



**ABSTRACT** In China, rapid economic growth and increasing foreign direct investment (FDI) is the driving force for urbanization, and transformation of urban spatial structures and transportation. Frequent interactive economic activities among the neighboring cities reinforce the already spatially clustered cities. In this paper we tried to extract the key urban transportation characteristics of seventy major Chinese city using the 1997 data involving various economic and transportation features. Principal component factor analysis (PCA) accompanied by analysis of variance (ANOVA) of the factor scores were used. We found that economic indicators such as foreign direct investment (FDI) and per capita gross domestic product (GDP), land use features such as population and job densities, and transportation supply features such as road length density, public transportation supply were among the key descriptive factors. China's urban transportation varied largely by geographic location and region. We also looked at the urban air quality over seventy cities and found that the annual average total suspended particles (TSP) and sulfur dioxide (SO<sub>2</sub>) concentrations had been decreasing continuously and significantly over the last two decades while nitrogen oxides (NO<sub>x</sub>) concentrations did not. Urban air quality showed distinct regional differences in China. Therefore, a big challenge facing Chinese urban and transportation planners is how to cope with urbanization and impacts of regional economic inter-dependency on urban transportation. We also urge the local governments to establish a transportation compliance framework to air quality standards when investing transportation projects.

## INTRODUCTION

China has undergone accelerated urbanization since the 1978 economic reform. Urban population increased by 29 percent from 69.6 million in 1989 to over 89.8 million in 1997. The average city area expansion rate in seventy major Chinese cities was 6 percent between 1981 and 1998. The number of metropolitan cities (i.e., those with a million plus population) rose from 30 in 1989 to 82 at the end of 1997. The economic reform and open-door policy were the “push factors” for urbanization in China (1, 2). The level of urbanization displays a rising positive correlation with per capita gross domestic product (GDP) (1). Foreign direct investment (FDI) has also played an important role in Chinese urban growth (1,3). In particular, coastal cities received favorable policies for economic development at the beginning of the open door policy including special economic zones and open development areas to attract foreign investment (4). Consequently the urbanization gap between the coastal and the inland is noticeably wide (1). In the late 80s and early 90s several urban clusters along the coast were enhanced as a result of the more and more tightened economic activities among the neighboring cities (5,6). The most noticeable urban clusters from north to south Liaodong Peninsula, Beijing-Tianjin-Tangshan, Shandong Peninsula, Yangtze River Delta, Fuzhou-Xiamen, and Pearl River Delta (Figure 1).

[Insert FIGURE 1]

Land reform in 1988 has led to the transformation of the urban internal structure of Chinese cities (7). Before the reform, mixed land uses essentially organized by workplace became the main features of these socialist cities (8). Land was not associated with monetary value. After the reform, the differential land value made industrial relocation financially viable in the peripheral areas where land is much cheaper. Farmers on the city periphery become urban residents. In the mean time, the more valuable urban center land is being converted into a central business district (CBD) to attract more commercial activities and jobs in the urban center. Because of the economic growth and decentralized urban structure, there is an increasing demand for private motor vehicles, which puts a huge pressure in the pre-auto road network system in Chinese cities.

Air pollutants originating in urban regions have been recognized as increasing sources of regional pollution (9). Historically the primary sources of air pollution in China were industrial and domestic energy use, such as coal burning, resulting in high particulates and SO<sub>2</sub> in the air. In recent years, the transportation sector has become an increasingly important urban air pollution contributor due to the explosion of motor vehicle population, low emission standards, poor road infrastructure, old vehicle technologies, and traffic congestion. In large cities like Beijing and Shanghai, more than 70% of CO and over 40% of NO<sub>x</sub> emissions were attributed to motor vehicles in 1996 (10).

