \frac{A_i}{n} \right)}$$  \hspace{1cm} (3)

In the formula, $S_i$ is the accessibility coefficient of node i, $A_i$ is the accessibility value of node i, and n
is the number of nodes. The higher the $S_i$ value, the worse the accessibility of the node. A value greater
than 1 indicates that the accessibility level of the node is lower than the regional average level, and a
value less than 1 indicates that the accessibility of the node is better than the regional average level.
3.1.2. **Strength analysis of economic ties.** The traditional gravity model [8] is commonly used to calculate the strength of economic ties, which is calculated by the shortest actual traffic distance between two cities [9, 10]. This study uses time-distance improved gravity model to improve the gravity model, and its expression is as follows:

\[
R_{ij} = \left(\sqrt{\frac{P_i G_i \times P_j G_j}{D_{ij}}}\right)^2
\]

In the formula, \(R_{ij}\) is the intensity of economic ties between regions i and j; \(P_i\) and \(P_j\) are the population of regions i and j; \(G_i\) and \(G_j\) are the GDP of regions i and j; \(D_{ij}\) is the travel time based on the shortest path of road network between regions i and j.

On the basis of gravity model, calculate the sum of economic ties between each region and all other regions, that is, the total amount of external economic ties of the region, expressed as:

\[
R_i = \sum_{j=1}^{n} R_{ij}
\]

In the formula: \(R_i\) is the total amount of external economic ties in region i, reflecting the density of economic ties between the region and other regions.

3.2. **Data source**

The data used in the study mainly include traffic data and economic data. The traffic data comes from the shortest travel time between different regions of the city under the self driving mode of Gould map. The research unit is abstracted as a node in the transportation network, and the specific location is the district and county government of the research area, that is, taking the district and county government as the starting or destination, the shortest travel time matrix is finally obtained. Economic data comes from Hunan statistical yearbook and Hengyang statistical yearbook.

**Table 1. The shortest travel time in Hengyang (h)**

|                 | Yanfeng District | Shigu District | Zhengxiang District | Nanyue District | Hengyang County | Hengnan County | Hengshan County | Hengdong County | Qidong County | Leiyang City | Changning City |
|----------------|------------------|----------------|--------------------|-----------------|-----------------|----------------|-----------------|-----------------|---------------|--------------|----------------|
| Zhuhai District| 0.283            | 0.117          | 0.3                | 0.833           | 0.867           | 0.633          | 1.033           | 0.983           | 1.567         | 1.383        | 1.233          |
| Yanfeng District| 0.1              | 0.3            | 0.783             | 0.817           | 0.65            | 1.033          | 1.017           | 1.5             | 1.4           | 1.4          | 1.217          |
| Shigu District  | 0.2              | 0.683          | 0.7                | 0.733           | 0.933           | 0.983          | 1.55            | 1.45            | 1.25          |              |                |
| Zhengxiang District| 0.667              | 0.517          | 0.8                | 0.9             | 0.916           | 1.45           | 1.383           | 1.15            |              |              |                |
| Nanyue District  | 0.95             | 1.25           | 0.416             | 0.617           | 1.75            | 1.45           | 1.617           |                 |              |              |                |
| Hengyang County  | 1.1              | 1.2            | 1.15               | 1.05            | 1.733           | 1.383          |                 |                 |              |              |                |
| Hengnan County   | 1.25             | 1.116          | 1.55               | 1.16            |                 |                |                 |                 |              |              |                |
| Hengshan County  | 0.566            | 1.95           | 1.45               | 1.833           |                 |                |                 |                 |              |              |                |
| Hengdong County  | 2                | 1.366          | 1.7                |                 |                 |                |                 |                 |              |              |                |
| Qidong County    | 2.3              | 1.2            |                    |                 |                 |                |                 |                 |              |              |                |
| Leiyang City     |                  |                |                    |                 |                 |                |                 |                 |              |              | 1.233          |
Table 2. Permanent population of Hengyang in 2018

| District / county | Permanent population / 10000 | District / county | Permanent population / 10000 | District / county | Permanent population / 10000 |
|-------------------|-----------------------------|-------------------|-----------------------------|-------------------|-----------------------------|
| Hengnan County    | 92.7                        | Qidong County     | 105.3                      | Zhuhui District   | 39.79                       |
| Hengyang County   | 104.88                      | Leiyang City      | 112.79                     | Yanfeng District  | 25.65                       |
| Hengshan County   | 37.04                       | Changning City    | 80.5                       | Shigu District    | 22.24                       |
| Hengdong County   | 61.52                       | Nanyue District   | 7.08                       | Zhengxiang District | 28.27                    |

