

A GIS-based Management Approach for Transportation Infrastructure Construction: A Case Study on Guangdong Province of China

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ABSTRACT: The economic growth of Guangdong province in southern China has drawn attention of various fields such as sustainable development and global environment. The corresponding infrastructure construction such as railways and highways has led to huge effects on industry structure, urbanization, and land use. Therefore, there is an urgent need to comprehensively study the interactions of infrastructure construction, economic development, land utilization, and environmental issues. In this research, first, the current situation of transportation infrastructures in Guangdong province is studied and compared with the developed countries. Then, the investment condition and financial resources of transportation infrastructure construction are investigated as well as its effects on the economical development. Numerical analyses are carried out for reflecting traffic accidents and land use due to the process in transportation service industry. Finally, a GIS-based management approach is presented for managing transportation infrastructures with spatial visible capacity.

Keywords: Transportation Infrastructure Construction, Economic Development, GIS

1. INTRODUCTION

The economic growth in the fast developing regions such as Guangdong province in southern China (as shown in Fig. 1) has drawn much attention from various fields such as sustainable development and global environment (Nisihira et al. 1997). The urban sprawl results in the rapid rural-urban land use conversion so that the previous small town has been evolved to a middle city containing several millions of people. The corresponding infrastructure construction such as railways and highways has led to huge effects on industry structure, urbanization, and land use as shown in a recent World Bank report (1998). Therefore, there is an urgent need to

comprehensively understand the interactions of infrastructure construction, economic development, land utilization, environmental issues, energy consumption, and so on in the fast developing regions (Eng 1997, Sit and Yang 1997, Wu 1998, Yang and Hayashi 1997, Yeh et al. 1995). In fact, the appropriate transportation infrastructure construction is conducive not only to economic production but also to coping with population growth and achieving social equity as well as improving environmental sustainability. On the contrary, if the infrastructure construction is performed only on the need of the current economic development, these regions would inevitably suffer from their transient economic successes in the future.

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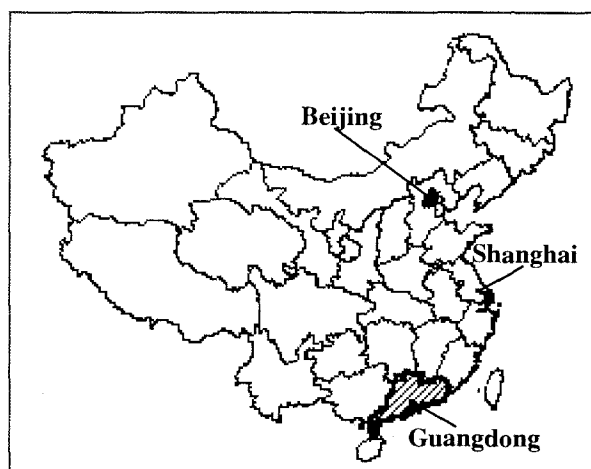


Fig. 1: Location of Guangdong Province

Guangdong province has been achieving rapid economic growth since the early 1980s because of its proximity to Hong Kong and Macao, and has been designed as a window of showing the reform and open-door policies in China. With the rapid urbanization, industrial development, population increase, and increasing volume of traffics as well as the rapid deterioration of aged transportation systems, effective management approaches are becoming important to keep the deteriorating infrastructure systems up with the growing transportation demands and to construct a new transportation infrastructure system. The major shortcomings in traffics and transportation have also shown demands for new railways, highways, and underground mass transit systems.

The rapid development of Geographic Information System (GIS) has provided a great opportunity for the transportation infrastructure management. For example, in previous research, efforts have focused on the development and applications of a GIS-based bridge lifecycle management system (Itoh et al. 1997, Liu et al. 1997). A system based on GIS is being developed by the Urban planning Division of Nagoya city for the comprehensively urban management. Actually, GIS is very necessary for the infrastructure construction management in China. because not only the planning of infrastructure construction but also the investment are carried out by the state or local government in China.

In this paper, the current situation of vehicles and

transportation infrastructure is first studied and compared with developed countries. Then, the investment condition, effects on the economical development and financial resources of transportation infrastructure construction are investigated. Furthermore, two numerical analyses are given for reflecting the effects of infrastructure construction on traffic accidents and land use, which indicates that a new management approach is needed to fit the current characters in infrastructure construction. Finally, a GIS-based management approach is presented for managing infrastructure construction with spatial visible capacities at both province and city levels.

2. TRANSPORTATION INFRASTRUCTURE CONSTRUCTION IN GUANGDONG

In 1987, about 34,000 square kilometers of land located at the southern tip of mainland China including Hainan island and many small islands around it in the South China Sea separated from Guangdong province to be an independent province, Hainan province. Therefore, this study will mainly focus on the changes of transportation infrastructure construction from 1988.

(1) Background on Road Construction and Vehicles in Guangdong Province

Fig. 2 shows the changes of total vehicles and private vehicles in Guangdong province between 1988 and 1996. In 1992, the private vehicles are only 12.7% of the total vehicles. However, this percentage increased to 33.7% in 1996.

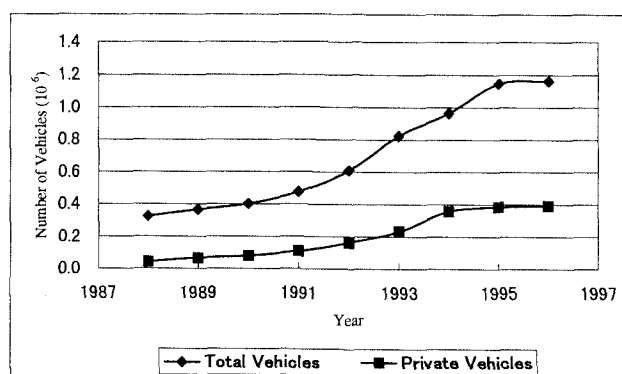


Fig. 2: Changes of Total and Private Vehicles

A detail comparison to illustrate the increase of private vehicles and transportation department professional vehicles in Guangdong province is shown in Fig. 3 by assigning an index in 1988 as 100. Until 1996, the private passenger vehicles and trucks have increased to 13.3 and 8.1 times of the values in 1988, respectively. However, the passenger vehicles owned by the transportation service department increased only 58.5% and the trucks even decreased to 62.8%.

