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Regional accessibility of land traffic network in the Yangtze River Delta

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Abstract: In a given district, the accessibility of any point should be the synthetically evaluation of the internal and external accessibilities. Using MapX component and Delphi, the author presents an information system to calculate and analyze regional accessibility according to the shortest travel time, generating thus a mark diffusing figure. Based on land traffic network, this paper assesses the present and the future regional accessibilities of sixteen major cities in the Yangtze River Delta. The result shows that the regional accessibility of the Yangtze River Delta presents a fan with Shanghai as its core. The top two most accessible cities are Shanghai and Jiaxing, and the bottom two ones are Taizhou (Zhejiang province) and Nantong. With the construction of Sutong Bridge, Hangzhouwan Bridge and Zhoushan Bridge, the regional internal accessibility of all cities will be improved. Especially for Shaoxing, Ningbo and Taizhou (Jiangsu province), the regional internal accessibility will be decreased by one hour, and other cities will be shortened by about 25 minutes averagely. As the construction of Yangkou Harbor in Nantong, the regional external accessibility of the harbor cities in Jiangsu province will be speeded up by about one hour.

Keywords: regional accessibility; land traffic network; Yangtze River Delta; GIS

1 Introduction

Hansen (1959) gives the fundamental formulation of accessibility, defining accessibility as the intensity of possibility of interaction (Johnston, 1994). In the last 40 years, study on accessibility has made great progress not only in abstracting the real world but also in opening out evolutive mechanism of regional spatial structure and simulating urban dynamic evolutive process (Kwan M P, 2003; Harvey, 2000; Van Eck J R, 1999; Hyun-Mi Kim, 2003). Accessibility has become a key factor which decides the individual life style and the regional tomorrow. Moreover, the change of regional accessibility will directly affect development of regional economy.

Gutierrez and Gonzalez (1996) predicated effects of the European high speed train network on accessibility patterns. Bowen (2000) evaluated international air accessibility of

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Southeast airline hubs. Linneker and Spence (1996) studied the regional development effects of the M25 London orbital motorway. Loo B P Y (1999), Cao Xiaoshu (2003) and Xu Di (2004) analyzed the impact of evolution of land network on spatial structure of accessibility. Li Siming (2001) and Cao Xiaoshu (2005) analyzed impacts of the national trunk highway system on accessibility in China. Jin Fengjun (2001; 2003; 2004) studied railway network expansion and spatial accessibility changes in China in 1906–2000 and spatial evolution of air network in China.

In recent years, the domestic and foreign accessibility studies have covered railways, highways and air routes. However, evaluation of accessibility mainly focuses on the interior of regions. In fact, internal and external accessibility should be evaluated by evaluating each point in the region (Lu, 2003). Using MapX component and Delphi, we developed an information system to calculate and analyze regional accessibility according to the shortest travel time. Based on land traffic network, we evaluated the present and the future regional accessibility of 16 major cities in the Yangtze River Delta.

2 The study area

The Yangtze River Delta is one of the most famous estuarine deltas in China as well as in the world. As far as the economic region is concerned, it includes Nanjing, Suzhou, Wuxi, Changzhou, Zhenjiang, Nantong, Yangzhou, Taizhou of Jiangsu province, Hangzhou, Jiaxing, Huzhou, Shaoxing, Ningbo, Zhoushan, Taizhou of Zhejiang province and Shanghai, covering an area of 10.9×10^4 km^2.

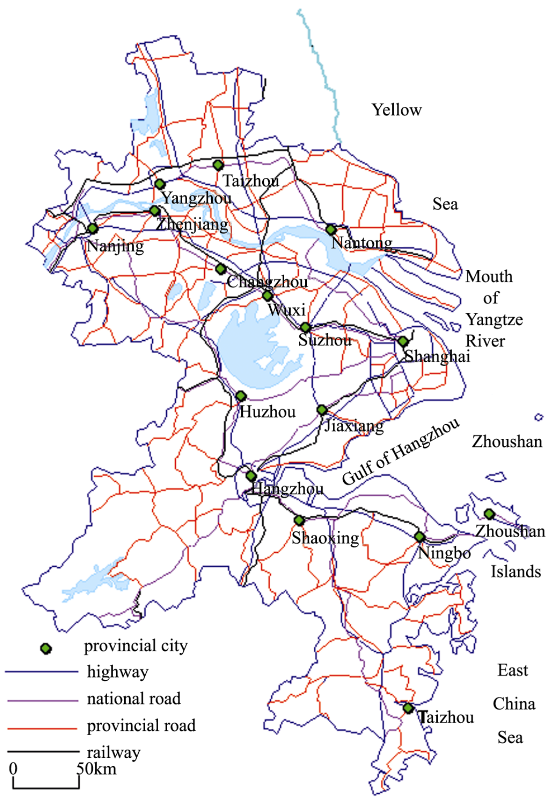

Figure 1 Traffic network in the Yangtze River Delta (YRD)

The open-to-traffic highway mileage is about 28,000 km in the Yangtze River Delta. There are many highways such as Ningbo-Taizhou-Wenzhou, Shanghai-Hangzhou-Ningbo, Suzhou-Jiaxing-Hangzhou, Hangzhou-Jinhua-Quzhou, Nanjing-Hangzhou, Nanjing-

Shanghai, Nanjing-Natong and Nantong-Qidong. And there are many national roads such as 104, 204, 205, 312, 318, 320, 328 and 329. Mileage in railway open to traffic is about 1200 km and the density of railway is 1.2 km/km^2. Shanghai-Nanjing, Nanjing-Qidong, Xinyi-Changxing, Xuancheng-Hangzhou, Shanghai-Hangzhou, Xiaoshan-Ningbo and Hangzhou-Zhuzhou are main railways in the Yangtze River Delta (Figure 1).