Much of the past research focused on explaining the urbanization phenomenon in China. There is now a need for better understanding of urban transportation scenarios in Chinese cities. There is also not enough attention paid to the more recent urban clustering phenomenon and its impacts on urban transportation and air quality. The purpose of this paper is to capture the Chinese urban characteristics with emphasis on public transport infrastructure and assess the regional effects on urban growth and air quality, which provides the analytical evidence for the need of regional thinking in urban and transportation planning. This paper begins with a literature review on China's urban development, followed by a description of methodologies and discussion of the multivariate analysis results. It ends with a discussion on policy implications and conclusion.

## SOURCES OF DATA AND METHODOLOGY

The original data set of seventy major Chinese cities (Figure 2) for year 1997 contains the following variables:

*Urban characteristics* (population, area, job density, residential area, area used for transportation purpose),

*Transportation supply variables* (road length, number of public transportation vehicles, number of taxis, and number of passengers),

*Transportation maintenance income and expenditure*,

*Economic indicators* (GDP and FDI).

The majority of the data were acquired through the China Urban Transportation Center (CUTC) affiliated with the Ministry of Construction. Variables like GDP, FDI and employment rates were extracted from the 1998 China urban yearbook. The seventy cities were classified into seven regions, i.e., the six regions defined in Figure 1 plus one “other” region. The analysis tool is principal component factor analysis (PCA). PCA identifies the key characters of urban transportation infrastructure in Chinese cities. A resulting factor is a composite of a group of interrelated variables from a data set (i.e., basic variables). In this study, the resulting factors are varimax-rotated (i.e., orthogonal) such that the results are generally easy to interpret. The cutoff point of factors chosen is determined by choosing those with eigenvalues greater than one. The numeric elements associated with a factor are called factor scores and define the desired scales of that particular group of interrelated variables (represented by the factor) within cases. A case with a high factor score has high weights of those variables involved. Factor scores are unitless.

[Insert FIGURE 2]

We also look at the historical trends and geographical characteristics of urban air quality. The data set contains the annual average ambient concentrations of three major pollutants, total suspended particles (TSP), sulfur dioxide (SO<sub>2</sub>), and nitrogen oxides (NO<sub>x</sub>) from 1981 to 2001, and emissions of SO<sub>2</sub> and TSP from 1991 to 2001. The air quality data were assembled from the China Environmental Yearbooks (emissions from 1981 to 2001 and concentrations after 1995), the China National Environmental Monitoring Station (concentrations from 1981 to 1990), and the National Environmental Protection Agency (NEPA, concentrations from 1991 to 1995).

## RESULTS AND DISCUSSION

Table 1 shows the 1997 basic urban statistics for the seventy cities and corresponding changes since 1991. The cities display a wide range of variation with respect to area, population density, and economy (GDP, FDI, etc.). In particular, FDI and transport maintenance are two thousand and one thousand times apart respectively between the lowest and the highest. Later we will see that the main differences are geographical. If compared between 1991 and 1997 urban area expanded by 30.7% and population density declined by about 14%. Per capita GDP grew by 70%. The most dramatic changes were FDI and transportation maintenance expenditure, which both increased by more than three fold. Per capita road length was seen 32.4% increase but the growth rate was not consistent with that of the transportation maintenance expenditure. Detailed discussion of the urban transportation features and air quality trends in Chinese cities follows.

[Insert TABLE 1]

### Characterization of Urban Transportation in Chinese Cities

Six factors that characterize China's urban transportation infrastructure in 1997 were extracted from the PCA. They are

- Economic Indicator*,
- Public Transportation Capacity*,
- Population-job Density*,
- Road Density*,
- Transportation Maintenance*, and
- Transportation Maintenance Intensity*.

A brief description of each factor is found in Table 2.

