EVALUATION AND ANALYSIS OF URBAN TRANSPORTATION EFFICIENCY IN CHINA

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Abstract: This paper first studies the definition and connotation of transportation efficiency. From the viewpoint of different groups participating in urban transportation systems, this paper analyzes different system functions and targets required by each group. Then the corresponding system targets and evaluation rules required by the administrator are mainly studied. Four primary aspects which have great impacts on urban transportation efficiency are proposed and the corresponding evaluation index framework and method are studied. Finally, this paper evaluates and compares the urban transportation efficiency of Beijing, Shanghai and Guangzhou, 3 most important metropolitan areas in China. The main impact factors of urban transportation efficiency of each city are summarized.

Keywords: transportation efficiency, urban transportation system, evaluation

1. DEFINITIONS

2.1 Definition of Transportation Efficiency

The basic definition of efficiency is the relationship between input and output, or between costs and benefits in a certain system. In economics, the general meaning of efficiency is the extent to which a certain amount of productive resources can meet the demand of human beings. The relationship between efficiency, input and output in a system can be explained by the following equation:

$$O = I \times E \qquad (1)$$

where:
O -- the capacity of satisfying certain demands, or the output of a certain input;
I -- the quantity of productive resources input in the system;
E -- the efficiency of the system.

From equation (1), it can be noticed that efficiency is the key parameter which determines the total supply of a system. Given the same amount of input, different efficiency will conduce to quite different output.

The relationship between demand and supply in a transportation system, which is an important component of the national economy, also satisfies equation (1). In this paper, **transportation efficiency** is defined as: the extent to which a certain transportation input can meet the travel demand of people in a transportation system. It is the main factor that determines the scale of transportation supply and the relationship between supply and demand in a transportation system. In a macroscopic point of view, if we take transportation infrastructure as the input element and take transportation mobility (or transportation capacity)

as the output element in transportation systems, then transportation efficiency is the macro parameter influencing the input/output proportion of the system. This can be explained using figure 1.

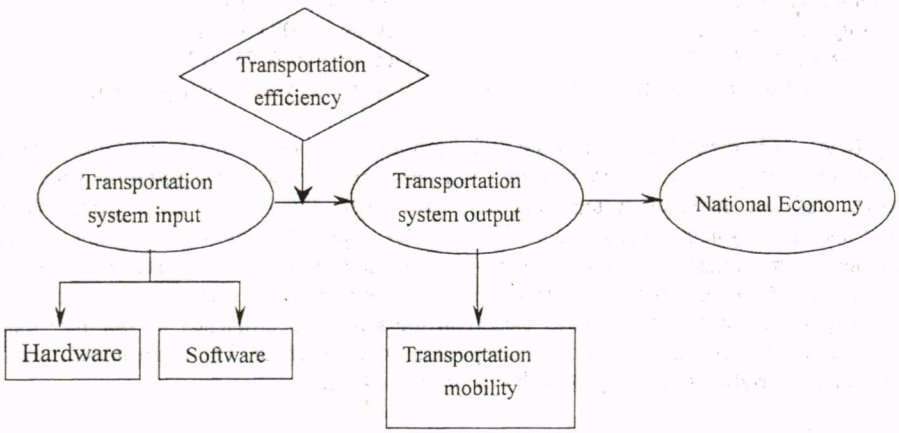

Figure 1 Relationships among transportation efficiency, input/output of transportation system and national economy

It can be seen from the figure that transportation efficiency influences the development of economy by means of influencing transportation mobility, the output of transportation systems. Given the same transportation input, the higher the transportation efficiency, the higher the transportation mobility and so the more favorable it is to the development of national economy. This is the significant meaning to research into transportation efficiency.