3 Method of regional accessibility evaluation

3.1 Evaluating index

$$A_i = \frac{\sum_{j=1}^{d} Tij}{d} \tag{1}$$

where A_i is the accessibility of node i, j is a point in the region, d is the number of points in the region, and T_{ij} is the shortest travel time between the node i and the point j.

3.2 Technical route

3.2.1 Division of grid

We divide the whole Yangtze River Delta into many square cells. The area of every cell can be defined arbitrarily. In this paper, we define area of one cell as 500 m×500 m. The whole region can be divided into 399,192 effective cells. Thus the cells number of each city can be gained (Table 1). One cell of 0.25 km^2 is very small compared with the Yangtze River Delta whose area is 10.9×10^4 km^2. Accessibility is almost no difference within such a cell. Therefore, we regard cells as points whose accessibilities are homogeneous in the region.

Table 1 The cells number of each city in the YRD

City	Number of cells	City	Number of cells	City	Number of cells
Nanjing	25064	Changzhou	16222	Huzhou	22072
Zhenjiang	14010	Taizhou(Jiangsu)	21893	Hangzhou	63124
Yangzhou	23983	Nantong	33344	Shaoxing	30755
Suzhou	24855	Shanghai	20679	Ningbo	32047
Wuxi	15673	Jiaxing	15314	Taizhou(Zhejiang)	36255

Annotation: Zhoushan has not been connected with other cities through land traffic. So, this paper does not consider its accessibility. Because Chongming Island is separated from Shanghai in space, Shanghai does not include Chongming Island in this paper.

3.2.2 Velocity of grid

We determine the velocity of each grade's road according to *PRC Trade Criterion-Design Specification for Highway Route* (JTJ 011-XX) and determine the velocity of each railway in the light of design velocity and actual travel conditions of railway in the Yangtze River Delta. We only draw highway, national road, provincial road and railway in the traffic network. As a matter of fact, regions without railways and high grade roads still have low grade roads. Therefore, we assign a default velocity of 20 km/h to the cells without highway, national road, provincial road and railway (Table 2).

Table 2 Constitution and velocity of land traffic network in the YRD (km/h)

The grade of road	Highway	National road	Provincial road	Railway							
				Shanghai-Nanjing	Nanjing-Qidong	Xinyi-Changxing	Xuancheng-Hangzhou	Shanghai-Hangzhou	Xiaoshan-Ningbo	Hangzhou-Zhuzhou	Default
Velocity	120	100	80	150	100	100	100	150	120	120	20

3.2.3 Algorithm of the information system to calculate and analyze regional accessibility

The region is divided into many square cells. And each cell is seen as $P(m, n)$ (m is row number, n is column number). Velocity of grid is marked as $V(m, n)$ and length of a side of grid is marked as L. We begin to look for the shortest-time routes from grid $P(m, n)$ of node i to some other grids in the region. Firstly, we calculate the time from grid $P(m, n)$ to grid $P(m–1, n)$, $P(m–1, n–1)$, $P(m–1, n+1)$, $P(m, n–1)$, $P(m, n+1)$, $P(m+1, n)$, $P(m+1, n–1)$ and $P(m+1, n+1)$. The results are as follows.

$$T(m-1,n)=\frac{L}{2V(m,n)}+\frac{L}{2V(m-1,n)}$$

$$T(m,n-1)=\frac{L}{2V(m,n)}+\frac{L}{2V(m,n-1)}$$

$$T(m-1,n-1)=\frac{\sqrt{2}L}{2V(m,n)}+\frac{\sqrt{2}L}{2V(m-1,n-1)}$$

$$T(m,n+1)=\frac{L}{2V(m,n)}+\frac{L}{2V(m,n+1)}$$

$$T(m-1,n+1)=\frac{\sqrt{2}L}{2V(m,n)}+\frac{\sqrt{2}L}{2V(m-1,n+1)}$$

$$T(m+1,n)=\frac{L}{2V(m,n)}+\frac{L}{2V(m+1,n)}$$

$$T(m+1,n+1)=\frac{\sqrt{2}L}{2V(m,n)}+\frac{\sqrt{2}L}{2V(m+1,n+1)}$$

$$T(m+1,n-1)=\frac{\sqrt{2}L}{2V(m,n)}+\frac{\sqrt{2}L}{2V(m+1,n-1)}$$

Secondly, we sort the time data ascendingly in a queue. From the queue we take out the grid with the shortest time and calculate the travel time from it to its eight adjacent grids. Lastly we insert them in the queue ascendingly. If the time data of the grid already exists in the queue, we compare two values and store the smaller one in. We propagate the calculation until we can get the shortest time and its travel route from grid $P(m,n)$ of node i to any other grids in the region.

3.2.4 Technical solution about close highway and railway

Highway and railway are not totally open to traffic. The service that they provide based on the entrances of highway and railway stations. Therefore not all the grids, which have railways or highways passing through, can share their services. So, it is necessary to amend the above algorithm.

Firstly, we define a category and a type for every road in the traffic network. Many roads may have the same category. The type can be closed or open. We suppose the kind of category is k and record them as 1, 2, …, k.