The economy plays an important factor in urban and transportation development. Literature concerning urban and mobility growth often uses per capita GDP as the economic indicator to understand the relationship between vehicle ownership growth and economic growth (11). For Chinese cities FDI was found positively correlated with local economy (1,2,6,12) and was a distinctive driving force in Chinese urbanization. Our factor analysis results also found *economic indicator* to be one of the significant factors of China's urban transportation scenario and indeed represents the combined economic force of per capita GDP and FDI. *Public transportation capacity* portrays the performance of a city's public transportation supply infrastructure including the number of passengers, number of taxis, total bus route length and total road length relative to the size of the city (population and area) and economic strength (GDP). The presence of *population-job density indicator* in the PCA results confirms the importance of urban form effectively depicted by population and job densities (11) for urban transportation system for Chinese cities. *Road density* gives the urban road supply in the forms of per urban area and per capita. Finally, *transportation maintenance* income and expenditure in Chinese cities still largely emphasize the supply side of the system, for instance, transportation infrastructure such as road construction, parking lots, and bus routes, etc. and public transportation supply and service.

[Inset TABLE 2]

### Regional Variations in Urban Transportation of Chinese Cities

China's urban transportation development displays large regional variability. For instance, the Beijing-Tianjin-Tangshan region had the highest per capita road length coverage in 1997 but a negative growth rate from 1991 (Table 3). Liaodong Peninsula and "Other" region had the fastest growth in per capita road length between 1991 and 1997 (over 40%). The Pearl River Delta, despite its highest FDI and per capita GDP, lagged behind all other regions in per capita urban road length coverage.

[Inset TABLE 3]

Figure 3 is a bar chart of the factor scores of the six resulting factors for the seven defined regions using 1997 data. This chart compares the performance of each factor among the regions as well as relative to average (i.e., zero horizontal axis). Beijing-Tianjin-Tangshan region had the highest public transportation capacity defined mainly by the size of the public transport fleet and road length. It also indicated that old industrial areas like Beijing-Tianjin-Tangshan, Liaodong and Shandong Peninsula had an overall better than average public transport capacity. The Minnan area topped other regions with respect to economic performance determined by per capita GDP and FDI but its transport capital

investment (and income) was lower than the average that might be explained by the already better-than-average road density ranking in the region. In contrast to the Minnan region, the Pearl River Delta actually had the worst ranking in road density despite its advanced economy and transport investment. Lastly, the Yangtze River Delta had the highest transport investment and income in the total monetary sense.

[Insert FIGURE 3]

The analysis of variance (ANOVA) of factor scores shows no statistical difference among the regions with respect to per unit area of transportation maintenance income/expenditure ( $P$  value=0.316), population-job density ( $P$  value=0.220) or road density ( $P$  value=0.883). However, there exists substantial variation in *public transportation environment, economic performance, and transport investment* at the 0.05 significance level across the regions.

### **Urban Air Quality Characteristics**

Between 1981 to 2001, annual daily average ambient total suspended particles (TSP) and sulfur dioxide (SO<sub>2</sub>) concentrations declined significantly by 62.9% and 55.8% respectively for over 70 cities in different regions of China, while nitrogen oxides (NO<sub>x</sub>) concentrations decreased only 9.8%. In fact, the SO<sub>2</sub> concentrations did not vary much between the year of 1981 and 1991, and with the largest reduction happening during the 1990s due to the control measures implemented. The ANOVA results indicate that TSP annual average concentrations in the years 1981, 1991 and 2001 across the four city types, i.e., north coastal, north non-coastal, south coastal, and south non-coastal, differed statistically significantly (at the 0.05 significance level), and so did NO<sub>x</sub> except for the year 1991. There are also significant regional differences on urban air quality (Figure 4).

[Insert FIGURE 4]

Although the urban TSP concentrations decreased dramatically over the last twenty years, TSP is still the key pollutant in most Chinese cities. Geographically speaking, northern cities were more polluted than southern cities by particles. Southern coastal cities had the lowest of TSP concentrations. The geographical distribution of SO<sub>2</sub> concentration was more localized and concentrated in some southwest, central and north cities which consumed large amounts of coal for heavy industry or mainly combusted high-sulfur coal. The average NO<sub>x</sub> concentrations in the north cities were higher than that in the south. Another feature is that the coastal cities had higher NO<sub>x</sub> pollution levels than non-coastal cities due to the higher vehicle ownerships in coastal cities corresponding to their more developed economy. Besides, in some metropolitan areas such as Shanghai, Beijing, and Guangzhou, the NO<sub>x</sub> concentrations gradually increased in the 1990s and became a serious environmental problem.

