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# Research on the Allocation of Transportation Resources Considering Fairness and Efficiency

Taking China's Highway as an Example\*

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Abstract—The allocation of transportation resources with fairness and efficiency is of great significance for the coordinated and efficient development of China's regional economy. This paper proposes an empirical analysis framework that takes into account the fairness and efficiency of traffic resources allocation, and takes China's highway resources as an example. Based on the data of 31 provinciallevel administrative regions in China from 2003 to 2016, the total mileage of highways is used to measure the fairness of the allocation of highway resources in each province. The ratio of highway freight volume to highway mileage and the ratio of cargo turnover to highway mileage are used to measure the efficiency of the allocation of highway resources in each province. Firstly, the Markov chain model is used to investigate and compare the degree of Matthew effect of fairness and efficiency, and to analyze the problems existing in the equilibrium allocation of equity and efficiency. On the basis of this, a two-dimensional matrix is constructed to study the implementation path of coordinated development. According to this study, we can find that the Matthew effect of highway resources is more serious, and the fairness problem of China's highway resource allocation is more serious. The decision makers should focus on supporting those provinces with high efficiency but low fairness, increase the investment, and make China's highway resources have fair and effective configuration.

Keywords—transportation economy; fairness; efficiency; Matthew effect; coordinated development

#### I. INTRODUCTION

The effective allocation of transportation resources can improve the accessibility among regions, promote the diffusion effect of regional economies, drive the development of surrounding areas and related industries, and ultimately promote the development of leading industries. In the current context, does China's transportation resource allocation achieve fair and efficient coordinated development? If not, how to implement a coordinated development path? This paper takes highway resources as an example to study Di Zhou\*\* School of Mathematics and Statistics Guangdong University of Foreign Studies Guangzhou, China \*\*Corresponding Author

this issue. Research on the fairness and efficiency of transportation resource allocation has always been a research hotspot in academia. Relevant literature has been reviewed, and it can be divided into the following three categories:

The first is research on the fairness of transportation resource allocation. For example, Chen Fang, et al. systematically analyzed the connotation of transportation equity in the process of urbanization [1]. Li Ni and Wang Jianwei studied the fairness of transportation resource allocation from the three dimensions of subject, space and time [2]. By establishing equilibrium evaluation model and accessibility evaluation model of Kunming public transportation resource allocation and overall accessibility evaluation model of traffic zone, Ji Xiaofeng, et al. analyzed the accessibility spatial pattern, the overall accessibility spatial difference of traffic zone, and the spatial equilibrium of the public transportation resource allocation. The second is research on the transportation resource allocation [3]. For example, Li Tao et al. studied the transportation network efficiency of the counties and cities in Pearl River Delta Economic Zone by constructing a transportation network model [4]. Some scholars have studied the influence of efficiency interference from the perspectives of space and environmental variables. For example, Gao Zhan took 18 prefecture-level cities in Henan province as an example to analyze the spatial structure of logistics efficiency by using data envelopment analysis method, and set the measurement model for analyzing overflow effect [5]. Zhang Yu, et al. used a three-stage DEA model to study the cost efficiency and service effects of public transportation in central cities in China. The third is to consider the research on the fairness and efficiency of transportation resources [6]. For example, Meng Yi made the evaluation study of the regional road network occupation land from the perspectives of fairness and efficiency [7]. Based on the theory of welfare economics, regional development theory and sustainable development, this paper uses the software to evaluate the efficiency and fairness of road occupation land in Shaanxi province with the data envelopment analysis method. Shi and Zhou studied and developed a quantitative evaluation method of transportation investment that considers the efficiency and fairness [8].

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Extensive research results have laid a solid foundation for this paper, and there are still some aspects for further improvement. The research on the existing transportation resources or highway resources is mostly combined with other topics for analysis, and the empirical research literature on individual topics is not enough. The research on the coordinated arrangement of the two is obviously not enough. Some scholars also consider two aspects at the same time; more of them are theoretical analysis. On the one hand, there is a lack of empirical analysis framework that balances allocation fairness and allocation efficiency. On the other hand, it lacks the specific implementation path for the coordinated development. Based on this, this paper establishes an empirical analysis framework for the coordinated development of transportation resource fairness and efficiency. Firstly, the Markov chain model is used to compare the Matthew effect degree of fairness and efficiency to find out the priority adjustment in the regional configuration process. Then, a resource allocation path which can realize priority adjustment, fairness and efficiency is designed.