1.2 Category of Transportation Efficiency

The transportation system is a complicate, open and boundless system. Therefore the meaning of transportation efficiency is not unique. Different group of interests, different system objectives and research perspectives, will all lead to different comprehensions and values to transportation efficiency. Generally, transportation efficiency can be further categorized as macrocosmic or microcosmic, intercity or intracity, passenger or freight transportation efficiency, etc. At the same time, different categories are interrelated. If combined by certain means, more particular categories can be obtained, for example: efficiency of urban passenger transportation system, efficiency of intracity freight transportation system etc. This paper mainly studies the efficiency of urban transportation systems.

The **efficiency of urban transportation systems** is the relationship between the input of an urban transportation system and its capability of satisfying the transportation demand in the system. Generally, the total efficiency of the urban transportation system is scaled by "social benefits/social costs" . The greater the ratio, the higher the transportation efficiency is. However, social benefits and social costs are both macrocosmic indexes and can not be quantified and analyzed exactly. Therefore the main objective of this paper is to discuss the detailed content of urban transportation efficiency and make quantitative analysis and evaluation.

2. THE EVALUATION OBJECTIVE AND EVALUATOR OF URBAN TRANSPORTATION EFFICIENCY

2.1 Basic Evaluation Objectives and Principles

The evaluation of any system is based on certain objectives. The development objective of urban transportation systems hold by the human being, has varied with the progress of their notions of city and development. The developing target of a sustainable urban transportation system can be divided into three groups, which are the target of transportation functions, the target of resources utilization and the target of environment protection. The target of transportation functions means to satisfy the normal transportation demand brought by the development of economy and the living of citizens. It is the most elementary target of an urban transportation will have system, and includes accessibility, swiftness, security and comfort. The environment protection target requires that the urban transportation behaviors should reduce as much as possible their negative effects to the environment and ecosystem. The resources utilization target requires the urban transportation system to effectively utilize the land, energy, and human resources.

Based on the definition of urban transportation efficiency, whether an urban transportation system can be evaluated as "efficient", is determined by whether the system can realize most its developing targets with the lowest transportation inputs. Corresponding to different developing targets, there are different principles for evaluating the urban transportation efficiency, which can be expressed in figure 2.