### **POLICY IMPLICATIONS FOR URBAN TRANSPORTATION**

In this study we found that China's urban transportation scenario in the 90s was typically defined by the public transport environment, economy, urban form, and transportation infrastructure. We could utilize such a similar approach to development of performance measures of an urban transportation for Chinese cities. Utilizing factors and factor scores not only reduces the number of parameters without leaving out the principal components but also provides guidance to government officials and planners when they develop urban and transportation plans. A set of performance measures typically includes public transportation capacity, per capita/area road length, the level of investment in transportation infrastructure

and facilities, economic strength, and urban population and job densities. There are more to add to the evaluation set, for instance, mobility indicator that describes vehicle ownership; congestion indicators that involve travel speeds and vehicle densities; and finally environmental indicators such as air pollutant levels.

Congestion and environmental violation are the two major challenges faced by transportation planners. Congestion in Chinese cities is often caused by high growth of vehicles and low road capacity. On one hand, the governments would like to promote higher auto ownership in order to increase individual mobility and stimulate the auto industry; on the other hand, they have to risk the almost inevitable consequence of severe congestion because of the not yet auto-oriented road network system. As a result, overall mobility is reduced for auto users and even more for public transportation users (13). The seventy-city time series data that the already low shared public transportation (less than 5% of total mode shares) has a tendency of losing its ridership in many cities despite the continuous increase in the number of public transit vehicles in the past two decades. Fuel consumption and roadside emissions have therefore increased in Chinese cities. The NO<sub>x</sub> concentration exceeds the national ambient air quality standards in most of China's largest cities (10). In Beijing, vehicle emissions have become the leading source of air pollution. In Guangzhou, seventy percent of the vehicles did not meet the mandated emission standards (10). It is time for the Chinese government to do something about it before the cities turn into a "Bangkok nightmare." With incorporation of congestion and environmental factors into the urban transportation evaluation system just described we hope it will initiate the process of establishing a transportation compliance framework with environmental standards so that no violation should be made by any transportation investments.

Finally, there exists the institutional challenge for urban and transportation planning in Chinese cities. Economic reform especially land market reform has stimulated the rapid transformation of urban spatial structure in Chinese cities. As market forces play an important role in urban land development, municipalities and development companies begin to undertake so-called "comprehensive development" which later evolves to market-oriented real estate development (14). The role of local governments in urban planning and management is becoming more and more important in the post-reform era. Within the government itself, it is critical to balance the departmental interests. From a land management perspective, for instance, revenue collecting and public spending departments favor land leasing for it is the major source for local revenue. The land administration departments, on the other hand, are responsible for long-term development of land and preservation of cultivated land. From an environmental protection perspective, they must establish a formal coordinating mechanism among transportation planning agency, traffic management bureau, and the environmental protection bureau to enforce compliance of transportation investment to national air quality standards. Finally, the tightened economic bond with the neighboring cities challenges the local agencies to think beyond local jurisdiction to incorporating impacts from the other cities when developing the Comprehensive Plan for the city.

## CONCLUSION

Since the economic reform, Chinese cities have experienced rapid urbanization and regionalization more recently. Such changes reshaped the urban transportation. In this study we found that *public transportation capacity* and *road length density* were key factors for

urban transportation. Per capita FDI and GDP also no doubt play a driving force for urban transformations. The presence of transportation financial indicators corresponds to the fact that China's urban transport development still largely focuses on infrastructure construction.

The resulting factors are not only useful for understanding Chinese urban transportation development in academia but also helpful in practice for developing urban transportation measures that are simple to apply. We hope rapid urban growth, congestion, and environmental challenges will soon if not already push planning agencies to establish a new urban planning system with the capability of accommodating economic and urban development needs as well as reducing air pollution.