Table 3. GDP of Hengyang in 2018

| District / County | GDP / 100 million yuan | District / County | GDP / 100 million yuan | District / County | GDP / 100 million yuan |
|-------------------|------------------------|-------------------|------------------------|-------------------|------------------------|
| Hengnan County    | 330.37                 | Qidong County     | 275.86                 | Zhuhui District   | 261.77                 |
| Hengyang County   | 348.06                 | Leiyang City      | 432.5                  | Yanfeng District  | 233.29                 |
| Hengshan County   | 174.63                 | Changning City    | 331.93                 | Shigu District    | 175.6                  |
| Hengdong County   | 266.4                  | Nanyue District   | 43.62                  | Zhengxiang District | 198                     |

4. Measurement of regional traffic connection

4.1. Regional traffic accessibility calculation

Based on the comprehensive strength of each district and county and the shortest travel time data of highway transportation network, the weighted average travel time of each county unit in Hengyang is calculated as shown in Table 3 and the accessibility coefficient as shown in Table 4.

Table 4. Weighted average travel time of districts and counties in Hengyang

| District / county       | Ai/h | District / county       | Ai/h | District / county       | Ai/h |
|------------------------|------|------------------------|------|------------------------|------|
| Zhuhui District        | 0.97 | Nanyue District        | 1.0  | Hengdong County        | 1.42 |
| Yanfeng District       | 0.95 | Hengyang County       | 1.56 | Qidong County          | 2.39 |
| Shigu District         | 0.93 | Hengnan County         | 1.45 | Leiyang City           | 2.96 |
| Zhengxiang District    | 0.91 | Hengshan County       | 1.12 | Changning City         | 1.84 |

Table 5. Accessibility coefficient of districts and counties in Hengyang

| District / county       | Si   | District / county       | Si   | District / county       | Si   |
|------------------------|------|------------------------|------|------------------------|------|
| Zhuhui District        | 0.6764 | Nanyue District    | 0.69 | Hengdong County        | 0.97 |
| Yanfeng District       | 0.65  | Hengyang County       | 1.07 | Qidong County          | 1.64 |
| Shigu District         | 0.64  | Hengnan County        | 0.99 | Leiyang City           | 2.02 |
| Zhengxiang District    | 0.62  | Hengshan County       | 0.77 | Changning City         | 1.26 |

It can be seen from the weighted average travel time that the total weighted average travel time of 12 districts and counties in Hengyang City is 17.5h, with an average of 1.46h. The highest accessibility level is Zhengxiang District, with a weighted average travel time of 0.91h, which is 0.62 times of the average level of Hengyang City; the worst is Leiyang City, with a weighted average travel time of 2.96h, which is 2.03 times of the average level of Hengyang City. According to the accessibility coefficient, there are 8 units with the accessibility higher than the average level of Hengyang City, including Zhengxiang District, Zhuhui District, Yanfeng District, Shigu District, Nanyue District, Hengnan...
County, Hengdong County and Hengshan County, and 4 units with the accessibility lower than the average level are Hengyang County, Qidong County, Changning City and Leiyang City. Among them, the accessibility coefficients from high to low are Zhengxiang District, Shigu District, Yanfeng District, Zhuhui District, Nanyue District, Hengshan County, Hengdong County, Hengnan County, Hengyang County, Changning City, Qidong County and Leiyang City. The accessibility coefficients of Zhuhui District, Yanfeng District, Shigu District, Zhengxiang district and Nanyue District are all 0.6-0.7. The accessibility coefficients of Hengshan County, Hengdong County, Hengnan County and Hengyang County around the central city are all 0.9-1.1, close to the average level. The reachability coefficients of Changning City, Qidong County and Leiyang City, which are far from the central urban area, are 1.26, 1.64 and 2.02 respectively.

