INFRASTRUCTURE CONSTRUCTION INDUCED SUSTAINABLE DEVELOPMENT OF GUANGDONG PROVINCE, CHINA

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Abstract: As civil infrastructures have long service lives and change the surrounding natural environment seriously and irreversibly, the infrastructure construction has brought attention to the environmentally and socially sustainable development in addition to the function, cost and safety. Sustainable development is a critical factor for the enhanced quality of living that results from a sound environment and a well-functioning civil infrastructure system. Promoting sustainable development of civil infrastructure at the global, regional, and local levels underlines the important objective of research. This study is first focused on the infrastructure construction in Guangdong province and its effects on the society including the regional economic development, urbanization, and change of employment structure. The effects of transportation infrastructure condition on traffics and transportation are analyzed from the viewpoints of traffic accidents and traffic congestion. Finally, quantitative analyses and a GIS-based management approach are used for studying the air pollution and waste emission problems.

1. INTRODUCTION

As the transportation infrastructures have long service lives and may change the surrounding natural environment seriously and irreversibly, the infrastructure construction has attracted attention to its Eco-social consequences on the environmentally and socially sustainable development in addition to its function, cost and safety. Sustainable development has been likened to a three-legged stool based on environment, economics, and social development. Sustainable development is important for the enhanced quality of living that requires a sound environment and a well-functioning transportation infrastructure system. Promoting sustainable development of civil infrastructure at the global, regional, and local levels underlines the important objective of research. It is being widely recognized that the quality and quantity of transportation infrastructure systems such as highway and railway systems have a direct bearing on the economic growth, urbanization and change of employment structure (Liu *et al.* 1998, Mohamad 1998, Man 1998, Taniguchi 1997). Bottlenecks in the provision of transportation service can severely retard the growth in all economic sectors of a country or region. Therefore, the developing countries are facing the challenges of updating and expanding their present infrastructure facilities so that the economic growth will not be jeopardized by infrastructure-related constraints. In addition, other potential Eco-social consequences of transportation infrastructure construction also needs to be studied such as the traffic accidents, traffic congestion, air pollution, noise, and waste emissions, and so on (Chan *et al.* 1995, Futawatari and Imura 1998).

The economic growth in the fast developing regions such as Guangdong province in southern China shown in Fig. 1 has drawn much attention from various fields such as sustainable development and global environment (Eng 1997, Wu 1998). 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. Therefore, there is an urgent need to comprehensively understand the interactions of infrastructure construction, economic development, land utilization, environmental issues, and energy consumption, and so on.

Such a study is profitable for the global environment as well as to the local economic development. 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 economic growth has resulted in demands for the further construction of the transportation infrastructure. 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 were performed only on the need of the current economic development, these regions would inevitably suffer from their transient economic successes in the future.

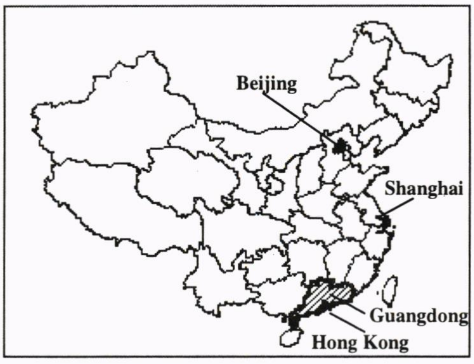

Figure 1. Location of Guangdong Province

The rapid development of Geographic Information System (GIS) has provided a great opportunity for the transportation infrastructure management. GIS allows the use of spatial coordinates to describe the structure of urban area, road networks, pollutant distribution in the atmosphere, and so on. An integrated traffic, transportation and transportation infrastructure management system needs developing for various urban administrative departments. Actually, GIS is quite necessary for the infrastructure management in China, because not only the planning of the infrastructure construction but also the main investment are carried out by the state or local government in China. In this research, first, the study is focused on the infrastructure construction in Guangdong province and its effects on the society including the regional economic development, urbanization, and change of employment structure. The effects of transportation infrastructure condition on traffics and transportation are analyzed from the viewpoints of traffic accidents and traffic congestion. Finally, quantitative analyses and a GIS-based management approach are used for studying the air pollution and waste emission problems.