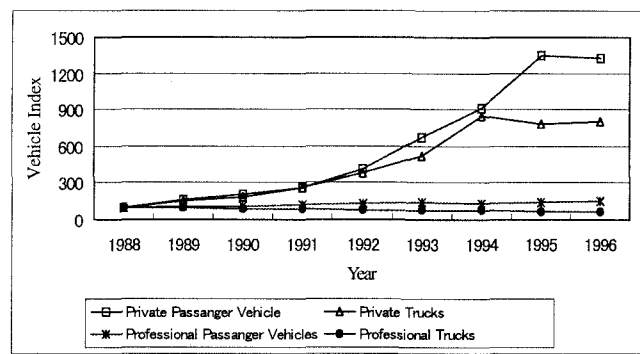


Fig. 3: Changes of Private and Professional Transportation Department Vehicles

Fig. 4 shows the changes of roads and paved roads in length. Since 1992, both kinds of roads have annually increased with a high speed of around 10%. Furthermore, the paved road ratios changed from 85.3% in 1988 to 94.5% in 1996 due to the shift of construction and reformation to high standard roads.

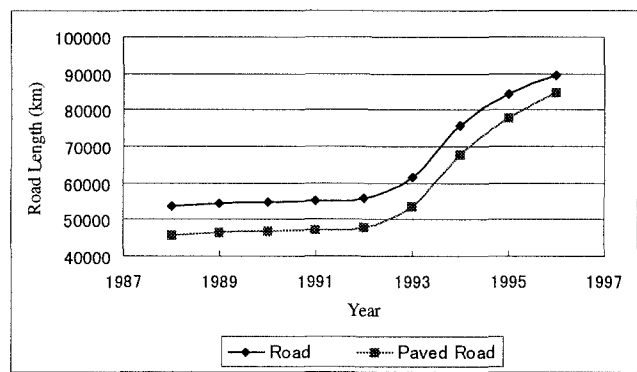


Fig. 4: Changes of Roads in Length

(2) Comparisons with Developed Countries

Comparative analysis has been used as a major means for recognizing the relationship among various problems (Suparat 19994, UNCRD 1997).

In Fig. 5, a comparison is given for the number of vehicles possessed by per 1000 persons in each province in China in 1996. It is clear that Guangdong province possesses the highest amount of vehicle (17) amount among 27 provinces except the three central cities Beijing, Shanghai, and Tianjin. The average of China (9) is shown in the last bar in this figure. However, in most developed countries, every thousands of persons owned more than 400 vehicles in 1996. Compared to developed countries, the vehicle amount in Guangdong province is still very low and further construction of transportation infrastructure is also needed.

The conditions of vehicles and roads in Japan, Germany, UK, France, and USA are used in this comparative study. Based on the statistical reports of International Road Federation (1986-1997) and Statistical Yearbook of China (1986-1997), comparisons have been done on the basis of both the number of vehicles and road construction from Figs. 6 to 9, respectively.

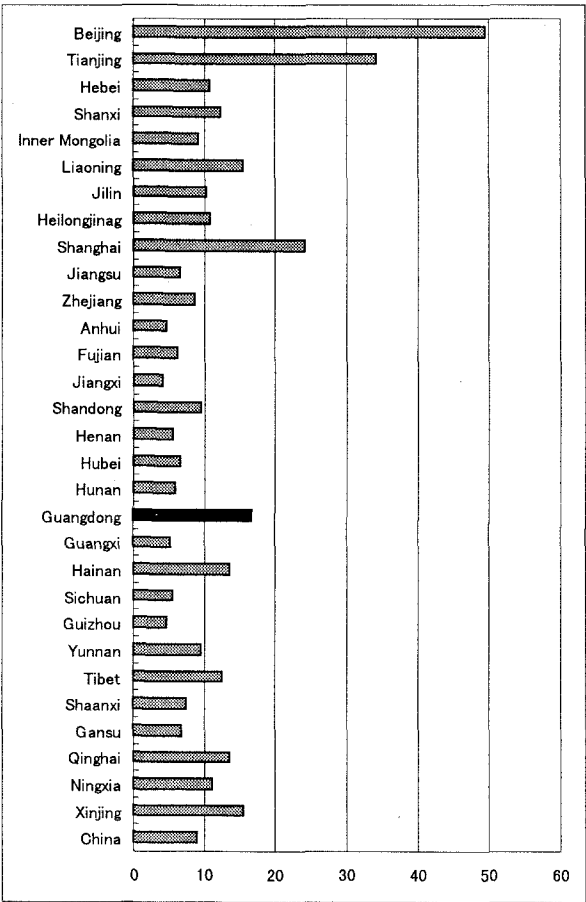


Fig. 5: Number of Vehicles per 1000 Persons

Fig. 6 shows a historical comparison of the numbers of vehicles per kilometer of roads among several countries and Guangdong province. The relative increasing rate of vehicles versus road length in Guangdong province is obviously higher than the average in China from 1990, and much lower than the developed countries. Fig. 7 represents a comparison of vehicles owned by per 1000 persons. The popularization of vehicles in China is still not enough to compare with the other developed countries. It can thus be predicted that a continuous increase of demand will endure for many years from now on although the increase in previous years was very rapid in some provinces. This scenario certainly challenges the civil engineers for the transportation infrastructure construction and management.