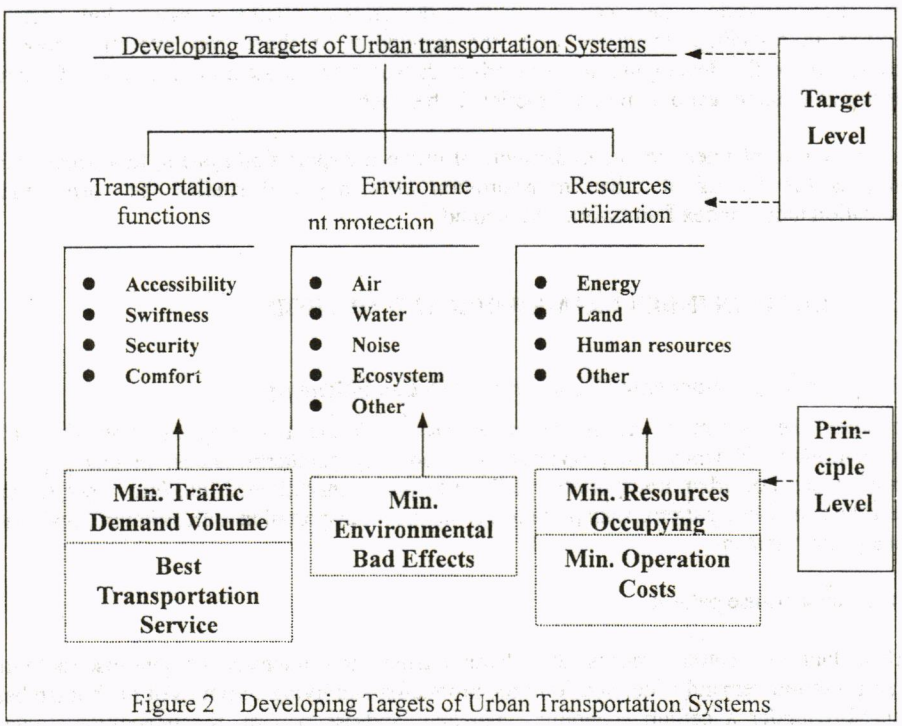

Figure 2 Developing Targets of Urban Transportation Systems

2.2 Category of Evaluators

Any evaluation procedure must be carried through from the viewpoint of certain evaluator and should take the ideal anticipation of the evaluator as its reference. As a highly opened public system, the urban transportation system has three groups of participants: the planner & administrator, the operator, and the user of urban transportation system. Different group of participants has different anticipations to the urban transportation system, correspondingly, the comprehensions and evaluation focus to urban transportation efficiency hold by each group are different.

Generally, the planners and administrators of urban transportation are in the view of the whole urban transportation system. They hope that the citizens' transportation demand, which derives from the producing and living activities, can be mostly satisfied, and that the occupation of resources and impacts to environment be diminished as much as possible. At the same time, they anticipate that the urban transportation can positively feed back and promote the economic development and land-use pattern of the city. For these reasons, the developing targets of urban transportation systems required by planners and administrators are the most complete. They involve all the aspects in figure 2.

The operators and users of urban transportation systems only partially participate in the urban transportation. As to the operators of urban transportation systems, which are often companies and enterprises, the developing target of urban transportation system is to provide for the society the best transportation services with the lowest costs, that is, to realize the maximum ratio of "benefit/cost" during the operational process of the companies. From the aspects of users in the urban transportation systems, what they concern most is the extent to which the urban transportation system can satisfy their demands of swiftness, safety, low costs and comfort in traveling. Therefore from the standpoint of those two interest groups, the anticipation to the developing target of urban transportation system is incomplete. Generally speaking, it can reflect only partial benefits on their behalf.

In the view of planners and administrators of urban transportation system, this paper mainly analyzes the factors of urban transportation efficiency and studies the corresponding evaluation target, index framework and method.

3. EVALUATION INDEX FRAMEWORK AND METHOD

3.1 Key Factors Influencing Urban Transportation Efficiency

To study the factors of transportation efficiency is the first step of evaluating urban transportation efficiency and proposing corresponding countermeasures. In this paper, the impact factors of urban transportation efficiency are mainly divided into four aspects, which are urban land-use pattern, transportation structure, transportation infrastructure, and traffic management system.

(1) Urban land-use pattern

Urban land-use pattern means the characteristics and intensity of land-use activities. Transportation demand is derived from the producing and living activities of the human being. Therefore under a certain economic level and land-use pattern, the generation/attraction intensity and spacial distribution of transportation demand have basically been determined.

Urban transportation efficiency varies with different land-use patterns greatly. Therefore, in order to improve urban transportation efficiency, it is an essential measure to build a suitable urban land-use pattern, which can decentralize urban functions, balance the distribution of transportation demand, cut down on total traffic volume and relieve traffic congestions in cities.

(2) The structure of urban transportation systems

Under a certain land-use pattern, the total capacity of the urban transportation system is basically determined by the composition of different transport modes in the system. Whether the structure of urban transportation system is harmonized with the land-use pattern, will directly impact the balance between transportation demand and supply. Given the total amount of transportation demand and a certain level of transportation infrastructure in a city, a good transportation structure will most effectively utilize the infrastructure and will help fully realize the functions of urban transportation systems.

(3) Urban transportation infrastructure

Urban transportation infrastructure mainly includes roads, parking lots, vehicles and transportation terminals. It is the direct carrier of urban transportation demands and the basic input of the capacity of transportation supply. From the viewpoint of the relationship among transportation efficiency, input and output, the operational efficiency of transportation infrastructure is the key factor which will directly influence the urban transportation capacity provided by the system.