Secondly, we define a two-dimensional array of categories of all the roads in the traffic network:

C: array[1…k, 1, …, k] of Boolean;

The two-dimensional array is used to store the information whether or not k kinds of categories connect with each other. If connected, the value of array element is “True”, otherwise it is “False”. The value of C [I, J] is true, which shows the road of category I is connected with the road of category J.

Because many categories of roads may pass one grid, we need to save the travel time of every category. When we calculate the travel time from the grid of the node i to other eight adjacent grids, we do not use the above algorithm but adjusted algorithms in 4 different cases

(1) If grid $P(m, n)$ has no road passing and its adjacent grids have no road passing either, we use the travel time of grid $P(m, n)$ to calculate its adjacent grids travel time.

(2) If grid $P(m,n)$ has no road passing and its adjacent grids have road passing, we use the travel time of grid $P(m,n)$ to calculate the travel time of all open roads in its adjacent grids.

(3) If grid $P(m, n)$ has road passing and its adjacent grids have no road passing, we use the shortest travel time of all open roads to calculate its adjacent grids travel time.

(4) If grid $P(m, n)$ has road passing and its adjacent grids have road passing, we use double loops to search all road categories in grid $P(m, n)$ and its adjacent grids. On the condition that the value of C[u, v] is “True”, we use the travel time of road category u in grid P(m, n) to calculate the travel time of road category v in its adjacent grids.

Using MapX component and Delphi, we developed an information system to calculate and analyze regional accessibility according to the shortest travel time based on the above algorithm, generated thus a mark diffusing figure of node accessibility.

4 The results of regional accessibility evaluation

4.1 The results of regional internal accessibility evaluation

We set fifteen provincial cities in the Yangtze River Delta except Zhoushan as nodes in the region. And then we calculate average travel time from each node to other nodes and the whole Yangtze River Delta through traffic network, i.e. the regional internal accessibility of each node (Table 3), thereafter we generate a mark diffusing figure (Figure 2). In order to show entire accessibility of cities in the Yangtze River Delta, we take the above 15 provincial cities as the nodes at the same time, calculate their accessibility, and then generate a mark diffusing figure (Figure 2).

4.2 The results of regional external accessibility evaluation

4.2.1 The results of regional external accessibility evaluation with harbors as nodes

Yangshan harbor in Shanghai and Beilun harbor in Ningbo are two major harbors in the Yangtze River Delta. And the overseas contact with the Yangtze River Delta is mainly through these two harbors (Song, 2001). We regard them as nodes and calculate regional external accessibility of 15 provincial cities in the Yangtze River Delta (Table 4), and generate a mark diffusing figure (Figure 3).

Table 3 Regional internal accessibility of 15 cities in the YRD (h: min: s)

Region	Node							
	Nanjing	Zhenjiang	Yangzhou	Suzhou	Wuxi	Changzhou	Taizhou (Jiangsu)	Nantong
YRD	3:41:28	3:41:18	3:47:42	3:13:44	3:02:26	3:13:27	3:45:33	4:00:24
Nanjing	—	1:41:21	1:36:34	2:46:28	2:20:48	1:53:47	2:16:13	3:31:49
Zhenjiang	0:56:57	—	1:40:35	1:45:23	1:19:46	0:50:19	2:01:59	2:42:57
Yangzhou	1:51:54	2:41:55	—	2:51:47	2:26:10	2:41:24	1:20:01	2:36:40
Suzhou	2:38:42	2:21:44	2:24:29	—	1:04:42	1:33:40	2:20:27	2:06:50
Wuxi	1:51:45	1:41:51	1:52:38	1:12:39	—	1:02:01	1:48:46	2:20:39
Changzhou	1:25:47	1:17:58	1:58:02	1:33:10	1:07:29	—	2:07:27	2:40:47
Taizhou (Jiangsu)	2:06:05	2:26:33	1:19:33	2:14:03	1:48:29	1:58:24	—	1:49:22
Nantong	2:55:29	3:02:50	2:07:52	2:11:06	2:16:48	2:32:26	1:38:21	—
Shanghai	3:09:37	2:53:45	2:52:50	1:18:28	1:34:19	2:03:45	2:48:49	2:29:54
Jiaxing	3:16:24	3:03:20	2:59:27	2:00:18	1:56:39	2:24:03	2:55:26	3:11:39
Huzhou	2:47:34	2:45:19	3:06:27	2:22:14	2:04:50	2:08:14	3:02:25	3:33:50
Hangzhou	4:41:43	4:39:20	4:46:32	3:58:08	3:45:34	4:02:15	4:42:30	5:09:31
Shaoxing	5:28:05	5:25:50	5:33:14	4:43:43	4:32:27	4:48:46	5:29:13	5:55:02
Ningbo	6:28:11	6:25:56	6:35:34	5:46:03	5:34:47	5:48:52	6:31:32	6:57:22
Taizhou (Zhejiang)	7:14:15	7:12:00	7:21:38	6:32:07	6:20:51	6:34:56	7:17:37	7:43:26