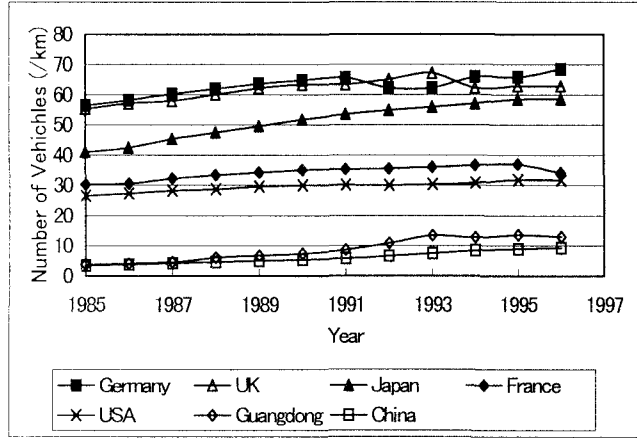


Fig. 6: Comparison of Number of Vehicles according to Road Length

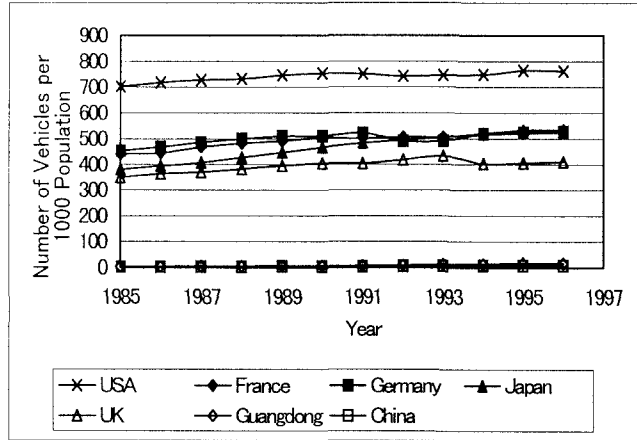


Fig. 7: Comparison of Number of Vehicles according to Population

Fig. 8 shows the comparison of road density. Compared to the amount of vehicles, the gap of road densities is not very high among Guangdong province and developed countries. Furthermore, the high increasing rates have lasted for several years, and reached to 10.2%, 23.0%, 11.7%, and 6.0% in 1993, 1994, 1995, and 1996, respectively. However, there is still a further need of construction of high standard expressway and railways for inter-city transportation and urban elevated highway and subways.

Fig. 9 shows the changes and a comparison of road length per 1000 persons. This index in China is relatively low due to the high population density. However, compared to the gap of vehicle popularization as shown in Fig. 7, this disparity is rather smaller.

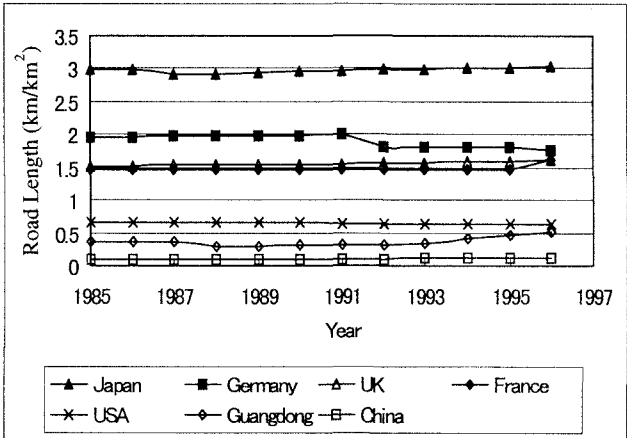


Fig. 8: Comparison of Road Density

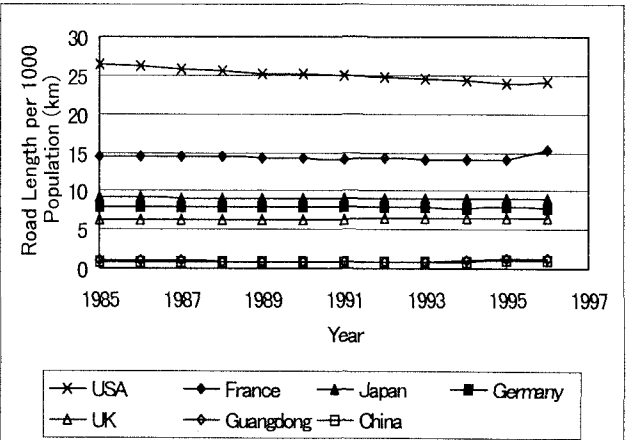


Fig. 9: Comparison of Road Length according to Population

Compared to the developed countries, it can be stated that the amount of constructed roads in Guangdong province is not very low. However, further rapid increase of the number of vehicles can be predicted.

3. INVESTMENT ON TRANSPORTATION INFRASTRUCTURE CONSTRUCTION

This section aims to investigate the investment condition and financial resources of transportation infrastructure construction as well as its effects on the economical development.

(1) Transportation Economy in Guangdong

Fig. 10 shows the tendency of compositions of Gross Regional Product (GRP) in Guangdong province. The manufacture industry (manufacture sector) and service industry (service sector) that consists of the transportation service industry have increased more rapidly than the agriculture industry (agriculture sector). The GRP ratio from agricultural, manufacture, and service industries was 100:131:91 in 1985. However, in 1996, this ratio became to 100:347:245. Furthermore, the values of GRP in 1996 from agriculture, manufacturing, and service industries were 6.0, 15.8 and 16.1 times of the values in 1985.