Issues related to travel characteristics have emerged but are not mentioned in this study. The general trends are longer trips both in distance and time and more shopping and recreational trips. Walking and bicycling still account for over 50% of all the trips made in Chinese cities (15) although their share has decreased. There are shifts from non-motorized transportation modes to motorized alternatives. The job-housing balance has started to emerge in the big cities, reflected by longer travel distance and longer travel time between work and home. An individual's travel decision is influenced by the urban land use, and inversely re-shapes the urban structure. That people live farther away from work or the city center also imposes a big challenge to public transportation sector.

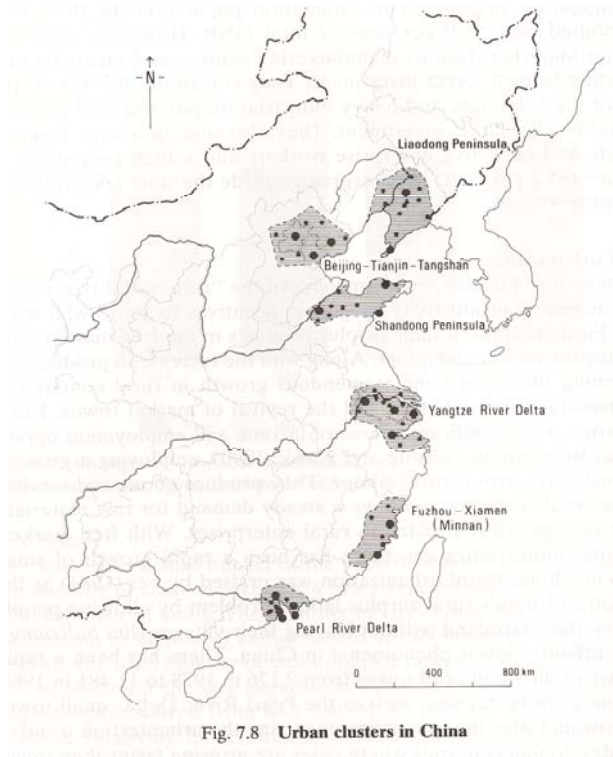
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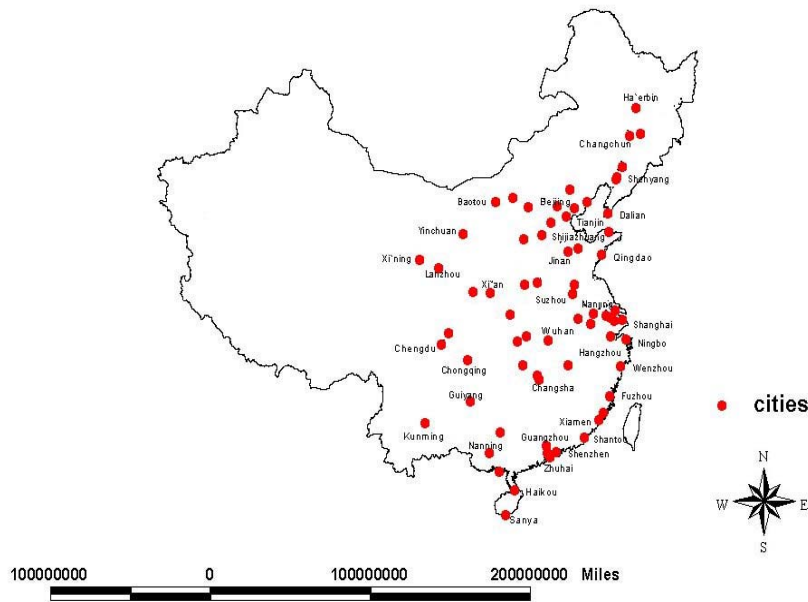
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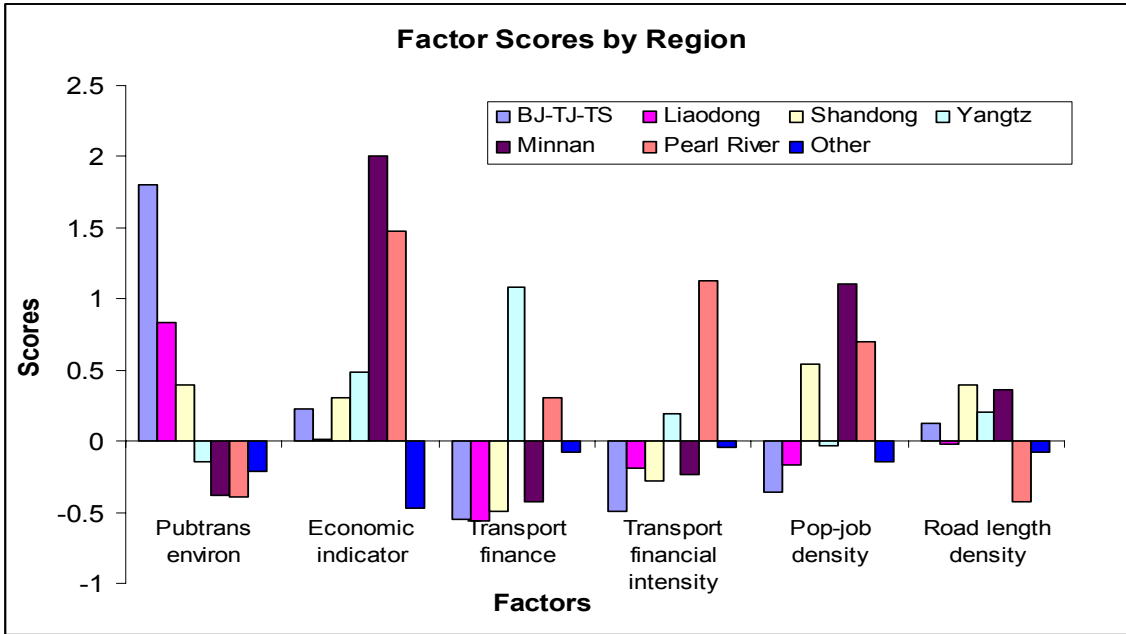