Region	Node							
	Shanghai	Jiaxing	Huzhou	Hangzhou	Shaoxing	Ningbo	Taizhou (Zhejiang)	Total
YRD	3:06:05	2:58:46	2:48:58	2:49:18	3:39:33	4:28:14	5:29:46	1:04:19
Nanjing	3:21:45	3:34:51	2:34:05	3:30:46	5:11:28	6:17:34	7:32:00	0:58:28
Zhenjiang	2:23:45	2:39:24	1:59:46	2:53:52	4:36:55	5:43:02	6:57:28	0:39:11
Yangzhou	3:19:41	3:26:32	3:29:32	3:55:32	5:54:43	7:00:50	8:15:16	1:00:52
Suzhou	1:18:33	1:51:38	1:46:35	2:22:16	4:16:00	5:22:07	6:36:33	0:47:39
Wuxi	1:50:02	2:02:02	1:29:25	2:08:24	3:58:53	5:05:00	6:19:26	0:42:02
Changzhou	2:11:21	2:28:19	1:30:21	2:23:10	4:06:39	5:12:45	6:27:11	0:46:39
Taizhou (Jiangsu)	2:42:00	2:48:50	2:51:40	3:17:51	5:17:03	6:23:10	7:37:36	0:54:00
Nantong	2:55:36	3:18:50	3:23:43	3:48:31	5:47:44	6:53:51	8:08:16	1:06:06
Shanghai	—	1:09:25	1:58:45	1:52:37	3:48:02	4:54:08	6:08:34	0:40:56
Jiaxing	1:14:53	—	1:44:30	1:03:29	2:57:36	4:03:42	5:18:08	0:36:24
Huzhou	2:16:20	1:59:00	—	1:20:27	3:01:13	4:07:20	5:21:46	0:45:27
Hangzhou	3:13:10	2:37:32	2:30:33	—	3:05:49	4:10:15	5:24:25	1:46:51
Shaoxing	3:55:52	3:21:03	3:16:53	2:34:28	—	1:37:41	2:30:29	0:55:01
Ningbo	4:58:12	4:23:37	4:16:59	3:36:48	1:38:46	—	2:31:58	1:09:51
Taizhou(Zhejiang)	5:44:17	5:09:41	5:03:04	4:22:52	2:24:36	2:06:43	—	1:11:51

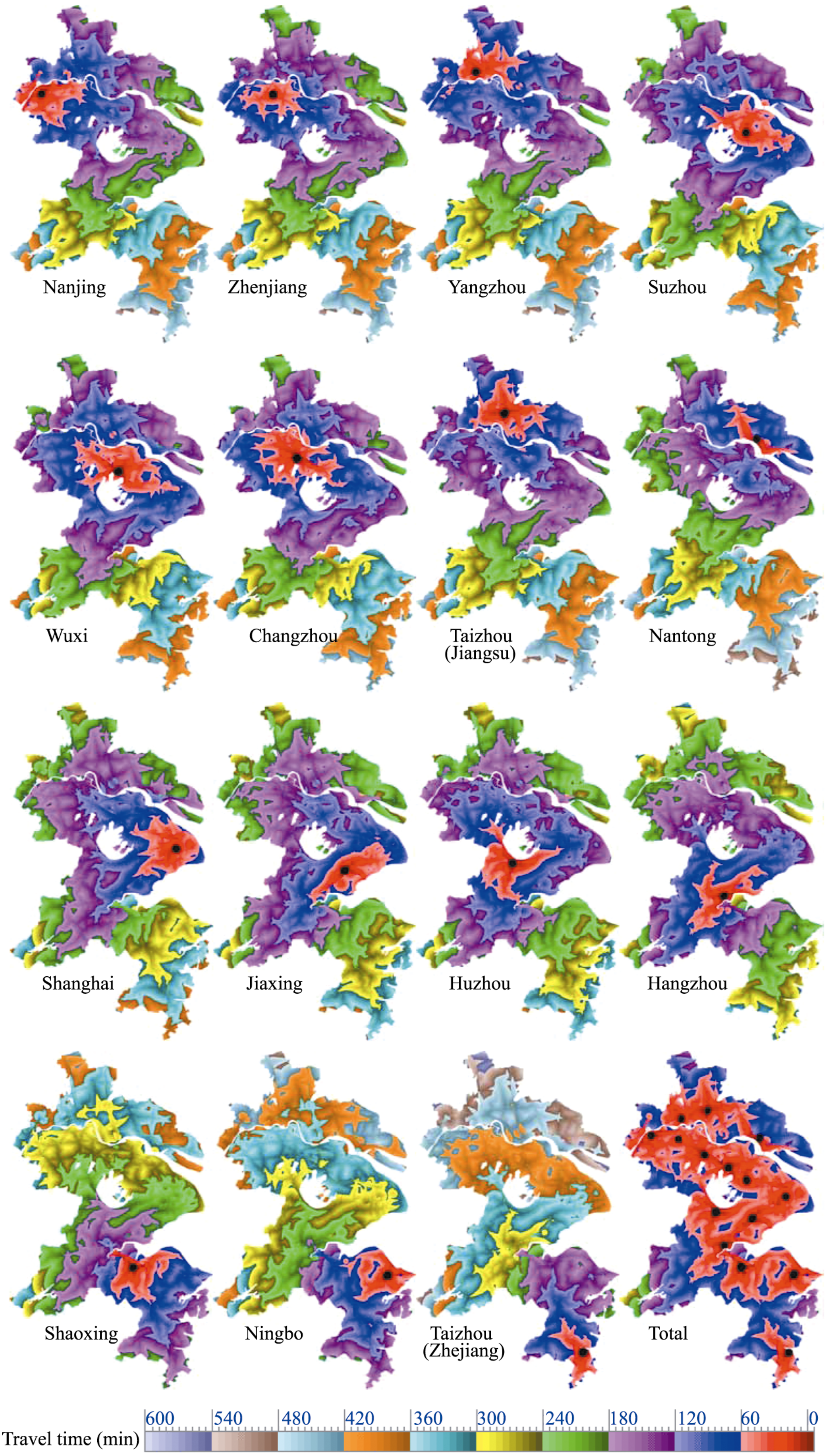

Figure 2 Diffusion figures of regional internal accessibility of 15 cities in the YRD