#### II. RESEARCH METHODS AND DATA

#### A. Research Methods

By drawing on Zhou Di's idea of using the Markov chain model to study the distribution dynamics of China's financial development level [9], the road resources of China's provinces are divided into four categories. Taking the mean of the provinces as the standard, the value less than the mean 50%, 50% -100%, 100%-150%, and higher than 150% are recorded as low level, medium low, medium high, high level. And then, we can find the transition probability among various types with time.

In *a* year, when the probability of Markov transition probability matrix is  $p_{ij}^{t,t+a} = p\{X_{t+a} = j | X_t = i\}$ , after *a* years, the transition probability of i-type areas transiting to j-type areas in the year of t can be shown as the following equation.

$$p_{ij}^{t,t+a} = \frac{\sum_{t=2003}^{2016-a} n_{ij}^{t,t+a}}{\sum_{t=2003}^{2016-a} n_{i}^{t}}$$
(1)

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In equation (1),  $n_i^t$  represents the total number of provinces of i type in t year. In the study period,  $n_{ij}^{t,t+a}$  represents the province number of i type of provinces in t year transiting to j type of provinces in t+a year. With Q statistic, the significance test of Markov transition probability matrix under different duration is carried out respectively:

$$Q = -2\log\left\{\prod_{l=1}^{2}\prod_{i=1}^{k}\prod_{j=1}^{k}\left[\frac{p_{ij}^{t,l+a}}{p_{ij}^{t,l+a}(l)}\right]^{n_{ij}(l)}\right\}$$
(2)

With this equation, the transition probability matrix calculated above is statistically tested, and we also can compare the degree of Matthew Effect of different indicators.  $p^{t,t+a}$ 

 $p_{ij}^{t,t+a}$  represents the transition probability value obtained by fixing fairness data and efficiency data together.  $p_{ij}^{t,t+a}(l)$  and  $n_{ij}(l)$  represent the estimated transition probability of the two indicators in a years and the corresponding number of provinces during the study period. k refers to the types of different levels. The Q statistic gradually obeys the chi-square distribution with the gap

between the freedom of k(k-1) and the number of zero transition probabilities.

#### B. Data Source and Processing

This paper takes 31 provinces, municipalities and autonomous regions (referred to as provinces) in China from 2003 to 2016 as the research object. This author uses the highway density of each province to measure the fairness of highway resources among regions. The ratio of highway freight volume to highway mileage, and the ratio of tonnage mileage to highway mileage are used to measure the free allocation efficiency of highways in each province, which is recorded as Efficiency I and Efficiency II, respectively. The data comes from "China Traffic Statistics Yearbook", the provincial statistical yearbook, the statistical bulletin of the national economic and social development of the provinces, and the news database of the provincial and municipal transportation network in the corresponding years.

## III. ANALYSIS ON MATTHEW EFFECT OF FAIRNESS AND EFFICIENCY OF HIGHWAY RESOURCES

# A. Comparison of Matthew Effect Between Fairness and Efficiency

"Table I" and "Table II" show the results of the fairness, efficiency I and efficiency II of highway resources in 1, 3, and 5 years, that is, the transition probability matrix. And n represents the number of the regions locating in i level. The data on the diagonal of the box in the table refers to the probability that the corresponding highway resource input level in each region is still at the original level. The larger the value is, the lower the inter-regional mobility of the fairness and efficiency of the corresponding regional highway resources will be, and the solidification will be higher. The data in the top left corner and lower right corner respectively indicate the probability that the low and high horizontal regions will always stay at the original level. These two values can better describe the degree of Matthew effect between regions.