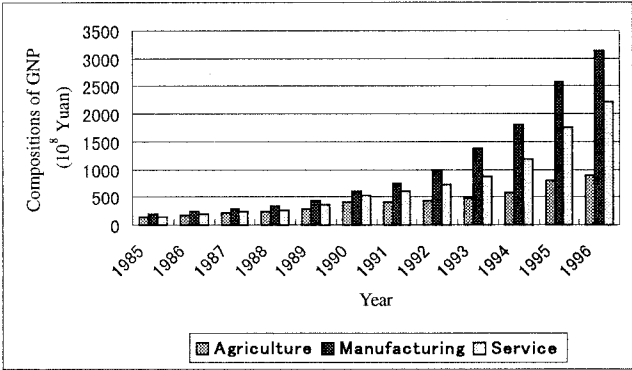


Fig. 10: Percentages from different Types of Industries in GRP Composition

However, as shown in Fig. 11, compared to the industry compositions in Japan and Aichi prefecture in 1996 (Aichi 1997, Japan 1997), the service industry

needs further development in both China and Guangdong province. The detail comparison in percentage on GRP composition in 1996 is shown in Table 1.

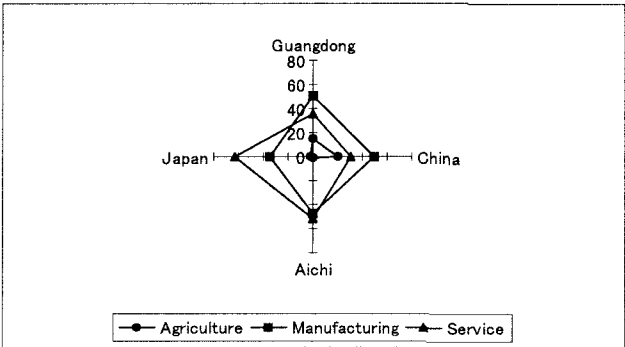


Fig. 11: Percentage Comparison in GRP Compositions

Table 1: Comparison of Compositions of GRP and Labor Forces (%)

	Agriculture		Manufacture		Service	
	GRP	Labor	GRP	Labor	GRP	Labor
Guangdong	14.4	39.7	50.2	28.1	35.4	32.2
China	20.2	50.5	49.0	23.5	30.8	26.0
Aichi	0.6	3.4	47.6	41.1	51.8	55.5
Japan	2.1	6.1	35.2	31.3	62.7	62.6

Fig. 12 shows the comparisons of labor forces engaged in the three types of industries. It can be predicted that employees in the service industry will increase in Guangdong province although an obvious change has been carried out since 1985 as shown in Fig. 13. The percentage of each composition of labor forces in 1996 is also shown in Table 1.

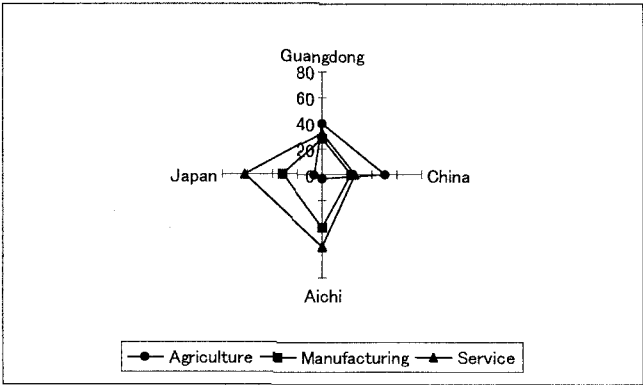


Fig. 12: Percentage Comparison in Labor Force Compositions

Fig. 13 shows the changes of percentage distribution of labor forces in difference industries of Guangdong province. The percentages of labor forces in agricultural, manufacturing, and service industries were observed to be about 60%, 20%, and 20% in 1985, respectively. However, in 1996, these percentages changed to 40%, 28%, and 32%, respectively.

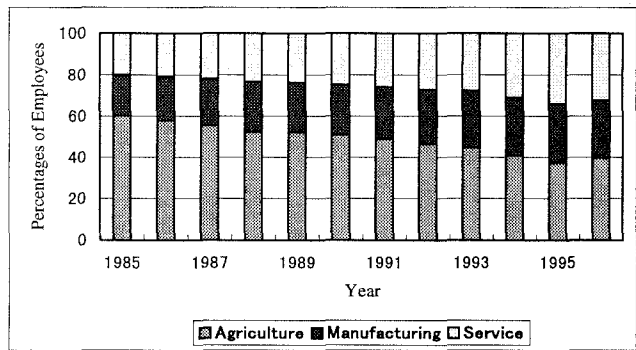


Fig. 13: Changes of Labor Force Compositions in Different Industries

(2) Economic Development and Transportation

Fig. 14 shows the relationship between the road construction in Guangdong province and its increase of GRP. The dashed line approximately represents the increasing trend of both indices in a linear manner. Furthermore, Fig. 15 shows the relationship between the economic development and vehicle amount in Guangdong province from 1988 to 1996.

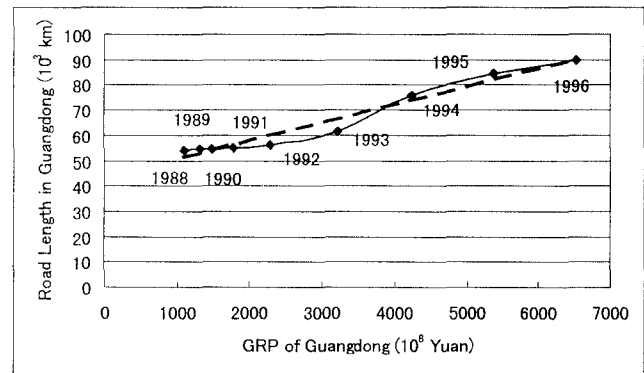


Fig. 14: Relationship between Economic Development and Road Construction

From these two figures, it can be stated that the economic development in Guangdong province

has a close relationship with the transportation infrastructure construction and the popularization of vehicles.