2. TRANSPORTATION INFRASTRUCTURE CONSTRUCTION

Infrastructure, or more formally, civil infrastructure systems represent the systems of public and private facilities that are constructed to transport people and goods, supply water, dispose waste, provide energy, and transmit information (Grivas 1998). Within the last decade, the engineering, financial, and management professions have recognized infrastructure as a major asset. Within the same time frame, infrastructure systems have expanded and become more complex in response to population growth, demographic changes, increased demands on existing, deteriorating systems, and demands for new types of infrastructure. Infrastructure engineering integrates the multitude of engineering disciplines relevant to the design, construction, maintenance, and operation of various types of infrastructure with key principles of business, finance and management. It shifts the emphasis of the civil engineering profession from the old paradigm of design-to-build toward the long-term view of design-to-build-and-maintain. The infrastructure elements are the facilities that millions of people use on a daily basis. Almost every human activity relies at least in part on the infrastructure of the civilized world. Without vast public works making transportation, trade, and basic living easier, the world would be a much darker and less habitable place.

2.1 Infrastructure Construction Investment Pattern

The adequacy of infrastructure helps to determine one country's success in diversifying production, expanding trade, coping with population growth, reducing poverty, or improving environmental conditions. Good infrastructure raises productivity and lowers production costs, but it has to expand fast enough to accommodate growth. The precise linkage between infrastructure and development are still open to debate. However, based on the World Development Report (1994), infrastructure capacity grows step by step with economic output: a 1% increase in the stock of infrastructure is associated with a 1% increase in GDP across the world. Further, as countries develop, infrastructure must adapt to support changing patterns of demands and the shares of roads, telecommunications, and power in the total stock of infrastructure increase compared to those basic services such as water and irrigation. In many rapidly growing cities, infrastructure expansion is lagging behind population growth, and causing local environments to be deteriorated. Therefore, the infrastructure amount and the long-term infrastructure investment patterns of a country or a region are important indicators to reflect its economic condition.

According to a World Bank report made using the panel data from 50 countries and 35 urban areas (Ingram and Liu 1997), relative to countries, urban areas obviously have much higher population densities, higher road network densities, more motor vehicle per unit of road, somewhat more vehicles per thousand persons, and much less road length per person. Furthermore, relative to high-income cities, developing cities have higher population densities, lower road network densities, fewer motor vehicles per thousand persons, and less road length per person. The result is a relatively small difference in motor vehicles per unit of road between developing and high income cities. The infrastructure investment pattern in the Guangdong province of China in previous years is studied. As shown in Fig. 2, the percentages of infrastructure investment in manufacturing, power and transportation (including communication) are so high to be around 60% of the total infrastructure investment. The infrastructure investment relative to the agriculture is rather small to be only about 1% from 1993 to 1996. The financial resources for infrastructure construction are varied (Liu and Itoh 1998). For example, the road construction investment in Guangdong province from the state financial allocation, domestic loans, foreign investment, fund raising, and others are 1.7%, 15.5%, 21.8%, 52.0%, and 9.0%, respectively.

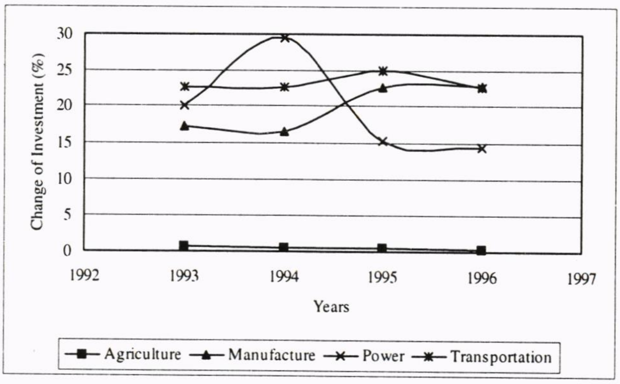

Figure 2. Changes of Infrastructure Construction Investments in Guangdong Province

2.2 Urban Growth and Transportation Infrastructure Gap

Many large cities in the developing countries are facing the rapid urban growth. Most of such rapidly developed cities suffer from the inadequate urban infrastructures such as roads, sewerage and parks. For these cities to achieve better urban amenities for the coming future and to fully benefit from their urbanization, the strategy for infrastructure improvement is becoming a very important factor. The urbanization of the developing countries and regions should be corresponding to the infrastructure construction in addition to the economic development and population growth. Figure 3 shows the growth pattern of several typical cities in both developed countries and developing countries (Mitchell 1998). From the urbanization point of view, the five mega-cities including Paris, London, Osaka, New York and Tokyo had reached their maximum populations until 1970. Then, the number of inhabitants decreased in these cities. However, other five cities including Nagoya, Guangzhou, Beijing, Shanghai and Bangkok have still been increasing their populations since 1990 due to the expansion of the urban areas or the immigration from other regions or cities. From 1992 to 1996, the population in Nagoya City decreased year after year. However, the population in Guangzhou City has continuously increased at a yearly rate greater than 1% since 1990.