(4) Urban traffic management system

Urban traffic management system is an important component which can properly control and guide the distribution of traffic flows on roads, and can help improve the urban environment. Even the urban transportation infrastructure in different cities is at the same level, the capacity of urban road systems may vary greatly with different traffic management systems. For example, according to our surveying of some main intersections in Beijing, capital of China, most of them have a queue of more than 200 meters during the morning and evening peak hour. And the average delay of motor vehicles at these intersections is about 2 or 3 minutes. However, the actual highest traffic volume of these intersections is only 60%~80% of that at similar intersections in developed countries. Therefore, given a certain land-use pattern and transportation structure in a city, traffic management system then becomes the key factor to determine the level of transportation efficiency and the relationship between transportation demand and supply.

3.2 Evaluation Index Framework And Evaluation Method

According to the above analysis, the hierarchical evaluation framework of urban transportation efficiency is proposed in table 1.

Table 1. Evaluation Framework of Urban Transportation Efficiency

Type of factors	Index level I	Index level II	Index level III
Urban layout and land-use pattern	A_1—population density in downtown areas		
	A_2-- ratio of job units to residential population		
	A_3-- ratio of population density in downtown areas to that in suburbs		
	A_4-- relative radius of transportation within 0.5, 1, 2 hours		
Urban transportation structure	A_5-- share of urban public transportation modes		
Urban transportation infrastructure	A_6-- efficiency of road infrastructure	B_1-- ratio of Average Travel Speed (ATS) to designed road speed	
		B_2 -- ratio of V/C	
		B_3 -- ratio of traffic volume in peak hours to AADT	
	A_7 -- efficiency of parking infrastructure	B_4-- ratio of average parking volume in peak hours to designed capacity	
		B_5-- ratio of average daily occupancy time of each berth	
		B_6-- ratio of average daily parking number of each berth	
	A_8-- efficiency of urban transportation vehicles	B_7 -- efficiency of bus systems	C_1 -- average load factor of bus systems
			C_2 -- average area of road occupancy per passenger of bus systems
			C_3 – average daily overload duration of bus systems
		B_8-- efficiency of urban rail systems	C_4 -- average load factor of rail systems
			C_5 -- average area of carriage occupancy per passenger of rail systems
			C_6-- average daily overload duration of rail systems
Urban traffic management	A_9 – status of traffic congestion	B_9 -- proportion of congested intersections without signal control during peak hours	
		B_{10} -- proportion of congested intersections controlled by traffic signal during peak hours	
		B_{11}--average daily congestion duration of main intersections	
	A_{10}-- status of traffic safety	B_{12} -- death toll per 10000 PCU	
		B_{13} -- death toll per 1 mil. (PCU • Km)	
Energy reservation	A_{11}-- average energy consumption per capita in urban transportation systems		
Environment protection	A_{12}-- share of air pollution		
	A_{13}-- share of noises pollution		

One of the main problems confronting the evaluation of urban transportation efficiency is that there is not a determined and absolute criterion to be referred. For example, although the idea of "giving priority to public transportation" has commonly been accepted by most countries, people can not exactly know how much the optimum share of public transport mode should be. Only relative comparison and evaluation can be given out. For another example, each city has its unique characteristics in size, land-use pattern, and transportation structure, etc. Therefore the same evaluation index will have different criteria when it is applied in different

type of transportation systems. The uncertainty of evaluation criteria is the most important problem needs to be solved.

There are two methods to solve such a problem. The first one is to classify cities according to their size before evaluation. This will eliminate the uncertainty caused by the difference of sizes among cities and improve the comparability among different systems. The second one is to adopt fuzzy theory to reduce uncertainty. When using fuzzy evaluation methods, the key step is to build a set of evaluable objects. Two possible methods can be adopted. The first one is to evaluate and compare the transportation efficiency in the context of different developing periods of a single city. The second one is to compare and evaluate the transportation efficiency of different cities in the same period. The outcome of the former method depends on the absolute evaluation criteria, which could be obtained by referring to the corresponding figures of typical cities with similar size in other countries. For the second method, the reference frame could be composed by the optimal figures chosen from those of the cities to be evaluated.