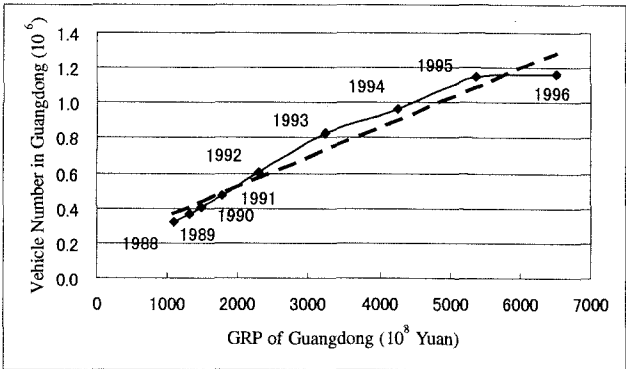


Fig. 15: Relationship between Economic Development and Vehicles

Fig. 16 shows the comparison of increases in road length, vehicle number, GRP, and transportation investment in Guangdong province by taking the values in 1988 as 100. The increase of vehicles is quite faster than the increase of roads although the total amount is still very low. In addition, from 1991 the construction investment developed obviously faster than the GRP due to the increase of extra-budgetary revenue such as issuing construction stocks and bonds on the transportation infrastructure.

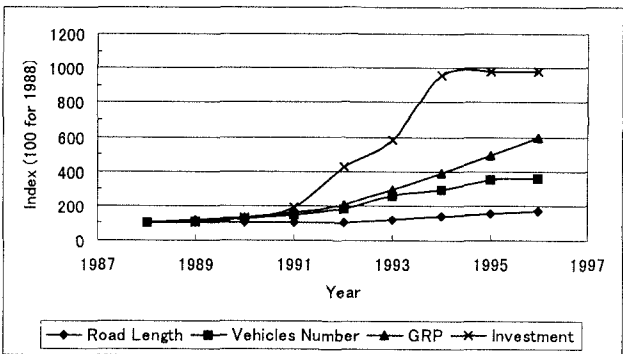


Fig. 16: Comparisons of Road Length, Vehicles, Economic Development, and Road Investment

Further comparison has been carried out for the revenue from transportation service industry, investment on road construction, and road maintenance expenditure as shown in Fig. 17. The

annual maintenance cost has been increasing steadily for many years, and the annual increase rate reached to 22%, 60%, 112%, 69%, 51%, 15%, and 19% from 1990 to 1996, respectively. The sum of road investment and maintenance cost is greater than the revenue from the whole transportation industry in some years.

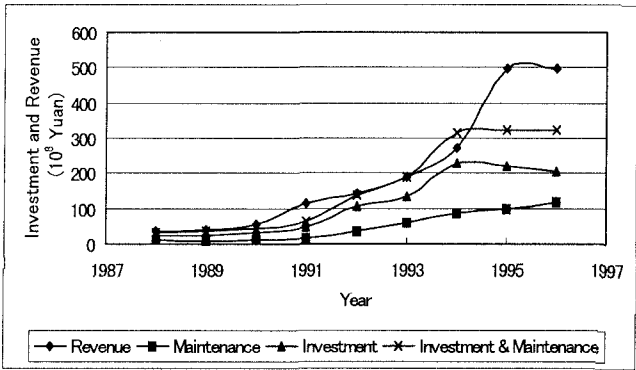


Fig. 17: Transportation Revenue, Road Investment and Maintenance Cost

(3) Financial Resources of Transportation Infrastructure Construction

Fig. 18 shows the financial resources for the road construction in Guangdong province.

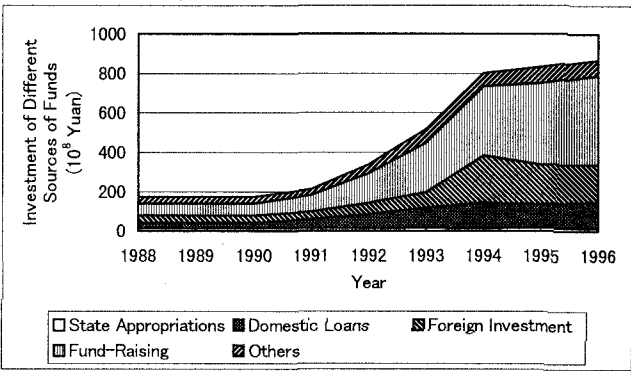


Fig. 18: Comparison of Financial Resources for Road Construction

A large percentage of expenditure is from the domestic loans, foreign investment, and fund-raising, especially from 1991. The investment amount of state appropriations (state budgetary investment) is fluctuating very little. However, the percentage decreased from 7.7% in 1988 to 1.7% in 1996 due to the increase of the total road

investment amount. Because of this limitation of state budgetary investment, it becomes more important and consumes more time to find the financial resources for a specific infrastructure project such as the bridge construction or road replacement. In 1996, 52% of infrastructure construction funds were raised by the construction enterprises from their responsible institutes, local government, and within enterprises for investment in fixed assets during reference period by issuing stocks, bonds and others. Stock is a usual type of funds for investment in fixed asset raised by share holding enterprises through issuing stocks. Bonds is another usual type of funds for investment in fixed assets raised by enterprises or financial institutes through issuing various bonds such as key enterprise bonds, key construction program bonds issued by the bands on behalf of state-owned investing companies.

According to a World Bank report (1994) on the highway development and management in China, the share of each funding resource for inter-city road construction in 1990 in Guangdong province is illustrated in Fig. 19.