Duration	Types	Fairness					Efficiency I					
		n	L	ML	MH	Η	n	L	ML	MH	Н	
1	L	73	0.9863	0.0137	0.0000	0.0000	97	0.8763	0.1237	0.0000	0.0000	
	ML	112	0.0625	0.8839	0.0446	0.0089	147	0.0680	0.8367	0.0816	0.0136	
	MH	114	0.0088	0.1140	0.8421	0.0351	69	0.0000	0.1304	0.7391	0.1304	
	Н	73	0.0137	0.0274	0.0548	0.9041	59	0.0000	0.0169	0.1525	0.8305	
3	L	61	0.9254	0.0164	0.0000	0.000 0	80	0.7875	0.2125	0.0000	0.0000	
	ML	94	0.0745	0.7872	0.1064	0.0319	122	0.1311	0.6885	0.1311	0.0492	
	MH	94	0.0106	0.1809	0.7021	0.1064	58	0.0000	0.3103	0.5345	0.1552	
	Н	61	0.0164	0.0492	0.1475	0.7869	50	0.0000	0.0000	0.3400	0.6600	
5	L	49	0.9796	0.0204	0.0000	0.0000	65	0.7692	0.215 4	0.015 4	0.0000	
	ML	76	0.0789	0.7237	0.1579	0.0395	101	0.1485	0.5743	0.188 1	0.0891	
	MH	75	0.0133	0.2267	0.6267	0.1333	40	0.0000	0.3750	0.4750	0.1500	
	Н	48	0.0208	0.0833	0.1458	0.7500	42	0.0000	0.0238	0.3810	0.5952	

TABLE I. ANALYSIS RESULT OF MARKOV CHAIN OF HIGHWAY RESOURCES INPUT FAIRNESS AND EFFICIENCY I IN CHINA

TABLE II. ANALYSIS RESULT OF MARKOV CHAIN OF HIGHWAY RESOURCES INPUT FAIRNESS AND EFFICIENCY II IN CHINA

Duration	Types	Fairness					Efficiency II					
		n	L	ML	МН	Н	n	L	ML	МН	Н	
1	L	73	0.9863	0.0137	0.0000	0.0000	107	0.9252	0.0654	0.0093	0.0000	
	ML	112	0.0625	0.8839	0.0446	0.0089	112	0.098 2	0.8125	0.0804	0.0089	
	MH	114	0.0088	0.1140	0.8421	0.0351	85	0.035 3	0.1176	0.7176	0.1294	
	Н	73	0.0137	0.0274	0.0548	0.9041	68	0.000 0	0.0147	0.1471	0.8380	
3	L	61	0.9254	0.0164	0.0000	0.0000	87	0.8506	0.137 9	0.0115	0.0000	
	ML	94	0.0745	0.7872	0.1064	0.0319	93	0.236 6	0.5699	0.1613	0.0323	
	MH	94	0.0106	0.1809	0.7021	0.106 4	72	0.069 4	0.305 6	0.4167	0.2083	
	Н	61	0.0164	0.0492	0.1475	0.7869	58	0.000 0	0.0000	0.2931	0.7069	
5	L	49	0.9796	0.0204	0.0000	0.0000	65	0.8308	0.1538	0.0154	0.0000	
	ML	76	0.0789	0.7237	0.1579	0.0395	76	0.368 4	0.3947	0.1974	0.0395	
	MH	75	0.0133	0.2267	0.6267	0.1333	63	0.1111	0.4444	0.1746	0.2698	
	Н	48	0.0208	0.0833	0.1458	0.7500	44	0.0000	0.0000	0.2955	0.7045	

According to "Table I" and "Table II", the following conclusions can be drawn. First, whether it is fairness, efficiency I or efficiency II, there is certain convergence characteristic, that is, the probability that different regions are still at the original level through certain years is greater, and the mobility among different levels is not high. There are certain Matthew effects in the clubs at different levels, but there are still obvious differences among different variables. The Matthew effect of the three variables such as fairness, efficiency I and efficiency II decreases in turn. Second, with the accumulation of time, the mobility of Chinese provinces among different clubs will gradually increase. However, comparing with the increased mobility of the fairness, the efficiency is obviously faster. According to "Table I" and "Table II", as the time passes, the decreasing amplitude of the data on the diagonal is greater than that on the left side. Taking low-level regions as an example, the decreasing amplitude of fairness in "Table I" is 0.0067, and the decreasing amplitude of efficiency I is 0.1071. In "Table II", the decreasing amplitude of efficiency II is 0.0944. It can be

seen that in the allocation of highway resources in China, the coordination of regional fairness is far less efficient than that of the efficiency. The government should increase the adjustment of the fairness of highway resources allocation.