Table 4 Regional accessibility and geometric centricity of 15 cities in the YRD (h:min:s)

City	Regional internal accessibility		Geometrical centricity mark	Regional external accessibility								Regional accessibility	
				Railway station		Entrance to external road		Air harbor		Harbor			
	Time	Mark		Time	Mark	Time	Mark	Time	Mark	Time	Mark	Mark	Normalized ratio
Nanjing	3:41:28	67	29	1:03:47	73	0:27:12	100	1:15:28	88	4:24:11	1	53.41	42
Zhenjiang	3:41:18	67	42	0:38:37	99	0:55:26	73	1:19:48	85	3:26:11	28	60.81	56
Yangzhou	3:47:42	63	30	1:01:36	75	0:33:09	94	2:37:34	34	4:22:07	1	45.51	26
Suzhou	3:13:44	85	82	0:47:41	90	1:40:31	30	1:59:54	59	2:15:58	63	69.22	72
Wuxi	3:02:26	92	74	0:44:00	93	0:51:51	77	2:03:32	57	2:51:29	46	72.19	78
Changzhou	3:13:27	85	61	0:56:15	81	0:41:12	87	1:35:50	75	3:13:46	35	68.24	70
Taizhou (Jiangsu)	3:45:33	65	30	0:52:05	85	0:36:38	91	2:48:58	27	3:44:25	20	51.99	39
Nantong	4:00:24	56	47	1:10:01	66	0:57:08	71	3:29:52	1	3:58:02	13	39.42	15
Shanghai	3:06:05	89	65	0:43:41	94	2:12:07	1	0:57:43	100	1:00:39	100	83.56	100
Jiaxing	2:58:46	94	92	0:37:39	100	1:47:58	23	1:02:29	97	1:39:58	81	82.38	97
Huzhou	2:48:58	100	100	0:47:50	89	0:36:57	91	1:20:51	85	2:58:15	42	78.19	89
Hangzhou	2:49:18	99	87	1:43:10	32	0:55:01	73	1:50:06	66	3:42:14	21	61.37	57
Shaoxing	3:39:33	69	69	0:57:49	79	0:40:24	87	1:36:18	75	2:11:36	65	71.58	77
Ningbo	4:28:14	38	45	1:14:37	62	1:26:12	44	1:17:20	87	1:39:44	81	59.84	54
Taizhou (Zhejiang)	5:29:46	1	1	2:13:54	1	0:38:40	89	2:15:29	49	2:41:35	50	32.03	1

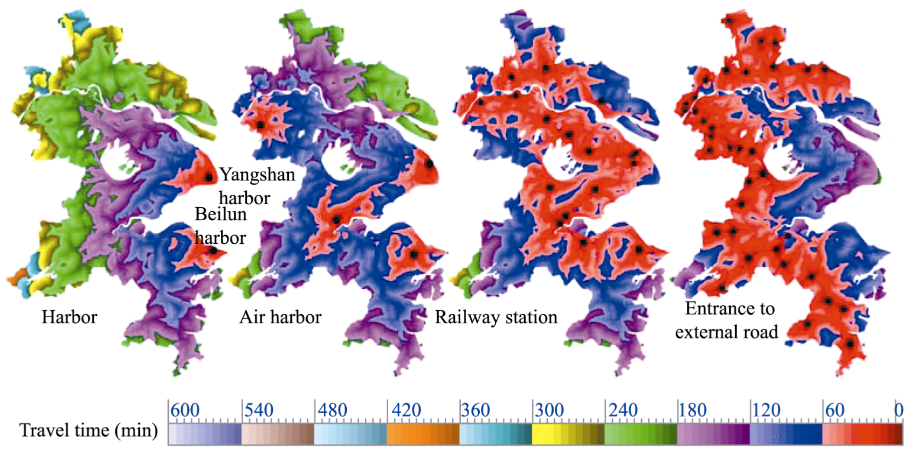

Figure 3 Diffusion figures of regional external accessibility in the YRD

4.2.2 The results of regional external accessibility evaluation with air harbors as nodes

Airports in the Yangtze River Delta are distributed mainly over Nantong, Changzhou, Wuxi, Taizhou (Zhejiang province), Nanjing, Shanghai, Hangzhou and Ningbo. Nanjing, Shanghai, Hangzhou and Ningbo are international airports. We set these four international airports as nodes and calculate regional external accessibilities of the 15 provincial cities in the Yangtze River Delta (Table 4), and generate a mark diffusing figure (Figure 3).

4.2.3 The results of regional external accessibility evaluation with railway stations as nodes

Railway is a kind of important traffic which connects the region inside with the regions outside of the Yangtze River Delta. There are 17 main railway stations in the Yangtze River

Delta, which are Nanjing railway station, Zhenjiang railway station, Taizhou (Jiangsu province) railway station, Yangzhou railway station, Nantong railway station, Suzhou railway station, Wuxi railway station, Changzhou railway station, Jiaxing railway station, Huzhou railway station, Shaoxing railway station, Ningbo railway station, Hangzhou railway station, the Hangzhou east railway station, the Shanghai west railway station, the Shanghai south railway station and Shanghai new railway station. We set these 17 railway stations as nodes and calculate regional external accessibilities of the 15 provincial cities in the Yangtze River Delta (Table 4), thus generating a mark diffusing figure (Figure 3).