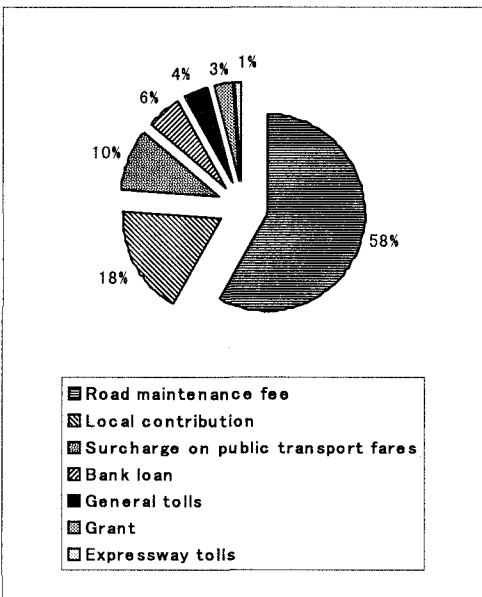


Fig. 19: Highway Financial Resources

The road maintenance fee that mainly consists of the tax of vehicles and the revenue tax of professional

transportation companies contributes 58% of the total highway construction expenditure. The road maintenance fee is the main earmarked user charge to provide most of the road financing needs at the provincial level. At the national level, that is the vehicle purchase fee which was introduced in 1985 and is administered the Chinese Ministry of Communications. The road maintenance fee was introduced in 1950 and is practically identical in all provinces. It is collected and administrated by the provincial communications department, and is the central element of the road funding system in China. The expected funding resources for intra-city transportation infrastructure in Guangzhou city, the capital of Guangdong province, are shown in Fig. 20. The 23% of foreign investment is a little bit higher than the average rate of 21% in the whole province.

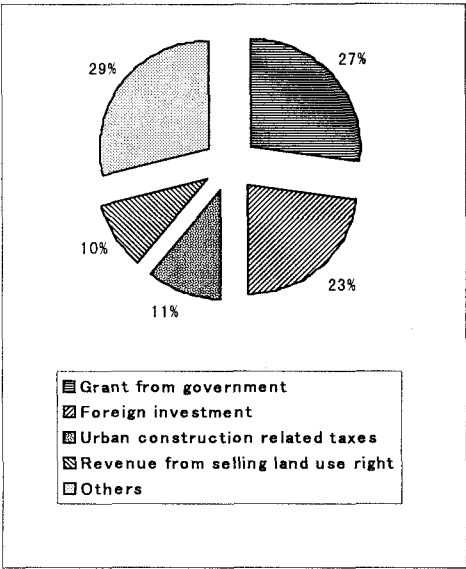


Fig. 20: Financial Resources for Transportation Infrastructure Construction in Guangzhou

4. CONSEQUENCES OF TRANSPORTATION INFRASTRUCTURE CONSTRUCTION

It has been widely noted that transportation infrastructure construction effects the regional economics, natural landscape and environment, and industry development. In this section, two numerical analyses state the effects on traffic accidents and land use.

(1) Traffic Accident Analysis

Traffic accident analysis is an important part of traffic and transportation management. Certain characters of traffic accidents need be highlighted to find appropriate solution ways. Fig. 21 shows a comparison among several countries and Guangdong province on annual traffic accident per 1000 vehicles in several years. According to this figure, it can be noticed that although the traffic accident rate has been decreasing continuously in Guangdong province, it is still higher than the state-level average rates of China and other countries. The perfection and strict enforcement of traffic regulations can guarantee against the occurrence of some traffic accidents.

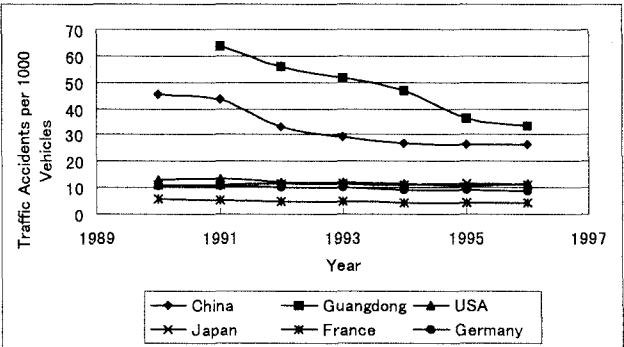


Fig. 21: Comparison of Traffic Accidents

Fig. 22 shows the shares of traffic accidents in each province to the traffic accidents in the whole country in 1991 and 1996. The percentages in Guangdong province are of the highest values in these two years and increased from 11.5% in 1991 to 13.5% in 1996. The point representing Guangdong province is isolated from the other points in both horizontal and vertical dimensions.

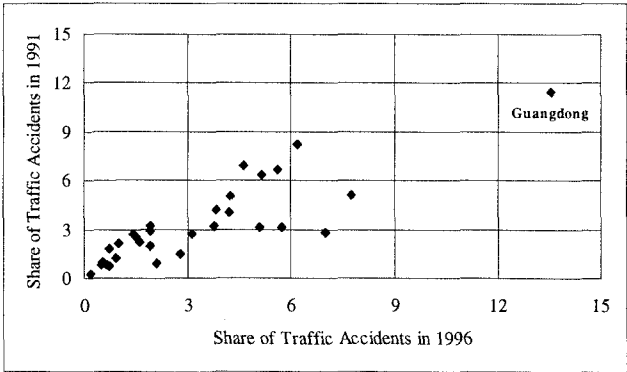


Fig. 22: Share Comparison of Traffic Accidents

Based on comparative results, the high share of traffic accidents in Guangdong province may be related to its high percentage of private vehicles. Fig. 23 shows the shares of traffic accidents and private vehicles in each province in 1996. These two types of shares are in an approximate linear relationship. By chance, in 1996 the percentages of both private vehicles and traffic accidents of Guangdong province are same as 13.6%, the highest value among all provinces. It is noticed the share of private vehicles in Hebei province is in the second position. Actually, a great number of these vehicles run in the two central cities, Beijing and Tianjin, which are geographically located in Hebei province due to the relatively difficult registration of vehicles in Beijing and Tianjin.