4.2. Spatial pattern of regional transport connection
In order to understand the spatial differentiation characteristics of regional traffic links more intuitively, the weighted average traffic time of 12 districts and counties in Hengyang City is interpolated by using ArcGIS statistical module. It can be seen that the core area of traffic accessibility is composed of five areas: Zhengxiang, Shigu, Zhuhui, Yanfeng and Nanyue, accounting for about 1/4 of the whole Hengyang City, with a weighted average traffic time of 0.91-1.11 h. The areas with higher accessibility than the average level are located in Hengyang County, Hengnan County, Hengshan County and Hengdong County in the northeast of the core area. The weighted average travel time isoline of Changning City in Southwest China is sparse compared with other parts, and the accessibility level is slightly lower than the average level. The worst accessibility is Leiyang City in the southeast and Qidong County in the West. The weighted average travel time is 2.75-2.95 h and 2.55-2.75 h respectively. As a whole, the weighted average travel time of each district and county in Hengyang City gradually increases from the Northeast core area to the surrounding area, presenting an irregular circular distribution pattern on the whole, forming a core edge distribution feature with five districts in Hengyang City as the core and gradually decreasing outward enclosure.

5. Measurement of regional economic
5.1. Analysis of differences in regional economic ties
According to the gravity model of time distance correction, the strength and total amount of economic ties of each district and county are calculated by using the time distance of the resident population, GDP and the time distance of each region of Hengyang City in 2018, as is shown in Table 6 and Table 7.
Table 6. Economic contact intensity of districts and counties in Hengyang (10000 person * 100 million yuan / h²)

| District/county | Yanfeng District | Zhuhui District | Shigu District | Zhengxiang District | Nanyue District | Hengyang County | Hengnan County | Hengshan County | Hengdong County | Qidong County | Leiyang City | Changning City |
|----------------|-----------------|-----------------|----------------|-------------------|----------------|----------------|----------------|----------------|----------------|--------------|-------------|---------------|
| Zhuhui District| 72778           | 359271          | 72066          | 1721.4            |                | 20258          | 35281          | 5748           | 10745          | 5319         | 9455        | 8306          |
| Yanfeng District| 404386          | 59256           | 1602           | 18758             | 21561          | 18254          | 4888           | 7455           | 3772           | 5968         | 5607        |                |
| Shigu District | 45605           | 1776.5          | 2456.6         | 52127             | 20210          | 6928           | 11322          | 5684           | 8651           | 8737         |            |                |
| Zhengxiang District | 2843         | 8278            | 5972           | 4596              | 16865          | 25450          | 12936          | 1449           | 813.8          |              |             |                |
| Nanyue District | 25098           | 9150            | 16828          | 25450             | 10842          | 28958          | 20813          | 3252           |                |              |             |                |
| Hengyang County | 7828            | 16626           | 7442           | 3252              |                | 112471.1       |                |                |                |              |             |                |

Table 7. Total amount of economic ties of districts and counties in Hengyang (10000 person * 100 million yuan / h²)

| District/county | Yanfeng District | Zhuhui District | Shigu District | Zhengxiang District | Nanyue District | Hengyang County | Hengnan County | Hengshan County | Hengdong County | Qidong County | Leiyang City | Changning City |
|----------------|-----------------|-----------------|----------------|-------------------|----------------|----------------|----------------|----------------|----------------|--------------|-------------|---------------|
| Zhuhui District| 600948.5        | Nanyue District  | 32227.8        | Hengdong County   |                |                |                |                |                |              |             |                |
| Yanfeng District| 616643.8        | Hengyang County  | 219227.5       | Qidong County     |                |                |                |                |                |              |             |                |
| Shigu District | 945434.7        | Hengnan County   | 219700.1       | Leiyang City      |                |                |                |                |                |              |             |                |
| Zhengxiang District | 359934         | Hengshan County  | 86949.93       | Changning City    |                |                |                |                |                |              |             |                |

In terms of the strength of economic ties among 12 districts and counties, the first level ties are the ties between Shigu District - Yanfeng district and Shigu District - Zhuhui District in the central urban area. The second level ties are the ties between Shigu District - Zhengxiang District, Zhuhui District - Zhengxiang District, Zhuhui District - Yanfeng district and Zhengxiang District - Hengyang County in the central urban area, reflecting the close economic relationship between the central urban area of Hengyang and its neighboring areas with strong comprehensive strength. The third level connection strength mainly refers to the connection between counties near the central urban area and districts in the central urban area, and the connection between counties near the central urban area and neighboring counties. The fourth level connection strength can be divided into two types, namely, the connection between counties far away from the central urban area and counties near the central urban area, and the connection between districts far away from the central urban area and districts in the central urban area. The fifth level is mainly the relationship between districts and counties far away from the central urban area.