## B. The Difference Test of the Matthew Effect of Fairness and Efficiency

From the above analysis, it can be seen that the transition probability matrix of highway density, highway resource efficiency I and efficiency II shows a certain difference, that is, the Matthew effect of highway density is the highest, followed by highway resource input efficiency I and efficiency II. Is this difference among highway density, highway resource efficiency I and efficiency II statistically

significant? With Q statistics, this paper takes the significant test <sup>1</sup>. No matter it is in a short time (1-2 years) or in a long

<sup>&</sup>lt;sup>1</sup> In order to shorten the article, the test results of this article are not given, and the readers who need it can ask the author.

time (4-5 years),  $\mathcal{Q}$  statistics are significant. It can be seen that the degree of Matthew effect of the fairness of regional resource allocation in China is indeed significantly greater than that of the efficiency.

## IV. COORDINATION IMPLEMENTATION PATH OF THE FAIRNESS AND EFFICIENCY OF HIGHWAY RESOURCE ALLOCATION IN CHINA

In the second part, we can see that the Matthew effect of the fairness of China's highway resource allocation is more significant than that of the efficiency. Therefore, China should give priority to solving the problem of fairness solidification relative to the efficiency of the province. Namely, it should increase investment in backward areas and focus on solving the problem of fairness solidification. Then, with limited resources, what measures should the government take? This paper proposes the following coordinated development path.

# A. Classification of China's Inter-provincial Highway Resource Allocation Types

The mean of highway resource allocation fairness and efficiency of 31 provinces in China from 2003 to 2016 are plotted in a two-dimensional matrix (see "Fig. 1", "Fig. 2"). The dotted line in the figure is the mean of the provinces, and all regions are divided into four quadrants, which are represented by the letters A, B, C, and D, respectively. Comparing "Fig. 1" and "Fig. 2", it can be found that except for some provinces, the other provinces tend to be consistent in the quadrant regions under the grouping of fairness and efficiency. For explaining conveniently, the following two figures are combined together for explanation.



Fig. 1. Matrix graph of "efficiency I - fairness".

<sup>a.</sup> The abbreviation of corresponding provinces: AH: Anhui province, LN: Liaoning province, BJ: Beijing, NM: Inner Mongoria, FJ: Fujian, NX: Ningxia, GS: Gansu, QH: Qinghai, GD: Guangdong, SD: Shandong, GX: Guangxi, SX: Shanxi, GZ: Guizhou, SN: Shaanxi, HI: Hainan, SH: Shanghai, HE: Hebei, SC: Sichuan, HA: Henan, TJ: Tianjing, HL: Heilongjiang, XZ: Tibet, HB: Hubei, XJ: Xinjiang, HN: Hunan, YN: Yunnan, JL: Jilin, ZJ: Zhejiang, JS: Jiangsu, CQ: Chongqing, JX: Jiangxi.



Fig. 2. Matrix graph of "efficiency II - fairness".

a. The abbreviation of corresponding provinces: AH: Anhui province, LN: Liaoning province, BJ: Beijing, NM: Inner Mongoria, FJ: Fujian, NX: Ningxia, GS: Gansu, QH: Qinghai, GD: Guangdong, SD: Shandong, GX: Guangxi, SX: Shanxi, GZ: Guizhou, SN: Shaanxi, HI: Hainan, SH: Shanghai, HE: Hebei, SC: Sichuan, HA: Henan, TJ: Tianjing, HL: Heilongjiang, XZ: Tibet, HB: Hubei, XJ: Xinjiang, HN: Hunan, YN: Yunnan, JL: Jilin, ZJ: Zhejiang, JS: Jiangsu, CQ: Chongqing, JX: Jiangxi.