According to the above analysis, a combined method is adopted in this paper to evaluate the urban transportation efficiency of 3 most important metropolitan areas in China. This method uses the Analytic Hierarchy Process (AHP) to calculate the weight of each index, and uses fuzzy theories to calculate the value of each individual index and the overall value of each city's transportation efficiency.

4. EVALUATING THE URBAN TRANSPORTATION EFFICIENCY OF 3 MOST IMPORTANT METROPOLITAN AREAS IN CHINA

In this section, the transportation efficiency of Beijing, Shanghai and Guangzhou, 3 most important metropolitan areas in China, is evaluated. The evaluation process has calculated several indices in the aspects of urban land-use pattern, transportation structure, road infrastructure and traffic congestion. These indices are also compared with those of London, Newyork City, Paris and Tokyo, 4 most important metropolitan areas in the world.

4.1 Basic Data

(1) Urban land-use pattern

Table 2. Comparison of Urban Land-use Pattern

Index	Beijing	Shanghai	Guangzhou	London	Newyork	Paris	Tokyo
Population density in downtown areas (per Km^2)	27358	44624	13882	6940	23610	21450	6330
Population density in downtown areas to that in suburbs	8.56	5.30	9.17	1.61	2.49	5.33	0.46

(2) Urban transportation structure

Table 3. Comparison of Urban Transportation Structure

	Share of public transport modes	Share of cars	Share of bicycles and other modes
Beijing (in 1994)	34.7%	15.4%	49.9%
Shanghai (in 1998)	28.0%	0.2%	71.9%
Guangzhou (in 1995)	44.5%	3.7%	51.8%
London	32.0%	64.0%	4.0%
Newyork City	44.0%	51.0%	5.0%
Paris	35.0%	65.0%	0.0%
Tokyo	64.0%	27.0%	9.0%

(3) Usage of road infrastructure

In order to analyze the relationship between the amount of motor vehicles and the total length of roads, this paper calculates the ratio of the amount of motor vehicles to the total length of roads. According to the data of Tokyo, Japan between 1965 and 1997, it is surprisingly found that this ratio of Tokyo has stopped rising after it reached about 200 unit/Km in 1989. (See figure 3)

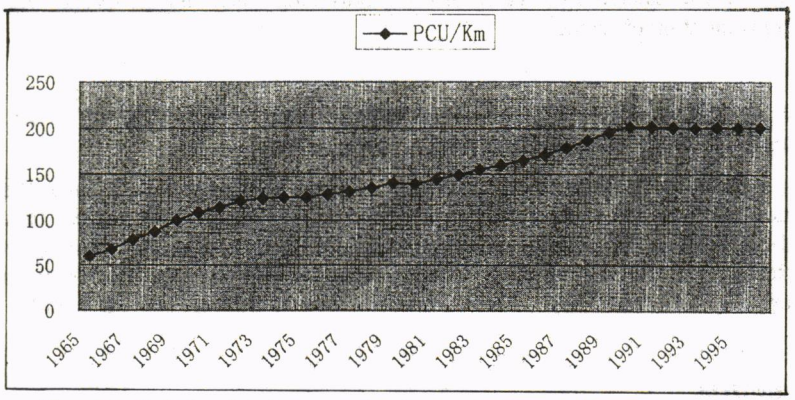

Figure 3. Relationship between the Amount of Motor Vehicles and the Length of Roads in Tokyo, Japan

Because this figure is obtained using the total amount of motor vehicles, it can't exactly show the road occupation of vehicles. Assuming that there are 10% of the motor vehicles left in parking lots each day, this paper takes 180 unit/Km as the highest limitation of the above ratio, and uses it to evaluate the usage of road infrastructure. If the value of the ratio is higher than 180 unit/Km, traffic congestion will happen in urban road systems and traffic efficiency may be damaged greatly.