5.2. Spatial pattern of regional economic linkages

Affected by the total economic volume, population size, and regional traffic accessibility of various counties and cities, the total economic linkages of each district and county vary significantly. First of all, corresponding to the scale of the economic aggregates and population of each district and county, the aggregate economic linkages of districts and counties show obvious hierarchical characteristics. The economy of districts and counties such as Shigu District, Yanfeng District, Zhuhui District and
Zhengxiang District. The number of contacts is high. The total number of economic contacts is more than 350,000. The highest is Shigu District. The total number of economic contacts is 945434.7, while the smallest total is Nanyue District, which is only 32227.8. The total economic links of the districts and counties in Hengyang are classified into 5 categories by natural breakpoints. The first gradient is the three districts of Shigu, Yanfeng and Zhuhui in the central city. The total economic links are between 359934 ~ 945434.7. It is the Zhengxiang District of the central urban area, with a total economic connection of 219700.1 ~ 359934.0. The third gradient is Hengyang County and Hengnan County around the central urban area, with a total economic connection of 129286.4 ~ 219700.1. And the fourth gradient Qidong County, Changning City, Liyang City, Hengdong County, and Hengshan County, located on the edge of Hengyang City, have a total economic connection of 32227.8 ~ 129286.4. The fifth gradient is Nanyue District, which has the lowest total economic connection. The differences in other gradient regions are large.

On the whole, Hengyang districts and counties have formed a central periphery radiation pattern with Shigu District, Zhengxiang District, Yanfeng district and Zhuhui district as the core to spread around. Hengyang County and Hengnan County, which are located around the central urban area, have strong connections with the central urban area and the surrounding areas of the central area, forming two sub-centers. However, the connection between the marginal counties and cities far away from the urban area is mostly weak. The economic relations among the districts and counties in Hengyang show a spatial pattern of "one core, two centers".

6. Conclusion and discussion

Based on the shortest travel time data and socio-economic data of 12 districts and counties in Hengyang, China, this paper studies the quantitative and spatial pattern analysis of traffic and economic relations among districts and counties in Hengyang by using accessibility and improved gravity model. The conclusions are as follows:

(1) The weighted average travel time of 12 districts and counties in Hengyang is 0.91-2.96h, with an average of 1.46h. The highest accessibility level is Zhengxiang District, with a weighted average travel time of 0.91h, which is 0.62 times of the average level of Hengyang City; the worst is Leiyang City, with a weighted average travel time of 2.96h, which is 2.03 times of the average level. From the perspective of accessibility coefficient, there are 8 districts and counties whose accessibility is higher than the average level of Hengyang City, and 4 districts and counties whose accessibility is lower than the average level.

(2) The accessibility level of each district and county in Hengyang is: central area > Northeast area > Northwest area > South area. In general, accessibility presents an irregular circular distribution pattern, forming a core edge distribution feature with five districts of Hengyang City as the core and gradually decreasing outward enclosure.

(3) The first level of economic connection intensity of 12 districts and counties in Hengyang is the connection between Shigu District Yanfeng district and Shigu District Zhuhui District in the central city; the second level is the connection between Shigu District Zhengxiang District, Zhuhui District Zhengxiang District, Zhuhui District Yanfeng district and Zhengxiang District Hengyang County in the central city; the third level of connection intensity can be mainly divided into counties adjacent to the central city and the central city. The connection between districts and the connection between counties adjacent to the central urban area and their neighboring counties; the four level connection can be divided into two types, that is, the connection between districts and counties far away from the central urban area and the connection between districts and counties far away from the central urban area; the five level connection strength is mainly between districts and counties far away from the central urban area links.

(4) In Hengyang, the economic relations among districts and counties form a central periphery radiating pattern with Shigu District, Zhengxiang District, Yanfeng district and Zhuhui district as the core, presenting a spatial connection pattern of "one core and two centers".

The gravity model of regional connection is a traditional geographical model. It can be used to
describe the strength of regional connection from the perspective of attraction. However, with the development of new technology and new methods, the traditional model method has certain limitations and real-time accuracy. In order to further explore the regional city connection more scientifically, it is suggested to combine the real-time big data method with the traditional analysis model.

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