The efficiency and fairness of A-type areas are low. In such areas, no matter highway density, the ratio of highway freight volume to highway mileage, and the ratio of tonnage mileage to highway mileage are low. Representative regions include Tibet, Qinghai, and Xinjiang. A-type area is the vulnerable area of China's fairness resource map. The efficiency of B-type areas is high and the fairness is not high. The representative provinces in this area are Hebei. Ningxia. Anhui, etc. Highway density is not large, and the efficiency is relatively high. We can see that the resource allocation capacity is strong, and the level of management services is high. The fairness and efficiency of C-type areas are high. Highway density, the ratio of highway freight volume to highway mileage, and the ratio of tonnage mileage to highway mileage are higher in such areas. Representative regions include Tianjin, Liaoning, Shanghai and other provinces. These advantages make the coordinated development of highway resources in these provinces at the forefront. The fairness of D-type areas is high, and the efficiency of D-type areas is not high. Representative regions include Hubei, Chongqing, Hunan and other provinces. There is no direct proportionality between highway resources input and production.

### B. Coordinated Development Implementation Path of Provincial Highway Resource Fairness and Efficiency

The coordinated development implementation path of provincial highway resource fairness and efficiency proposed in this paper is as follows:

For B-type areas, the government should adopt a key development path, which can enhance the fairness of

HN: Hunan, YN: Yunnan, JL: Jiln, ZJ: Zhejiang, JS: Jiangsu, CQ: Chongqing, JX: Jiangxi. highway resources and alleviate the Matthew effect. On the other hand, this kind of "precise support" can have good incentive demonstration effect on the A-type areas. The demonstration effect will encourage these regions to gradually make the improvement from the management level and service quality to efficiency, and ultimately obtain the government's "key support" to achieve the dynamic balance of fairness and efficiency.

For A-type areas, that is, areas with low fairness and efficiency, the development path of "steadily improving" should be adopted. Namely, A-type areas should learn from the provinces of Shanghai, Ningxia and other provinces in the B-type areas, learn from the allocation capacity and management service level, and improve the unit output. Then, A-type areas may upgrade to the B-type areas with the incentives. At the same time, the government should increase highway resource input and highway density, and A-type areas may enter the C-type areas as soon as possible. In general, it is to guide the A-type provinces to take the  $A \rightarrow B \rightarrow C$  progressive path.

For the D-type regions, the "unilateral breakthrough" development path is adopted. Due to low efficiency, C-type areas should be taken as a benchmark to guide the efficiency improvement. Also, D-type areas should learn the allocation capability and management service level of C-type area, entering the C-type areas as soon as possible. For example, in terms of the ratio of highway freight volume to highway mileage, and the ratio of tonnage mileage to highway mileage, Hubei province and Hunan province should learn from Shandong province and Shanghai city to improve the efficiency.

# V. CONCLUSION

Based on the Markov chain model, this paper analyzes the Matthew effect of highway resource input fairness and efficiency in China's transportation resources, and compares the problems of "long-term injustice" and "long-term inefficiency" of China's highway resources to analyze the current situation whether the fairness or the efficiency of transportation resources should be adjusted first. Then, it will point out the key adjustment points for the government. Finally, this paper proposes the idea and the specific development path of coordinated development of China's highway resources.

The Matthew effect of China's highway resource fairness is more efficient than that of the efficiency. There are significant differences in the degree of Matthew effect between the highway resource fairness and highway resource efficiency. The issue of fairness is more serious. For highlevel areas, they are at a high level for a long time. The horizontal areas are at a low level for a long time. The solidification phenomenon of "the strong areas always being strong and the weak areas always being weak" is obvious. The government should increase regional coordination on the fairness of highway resources.

In response to the strategic goal of attaching equal importance to developing China's highway resource input fairness and efficiency coordinately, Chinese government should give priority to supporting provinces in the B quadrant when it guarantees the highway investment in all provinces, that is, "higher efficiency, lower fairness". It is possible to strengthen the investment in highway resource allocation in these areas and increase the highway density. On the one hand, this aspect can alleviate the Matthew effect problem existing in the balanced allocation of China's highway resources. On the other hand, it can also produce positive incentive competition effect, promote the provinces located in A-type areas to improve their management and service capabilities, develop and operate the transportation market in depth, transiting to B-type areas. This will achieve a dynamic and balanced development of China's highway resource allocation fairness and efficiency, and ensure the coordinated development path of China's highway resource allocation fairness and efficiency.

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