**FIGURE 1 Urban Clusters In China (6)**

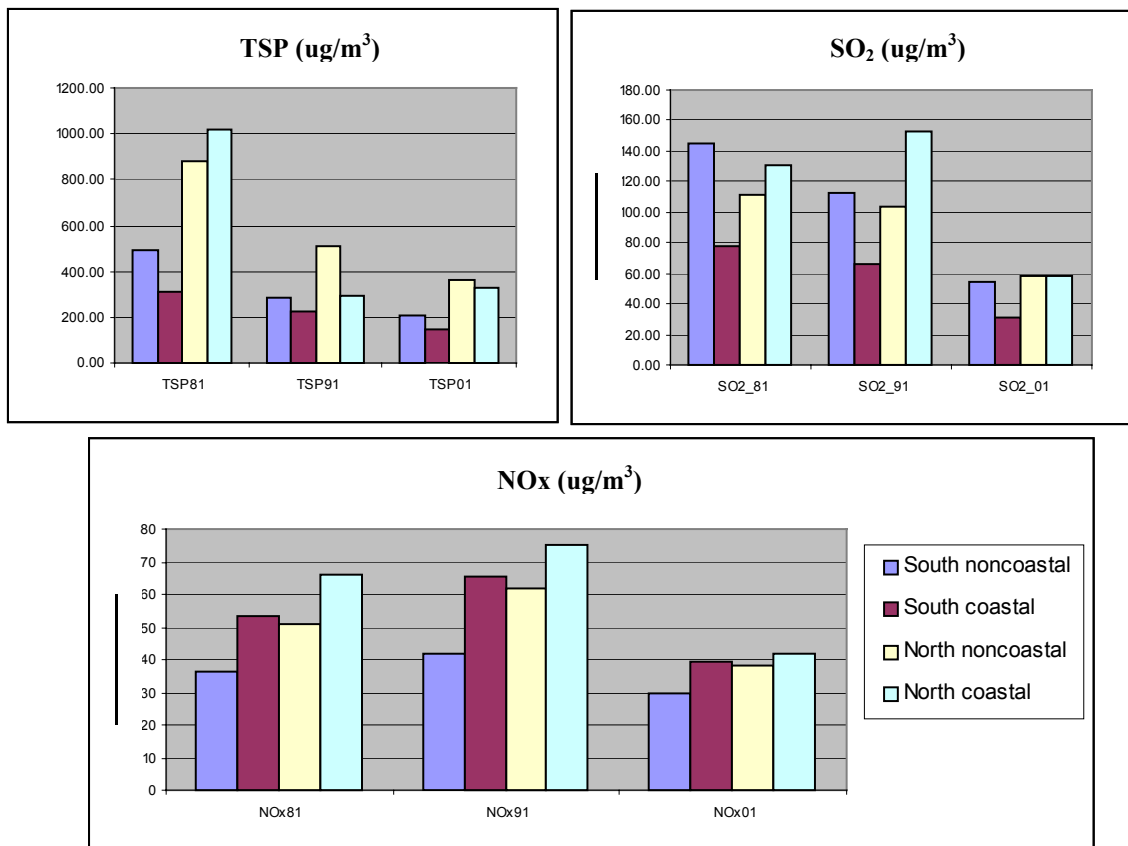
**Chinese cities of preliminary study**



**FIGURE 2 Locations of Chinese Case Study Cities**



**FIGURE 3 Factor Scores by Region**



**FIGURE 4 Air Pollution Annual Average Concentrations: TSP, SO<sub>2</sub>, and NO<sub>x</sub>**

**TABLE 1 Descriptive Statistics of The Seventy Chinese Cities for Year 1997**

	<b>Avg</b>	<b>Change from 1991 (%)</b>	<b>Min</b>	<b>Max</b>
Area (km <sup>2</sup> )	111.55	+26.18 (+30.7%)	17.95	488.13
Population density (persons/km <sup>2</sup> )	16,346	-2,638 (-13.9%)	2,739	49,350
Per capita GDP (yuan/capita)	17,440	+12,239 (+70.2%)	5,900	64,500
FDI (10 <sup>4</sup> US\$)	35,542	+26,900 (+311.3%)	240	480,816
Per capita road length (m/capita)	0.49	+0.12 (+32.4%)	0.16	1.07
Transport maintenance expenditure (yuan)	121,817	+96,360 (+378.5%)	2,335	2,209,500

**TABLE 2 Factors of China's Urban Transportation Scenarios**

	<b>Factor definition</b>	<b>Description</b>
1	Public transportation capacity	A composition of variables such as road length, route length, number of taxis, and number of passengers, population, area, and total GDP.
2	Economic indicator	A composition of economic variables such as per capita GDP and per capita FDI.
3	Transportation maintenance	An indication of the level of transportation maintenance income and expenditure.
4	Transportation maintenance Intensity	A descriptive variable involving per transportation area transportation maintenance expenditure and per unit road density transportation maintenance income
5	Population-job density	A composition of population and job density
6	Road density	A composition of per capita road length and road length density

**TABLE 3 Descriptive Statistics of The Seventy Chinese Cities By Region**

<b>Region</b>	<b>FDI ('0000 US \$)</b>	<b>Per capita GDP (yuan)</b>	<b>Road length per capita (m)</b>	<b>Change from 1991</b>
Beijing-Tianjin-Tangshan	84,630	17,154	0.56	-1.6%
Liaodong	45,146	16,527	0.49	+44.1%
Shandong	23,909	17,553	0.52	+4.0%
Yangtz	79,443	23,029	0.52	+33.3%
Minnan	72,594	30,303	0.51	+18.6%
Pearl River	89,846	34,994	0.43	+26.5%
Other	10,293	12,992	0.48	+41.2%