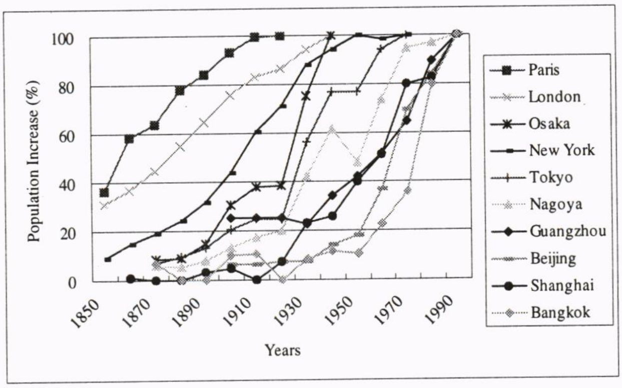

Figure 3. Population Increase in Several Mega-Cities

In each metropolitan area, there may exist a gap between the demand of inhabitants on civil infrastructures such as roads and communication service and their current conditions. Usually, the sprawl cities in the developing regions have large gaps due to the high increases in population, the rural urbanization, and the unbalanced investment between the infrastructure construction and the productive development. This gap can be defined as a rate between the satisfied population for infrastructures and the citizen population. This rate can be called the satisfied rate in infrastructures, for example the satisfied rate in roads. The satisfied population may be calculated according to the given infrastructure level and population density in each region or city, which may be the long-range construction goal as announced by the national government or local administrative agency. In this research, it is assumed that the average population density is 6000 per square kilometer and the satisfied road network density is 3.5 km/km^2. The Ministry of Construction of Japan (1986) defined this road network density as the target of urban road improvement by 2000 in the long-term plan of national construction. For the purpose of comparison, Figure 4 shows the satisfied ratios in roads in both Nagoya and Guangzhou cities according to the Guangzhou Statistical Yearbook (1997) and Nagoya Statistical Yearbook (1997). In 1996, the population density and road density in Nagoya are 6615 $persons/km^2$ and 15.39 km/km^2, respectively. However, in Guangdong, the population density is only 2703 $persons/km^2$ since an undeveloped district named Baiyun takes 20% in the population and 72% in the area, and the road density is 0.65 km/km^2. This comparison represents that the road network in Nagoya City can satisfy the inhabited population very well but the further road construction is quite necessary in Guangzhou City.

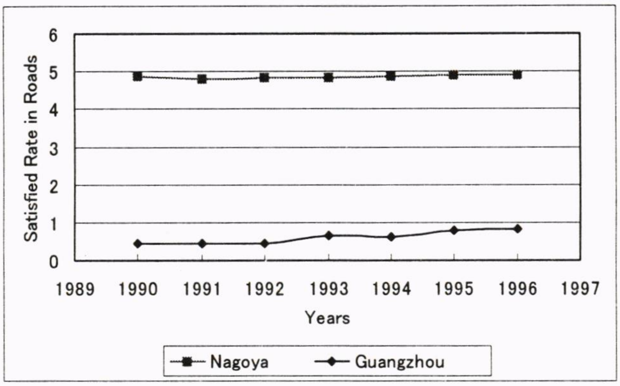

Figure 4. Transportation Infrastructure Gaps in Guangzhou and Nagoya Cities

2.3 Economic Development and Employment Change

Economic development results in dramatic changes in the structure of employment. As the increase of labor cost together with technological advances, the pattern of work in traditional industries changes and encourages new methods. Meanwhile job opportunities expand in services and industry, as employment in agriculture declines, and workers move to urban area and change from the informal to the formal sector. Workers have prospered more when the process of productivity upgrading and labor transfer has been based on market realities. Attempts by governments to force the pace of change by protecting industry and formal employment have proved unsustainable and often counter-productive, slowing economic growth, depressing labor demand, and encouraging information. Productivity growth and rising real wages change the way economies work. As skills and capital become more abundant, countries find it economical to use their labor to produce more skill-intensive and capital-intensive manufacture products and services and fewer labor-intensive agricultural goods. It was indicated in the World Development Report (1995) that on average, agriculture's share of employment falls from 90% of the total in poor countries to roughly 5% in rich ones. The industrial share, which includes manufacturing, construction, and mining, rises from 4% to about 35%, and that of services from 6% to 60%. Different resource endowments can produce wide variations from this basic pattern. Figure 5 shows the change of percentages of employment in the three sectors including the agriculture, industry, and service sectors in Guangdong province from 1985 to 1996 according to the Guangdong Statistical Yearbook (1997). The horizontal axis represents the GDP per capita.