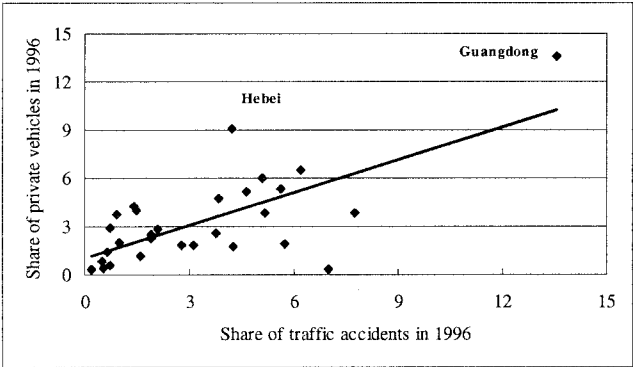


Fig. 23: Share Comparison of Private Vehicles and Traffic Accident

Fig. 24 shows the shares of private vehicles and traffic accidents in Guangdong province in several years.

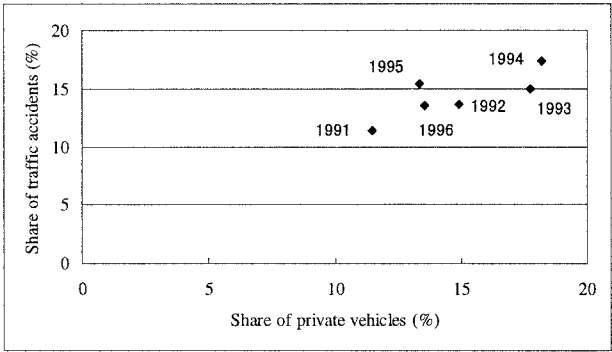


Fig. 24: Changes of Shares in Traffic Accidents and Private Vehicles

This figure also proves that a higher share of traffic accidents happens when the share of private vehicles is larger in some year from another point of view. The lowest and highest values of both shares are in the same years, 1991 and 1994, respectively.

(2) Effects on Land Use

Fig. 25 shows the change of cultivated area in Guangdong province. This value was decreased drastically in 1992, 1993, and 1994 due to the large scale of infrastructure construction. Furthermore, Fig. 26 shows a comparison on the percentages of cultivated area and decreased cultivation area of Guangdong province to China. In 1993, about 14% of decreased cultivation is in Guangdong province although its cultivated area is only 2.5% of the cultivation in China. The peak period of decreased cultivation from 1992 to 1995 further match the rapid road construction within these years as shown in Fig. 4.

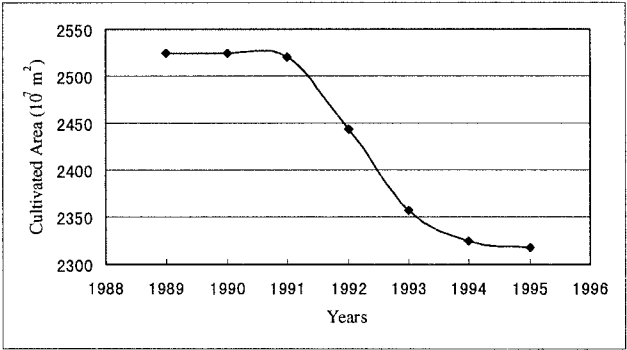


Fig. 25: Change of Cultivated Area

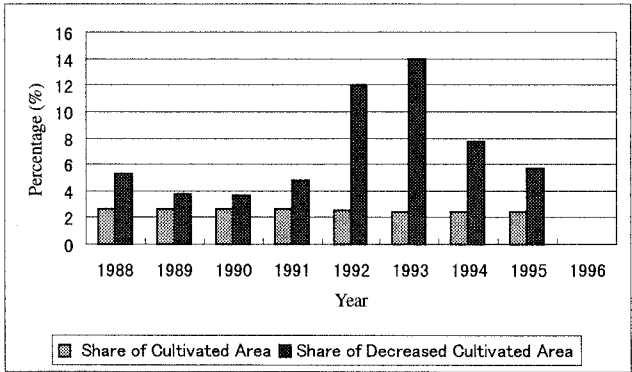


Fig. 26: Percentages of Cultivation and Decreased Cultivation of Guangdong to China

5. GIS-BASED MANAGEMENT APPROACH

GIS offers the spatial and statistical analysis capacities by integrating graphic processing and database functionality with a powerful user interface. GIS separately manages topographic information and attribute information, and is able to join them.

A management system for the transportation infrastructure construction in Guangdong province is being developed using the GIS. A workstation-based ArcView GIS is used to represent and process all geographic information and databases in this research. ArcView provides the power to visualize, explore, query, and analyze data geographically. This system aims to make it possible to manage transportation infrastructures in general at a province level and in special for a specific city with the capacities of spatial visible analysis. The followings are two examples of functions of the management system under development.

(1) Province-Level Transportation Infrastructure Management

Fig. 27 shows a developed system window for the management practice of transportation infrastructure at a province level. Several types of

topographic information can be accessed by developing coverages with different features such as polygons (e.g., administrative division) or arcs (e. g., roads and railways). The attributes of each component in one coverage are held in the tabular format that can be revised with the latest information in the ArcView environment. Further study on each field of the feature attribute table can be carried out by charts to gain insights, solve problems, or achieve new results.