The similar ratio of Beijing, Shanghai and Guangzhou is 365 unit/Km, 87 unit/Km and 320 unit/km respectively.

(4) Urban transportation service level

Table 4 Comparison of Urban Transportation Service Level

City	Average speed on main roads in peak hours (km/h)	V/C ratio on main roads in peak hours
Beijing	≤20	0.9
Shanghai	16	≥0.8
Guangzhou	19.2	≥0.8

4.2 Results and Analysis

Using the method proposed in section 3, the relative transportation efficiency of the 3 metropolitans is:

Guangzhou : Shanghai : Beijing=1 : 0.99 : 0.85

It can be seen that the urban transportation efficiency of Guangzhou and Shanghai is at the same level and that of Beijing is a little lower. However, urban public transportation systems in China are still underdeveloped and the overall urban transportation efficiency in China is not high. Among these three metropolitan areas, the critical factors of urban transportation efficiency are different.

(1) Considering the distribution of populations in the three cities, the population density in downtown areas is much higher than that in the peripheral areas. This will cause an overhigh generation/attraction intensity of transportation demand. The spacial concentration of traffic demand has great pressures on urban transportation systems, and will obstruct the enhancement of urban transportation efficiency.

(2) If considering the transportation structure, the private transportation mode shares a large portion in Beijing. Especially the amount of private cars increases rapidly and the public transportation system developes slowly. Such a situation is not consistent with the land-use pattern in Beijing and is the main reason for traffic congestion and low transportation efficiency. Bicycles in Shanghai share a larger part than that in Beijing and Guangzhou, and the share of public transportation modes in Shanghai is the smallest among the three cities. Therefore, such transportation structure in Shanghai has resulted in an overhigh share of non-motor modes and a high volume of mixed traffic flow. The road infrastructure in such a condition can not be used sufficiently. Compared with the other two cities, the share of public transportation modes in Guangzhou is as large as that of bicycles and increases annually. The share of private cars in Gurangzhong is not so high as that in Shanghai. Therefore, the urban transportation structure in Guangzhou is relatively better.

(3) Considering the usage of roads, the ratio of "the amount of motor vehicles over total length of roads" in Beijing and Guangzhou is much higher than 180 unit/Km. Though each day there are more vehicles which are not driven on roads in China than in Japan, the load on roads in the two cities is still very high. This figure in Shanghai is much lower because the growth of motor vehicles is strictly controlled in Shanghai.

(4) Considering the transportation service level in downtown areas, the three cities all have severe traffic congestion. But the reasons are different. The high amount of motor vehicles and overload of roads are the main reasons for the traffic congestions in Beijing and Guangzhou. But the traffic congestion in Shanghai is caused by mixed traffic flow and the uneven time distribution of traffic demand.

5. CONCLUSIONS

Urban transportation efficiency is the key factor which determines the capacity of urban transportation systems and the balance between transportation demand and supply. The transportation input (i.e. construction of transportation facilities) can not increase within a short period of time, but the demand of transportation is growing rapidly. Therefore to improve the efficiency of urban transportation systems is the best way to effectively utilize the existing inputs, enhance the capacity of the systems and relieve urban traffic congestion. Among the factors influencing urban transportation efficiency, the effects of urban land-use pattern and transportation structure are chronic and long term, while those of urban transportation infrastructure and traffic management systems are obvious and short term. This has resulted that the evaluation of urban transportation efficiency may involve many indecies, many of which are highly uncertain or complex. Through establishing the hierachical evaluation framework and adopting fuzzy evaluation method, this paper has solved the above problems and evaluated the urban transportation efficiency of Beijing, Shanghai and Guangzhou, three most important metropolitan areas in China. It is found from the evaluation results that improper land-use pattern and transportation structure are the main factors restraining the improvement of urban transportation efficiency in China.

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