4.2.4 The results of regional external accessibility evaluation with entrance to external road as nodes

The road contacts between region inside and region outside of the Yangtze River Delta is mainly through highways, national roads and provincial roads. We choose 35 important entrances as nodes and calculate regional external accessibilities of the 15 provincial cities in the Yangtze River Delta (Table 4), and generate a mark diffusing figure (Figure 3).

4.3 The results of regional accessibility evaluation

Regional accessibility is the weighted sum of regional internal accessibility and regional external accessibility (Lu, 2003).

$$R = f_1R_1 + f_2R_2 + f_3R_3 + f_4R_4 + f_5R_5 \quad (2)$$

where R is the total mark of regional accessibility; f_1, R_1 are the weight and mark of regional internal accessibility respectively; f_2, R_2 are the weight and mark of regional external accessibility with harbors as nodes respectively; f_3, R_3 are the weight and mark of regional external accessibility with air harbors as nodes respectively; f_4, R_4 are the weight and mark of regional external accessibility with railway stations as nodes respectively; and f_5, R_5 are the weight and mark of regional external accessibility with entrance to external road as nodes respectively.

According to the second formula, we can get mark of regional accessibility. In order to make the comparison easier, we normalize mark of regional accessibility on the basis of the third formula (Table 4).

$$P_i = 100 - \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \times 100 \quad (3)$$

where P_i is normalized mark of accessibility; x_i is mark of accessibility, min (x_i) is minimum mark of accessibility and max (x_i) is maximum mark of accessibility.

We define f_1, f_2, f_3, f_4 and f_5 as 0.36, 0.31, 0.11, 0.10 and 0.12 according to the volume of passengers and goods traffic of the 15 provincial cities in the Yangtze River Delta from 2000 to 2004, combining the method of AHP.

5 Analysis of evaluation results

5.1 Regional internal accessibility reflects location centricity

5.1.1 Analysis of regional internal accessibility

(1) Hangzhou, Jiaxing and Huzhou have the best regional internal accessibilities in the Yangtze River Delta which are about 3 hours and the marks are greater than 94. (2) Shanghai,

Suzhou, Wuxi and Changzhou have better regional internal accessibilities whose time is between 3 hours and 3.5 hours and marks are between 85 and 92. Nanjing, Zhenjiang, Yangzhou, Shaoxing and Taizhou of Jiangsu province have medium regional internal accessibilities whose time is between 3.5 hours and 4 hours and marks are between 63 and 70. (3) Nantong and Ningbo have worse regional internal accessibilities whose time is between 4 hours and 4.5 hours and marks are between 38 and 56. Taizhou of Zhejiang province has worst regional internal accessibilities whose time is 5.5 hours and mark is 1. (4) Suzhou, Wuxi and Changzhou can reach Shanghai in 2 hours through land traffic network. The eight cities of Jiangsu province can reach Shanghai, Jiaxing and Huzhou in 4 hours and reach other areas in 6 hours. Hangzhou, Jiaxing and Huzhou can reach Shanghai in 2 hours and reach other areas except Taizhou of Jiangsu province and Ningbo in 4 hours. Shaoxing, Ningbo and Taizhou of Zhejiang province can reach each other in 3 hours. In order to realize the goal that all cities in the Yangtze River Delta can reach each other in 4 hours, we must strengthen traffic connections between Nantong and Yangzhou and Ningbo and Taizhou of Zhejiang province.

5.1.2 Calculation of regional centricity

Firstly, we use Mapinfo to find geometric centre of the Yangtze River Delta. Secondly, we calculate geometric centricities of the 15 node cities in the Yangtze River Delta according to the fourth formula. Lastly, we normalize the value of the geometric centricities (Yu, 2005).

$$Q_i = \frac{D_i}{\sqrt{\frac{S}{\pi}}} \tag{4}$$

where Q_i is geometric centricity of node i, D_i is the distance between node i and regional geometric center, and S is the area of region.

5.1.3 Correlative analysis of regional internal and external accessibility

We analyze the relativity of the normalized value of regional internal accessibility and regional centricity of the 15 node cities in the Yangtze River Delta by SPSS. Relative coefficient is 0.86 and simulative formula is as follows.

$$Y = e^{\left(4.3914 - \frac{4.4059}{x}\right)} \tag{5}$$

where x is the value of geometric centricity and Y is the value of regional internal accessibility.

From this, we can see that regional internal accessibility of the nodes reflects their regional centricity.

5.2 Regional external accessibility reflects regional external conveniency

5.2.1 Regional external accessibility with harbors as nodes

Shanghai has the best regional external accessibility with harbors as nodes whose time is about 1 hour. Ningbo and Jiaxing have better accessibilities whose time is less than 2 hours. Nanjing and Yangzhou have worse accessibilities whose time is more than 4 hours.

The average city accessibility marks in Jiangsu and Zhejiang provinces are 26 and 57 separately (Table 5). Jiangsu province has no harbors in the Yangtze River Delta, so its external marine connection falls behind Zhejiang province's.

5.2.2 Regional external accessibility with air harbors as nodes

Shanghai and Jiaxing have better regional external accessibilities with air harbors as nodes and the time is about 1 hour. Nantong, Taizhou (Jiangsu province) and Yangzhou have worse accessibilities and the time to harbors is more than 2.5 hours. And other cities' accessibilities are between 1 hour and 2.5 hours.