In this example window, three views are shown to represent different types of information: counties and main cities, roads, and railways of Guangdong province. A part of the feature attribute table is related to the coverage of counties and main cities, and the chart is produced from this table. The fields in the feature attribute table of counties represent the data on general survey, population, transportation infrastructure investment, numbers of various types of vehicles, industries, resources, and so on in one county or city. The same fields are given for both road and railway coverages, which are from-node, to-node, left-polygon, right-polygon, length, order-number, identified-number, and type. Further information is expected to be collected and related to this system, such as expressways, bodies of water, traffic volume of each main road, and so on.

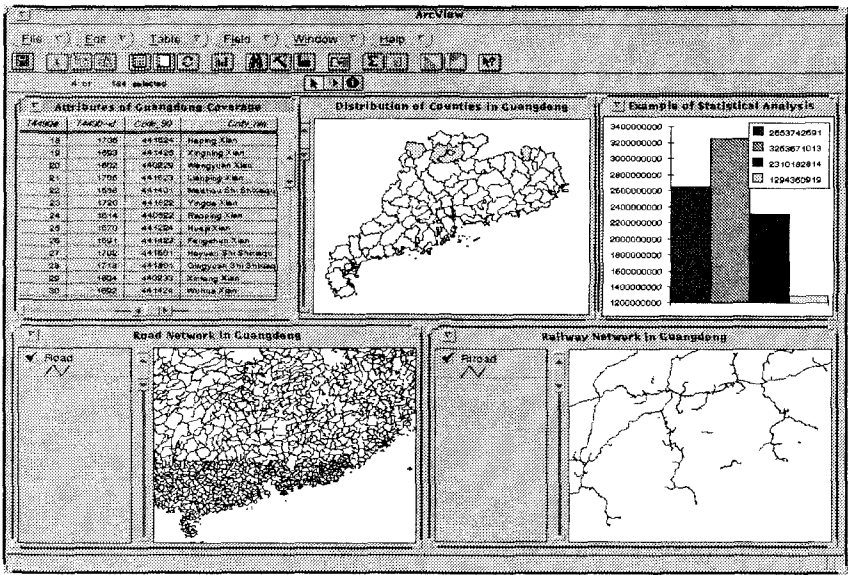


Fig. 27: GIS Application for Transportation Infrastructure Management in Guangdong Province

(2) Urban Management Approach

Fig. 28 shows another example of the system under development at the urban level. Six geographic information coverages in Guangzhou city (ward border, national road, province road, expressway, expressway under construction, and railway) have been digitized and made useful by relating with their feature attribute tables. The attributes of these coverages are being collected as possible to join the available feature attributive tables. The main fields of roads contain the traffic volume and types of vehicles at different time period. Further coverages are necessary for the water area, mountain area, land use, and others.

In this figure, a project file (proj1.apr) contains a view entitled “Management System for Transportation Infrastructures in Guangzhou”. In this view, the city wards are identified according to the resident population in 1997. Several types of roads are displayed using different lines. Each type of geographic information can be easily distinguished according to the color of each coverage displayed on the computer screen. This kind of representation allows linking location's data and features' data in the coverages, and therefore, it allows matching several coverages in a way that is useful for the transportation infrastructure management.

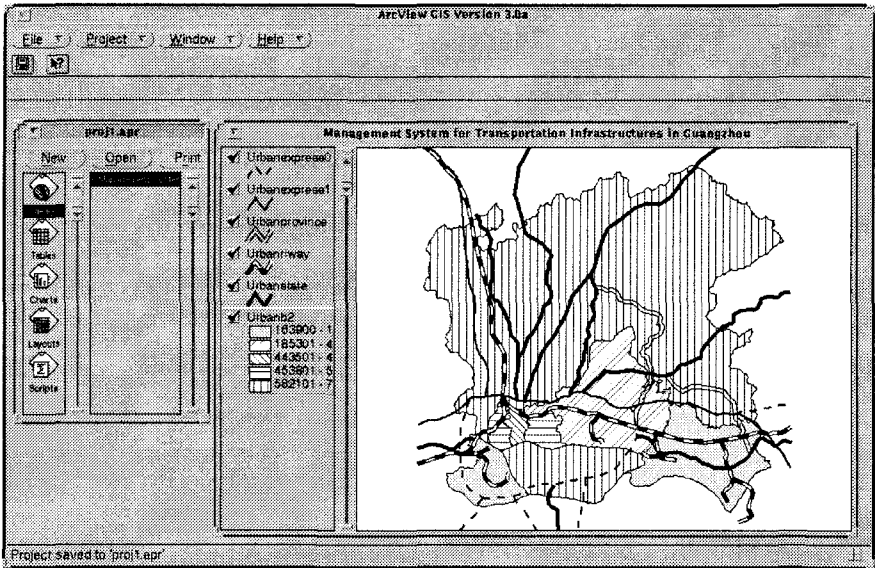


Fig. 28: Overlapped Coverages of Transportation Infrastructure in Guangzhou

6. CONCLUSIONS

Based on this study, the following conclusions can be summarized:

- ① Compared to the developed countries, the amount of constructed roads in Guangdong province is not very low, and the number of vehicles will continue increasing. In 1996, the number of vehicles and length of roads per 1000 people in Japan are 32 and 7 times of the values in Guangdong province, respectively.
- ② The transportation industry needs further

- development in both China and Guangdong province, and employees in transportation industry are in a great increase.
- ③ The economic growth of Guangdong province is closely related to the transportation infrastructure construction and popularization of vehicles.
- ④ The increase of vehicles and the infrastructure construction have various effects on the whole society, economics, and environment, and a new management system based on GIS is needed for the systematic transportation infrastructure construction.

Further research will be carried out in the following ways for implementing the proposed GIS-based management approach: automated data collection will be adopted for acquiring data for GIS analysis. Internet will be used to make it possible to access the GIS-based management system from different computer platforms in different agencies.

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