The average city accessibility marks in Jiangsu and Zhejiang provinces are 53 and 77 separately (Table 5). Jiangsu province has only one international air harbor and its south external aerial connection is mainly through Shanghai air harbor, therefore its external aerial connection falls behind Zhejiang province's.

5.2.3 Regional external accessibility with railway stations as nodes

Jiaxing, Zhenjiang, Shanghai, Wuxi, Suzhou, Changzhou, Taizhou (Jiangsu province), Huzhou and Shaoxing have better regional external accessibilities with railway stations as nodes whose time is less than 1 hour. Taizhou of Zhejiang province has the worst accessibility whose time is more than 2 hours.

The marks of average accessibilities of the cities in Jiangsu and Zhejiang provinces are respectively 83 and 61 (Table 5). The railway mileage in Zhejiang province is shorter than that in Jiangsu province and Taizhou of Zhejiang province has no railway, therefore external railway connection of Jiangsu province is better than that of Zhejiang province.

5.2.4 Regional external accessibility with entrance to external road as nodes

Nanjing has the best regional external accessibility with entrance to external road as nodes and the time is less than 0.5 hour. Shanghai has worst accessibility which is more than 2 hours. And other cities accessibilities are between 0.5 hour and 2 hours. The mark of average accessibilities of cities in Jiangsu province is better than that in Zhejiang province (Table 5).

Table 5 Mark of regional accessibility and geometric centricity of each region in the YRD

Region	Regional external accessibility				Regional internal accessibility	Regional accessibility	Regional centricity
	Railway station	Entrance to external road	Harbor	Air harbor			
Shanghai	94	1	100	100	89	100	65
Jiangsu	83	78	26	53	73	50	50
Zhejiang	61	68	57	77	67	63	66

5.3 Regional accessibility is integration of internal and external accessibility

Regional accessibility of the Yangtze River Delta presents a fan with Shanghai as its core. The top two most accessible cities are Shanghai and Jiaxing whose accessibility marks are more than 90, and the bottom two ones are Taizhou (Zhejiang province) and Nantong whose accessibility marks are less than 20.

The mark of regional internal and external land accessibility of Jiangsu province is better than that of Zhejiang province. However, the mark of regional external accessibility with harbors and air harbors as nodes of Jiangsu province is worse than that of Zhejiang province. Therefore, regional accessibility of Jiangsu province is worse than that of Zhejiang province.

6 Regional accessibility of the YRD in 2008

6.1 Construction of Sutong Bridge, Hangzhouwan Bridge and Zhoushan Bridge

Hangzhouwan Bridge with a length of 36 km and velocity of 100 km/h will be built in 2008. Sutong Bridge is located in-between Nantong and Suzhou with a length of 32.4 km and velocity of 100 km/h. Zhoushan Bridge connects Ningbo and Zhoushan with a velocity of 100 km/h.

We define traffic velocity of Hangzhouwan Bridge, Sutong Bridge and Zhoushan Bridge as 100 km/h in this paper.

6.2 Construction of Yangkou harbor in Nantong

Scientists found a natural deep water fairway in Yangkou region of Nantong which is 17 m deep and 2.4 km wide. It is the only harbor where it is possible to build deepwater port of 10×10^4 tone to 20×10^4 tone except for Lianyungang in Jiangsu province. It will be the Jiangsu's biggest avenue to the sea. Construction of the Yangkou harbor began in 2005 and will be put to use in 2008.

6.3 The results of regional accessibility evaluation of the YRD in 2008

6.3.1 The results of regional internal accessibility evaluation

We set 16 provincial cities in the Yangtze River Delta including Zhoushan whose grid number is 2520 as nodes in the region. And then we calculate average travel time from each node to other nodes and the whole Yangtze River Delta through traffic network (Table 6).

6.3.2 The results of regional external accessibility evaluation

We set Yangshan Harbor of Shanghai, Beilun Harbor of Ningbo and Yangkou Harbor of Nantong as nodes and calculate regional external accessibilities of 16 provincial cities (Table 6), and generate a mark diffusing figure (Figure 4). Keeping nodes of airports, railway stations and entrance to external road unchanged, we recalculate regional external accessibility of the 16 provincial cities according to present traffic network and generate mark diffusing figures (Figure 4).

Table 6 Regional accessibility of 16 cities in the YRD in 2008 (h:min:s)

City	Regional internal accessibility		Regional external accessibility: Railway station		Entrance to external road		Air harbor		Harbor		Regional accessibility	
	Time	Mark	Time	Mark	Time	Mark	Time	Mark	Time	Mark	Mark	Normalized ratio
Nanjing	3:18:34	58	1:01:52	75	0:26:56	100	1:15:11	90	3:33:10	1	50.59	49
Zhenjiang	3:19:34	57	0:49:19	88	0:54:59	74	1:21:49	86	2:56:32	22	54.48	57
Yangzhou	3:32:03	47	0:59:50	78	0:32:13	95	2:40:10	34	2:38:46	32	49.78	48
Suzhou	2:40:22	90	0:47:20	89	1:39:32	32	2:03:30	59	2:12:11	30	60.93	71
Wuxi	2:36:52	93	0:42:29	95	0:51:43	75	2:03:30	59	2:39:41	31	68.08	85
Changzhou	2:50:22	82	0:56:06	81	0:40:51	85	1:35:33	76	2:57:38	21	62.69	74
Taizhou (Jiangsu)	3:19:51	57	0:49:17	88	0:36:35	91	2:48:14	28	1:54:49	58	61.3	71
Nantong	3:38:05	42	1:09:22	65	0:57:24	71	3:22:29	1	1:12:02	83	55.98	61
Shanghai	2:41:03	90	0:43:35	94	2:12:04	1	1:00:26	100	1:30:43	72	75.24	100
Jiaxing	2:32:41	97	0:37:38	100	1:39:59	31	1:08:31	95	2:05:24	52	75.21	99
Huzhou	2:32:35	97	0:47:20	88	0:36:27	90	1:17:05	89	3:02:46	18	69.89	89
Hangzhou	2:29:00	100	1:43:05	32	0:54:43	74	1:48:58	68	3:26:22	4	56.8	62
Shaoxing	2:43:45	88	0:57:02	79	0:39:56	88	1:20:28	87	2:10:22	49	74.9	99
Ningbo	3:04:47	70	1:14:37	62	1:25:58	43	1:18:12	88	1:36:02	69	67.63	84
Taizhou (Zhejiang)	4:27:18	1	2:13:24	1	0:38:27	89	2:13:40	52	2:39:52	31	26.47	1
Zhoushan	3:48:06	33	1:06:27	71	2:13:10	1	1:23:45	85	0:42:56	100	59.45	68

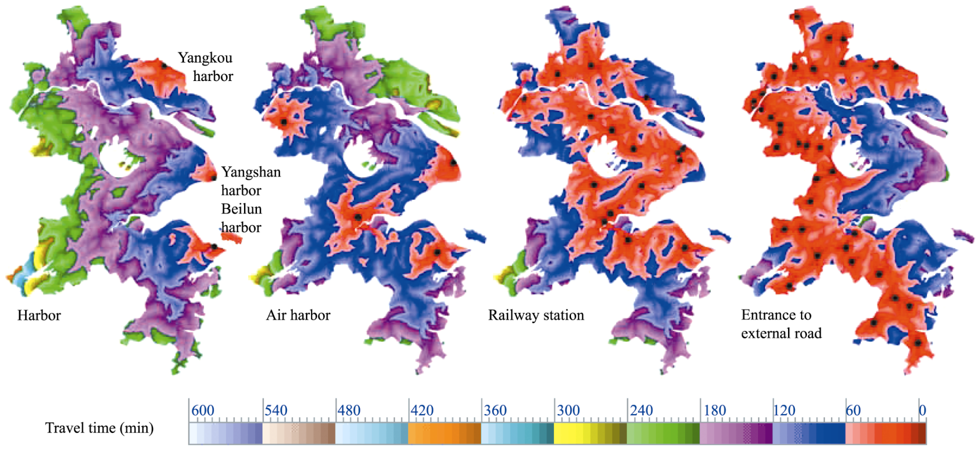

Figure 4 Diffusion figures of regional external accessibility in the YRD in 2008

6.4 Analysis of evaluation results

6.4.1 Regional internal accessibility will be improved

With the construction of Sutong Bridge, Hangzhouwan Bridge and Zhoushan Bridge, the regional internal accessibility of all cities will be improved. Especially for Shaoxing, Ningbo and Taizhou (Zhejiang province), the regional internal accessibilities will be speeded up by one hour, and other cities by about 25 minutes averagely.

The marks of average accessibility of cities in Jiangsu and Zhejiang provinces are 66 and 69 (Table 7).

Table 7 Mark of regional accessibility of each region in the YRD in 2008

Region	Regional external accessibility				Regional internal accessibility	Regional accessibility
	Railway station	Entrance to external road	Harbor	Air harbor		
Shanghai	94	1	72	100	90	100
Jiangsu	82	78	35	54	66	65
Zhejiang	62	59	46	81	69	72

6.4.2 Regional external accessibility with harbors as nodes will be improved and regional external accessibility with airports, railway stations and entrances to external roads will have no change

As the construction of Yangkou Harbor in Nantong, regional external accessibility of the harbor cities in Jiangsu province will be improved. Travel time between Nanjing, Zhenjiang, Yangzhou, Taizhou (Jiangsu province) and Nantong harbors will be accelerated by more than 30 minutes. Most regions of Jiangsu province reach the sea through Yangkou Harbor. Regional external accessibility of the harbor cities in Zhejiang province will be speeded by a little. Regional external accessibility of Jiaxing and Shanghai will be decelerated by 30 minutes because of competition of Yangkou Harbor. Regional external accessibility with airports, railway stations and entrances to external roads will have no change (Table 7).

7 Conclusions

(1) Traditional research about accessibility only concerns regional internal accessibility. Regional internal accessibility is closely related to regional centricity. In fact, region is not close. So, research which only considers regional internal accessibility of nodes will ignore their external conveniency. As far as the Yangtze River Delta which is close to the sea is

concerned, harbor as gateway should not be ignored.

(2) Using MapX component and Delphi, we develop an information system to calculate and analyze regional accessibility according to the shortest travel time, thus generating a mark diffusing figure. From this, we can get the shortest time and its travel route from node to any other point in the region. It is definitely a new exploration in the researches about accessibility evaluation.

(3) Regional internal accessibility and external land traffic accessibility of Jiangsu province is better than that of Zhejiang province. However, regional external accessibilities of the harbor cities and the air harbor cities are worse than that of Zhejiang province. With the construction of Yangkou harbor in 2008, an international harbor group with Shanghai as its hub and Ningbo and Nantong as its wings will be built in the Yangtze River Delta. Regional external accessibility with harbor as nodes and regional accessibility of Jiangsu province will be improved dramatically. Finally, we suggest building an international airport in the south of Jiangsu province in order to raise external conveniency of the Yangtze River Delta.

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