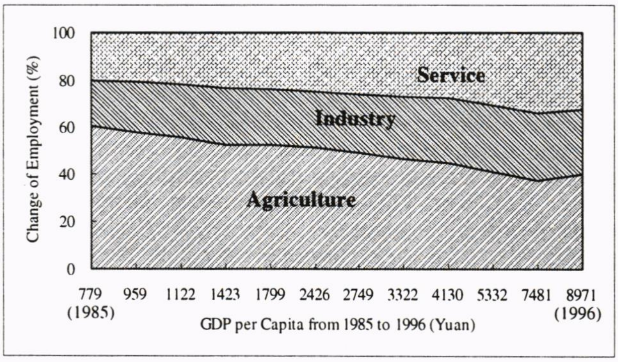

Figure 5. Employment and GDP per Capita in Guangdong Province

As the economic expansion of a developing region, new employment opportunities compete with the existing ones. With the demand rising elsewhere, workers move out of the low-productivity and low-wage activities such as the agricultural sector. Figure 6 show the labor productivity trends of three economic sectors including industry, service and agriculture in Guangdong from 1985 to 1996 in Chinese Yuan (1 US$ is about 8 Yuan in 1996). The annual values and increase speed per employee in both industry and service are much bigger than those in the agriculture sector. This is corresponding to the changed trends of employee in these years as shown in Fig. 5. The Guangdong's impressive productivity performance partly reflects an expansion of employment in the high-productivity services and industrial sectors, and also reflects the fact that agriculture boosted the efficiency of its productivity while reducing the number of workers.

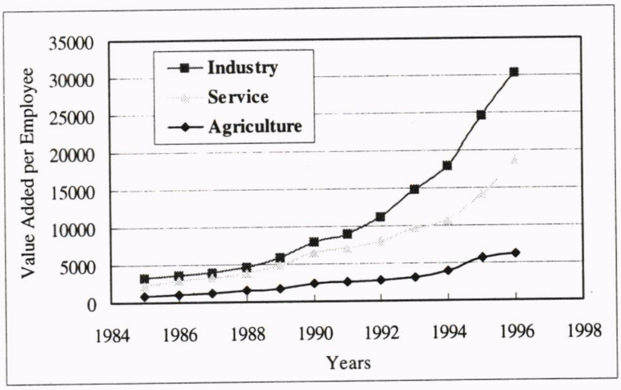

Figure 6. Value Added per Person in Guangdong Province (unit: Yuan)

3. TRAFFIC SAFETY AND TRAFFIC CONGESTION

Growing road traffics causes several problems such as the traffic congestion, traffic accidents and environmental pollution. A considerable success has been achieved in improving the traffic safety for several decades in the developed countries (Bly and Dasgupta 1995). By contrast, problems of congestion and environmental damage have become more marked and widespread as the traffic has grown and some of the less obvious environmental effects have become clearer with greater scientific knowledge. In the developing countries and regions, the traffic safety, congestion and noise as well as the waste emissions are still serious problems that needs much attention and effective solutions.

3.1 Traffic Accident Analysis

Traffic accident analysis is an important part of traffic and transportation management. Certain characters of traffic accidents need to be highlighted to find appropriate solutions as mentioned in previous research (Al-Ghamdi 1996, Karim 1995, and Liu and Itoh 1998). Figure 7 shows a comparison among several countries, Aichi prefecture in Japan and Guangdong province on the annual average traffic fatalities per 1000 vehicles in several years. The used data are from Guangdong Statistical Yearbook (1991-1997), Road Statistics (1997), and World Road Statistics (1991-1997). According to this figure, it can be noticed that although the traffic death accident rates have been decreasing continuously in Guangdong province, they are still much higher than the state-level average rates in other countries and Aichi prefecture. In addition to improve the levels of all road quality, vehicle quality and the driver capability, the perfection and strict enforcement of traffic regulations can guarantee against the occurrence of some traffic accidents. It is noticed that there may exist some particular reasons in Guangdong province relative to the severely high ratios of traffic fatality accidents. One reason may be the huge amount of motor cycles riding for the own traffic, goods transportation, and commercial passenger transportation. In 1996, there are about 3,700,000 and 380,000 registered motor cycles in the whole Guangdong province and the urban area of Guangzhou City, which are almost three time and twice of the motor vehicles, respectively. The annual average increasing rates of motor cycles from 1991 to 1996 was high as 10% and 15%, respectively. On the other hand, the change of number of motor cycles may reflect the change the economic and living levels of a country or region. In Japan, the number of motor cycles increased year by year during the 13 year period of high oil prices from 1973 to 1986. Since 1986, the number of motor cycles decreased year after year due to the reduction of oil prices and the improvement of income and living standard.

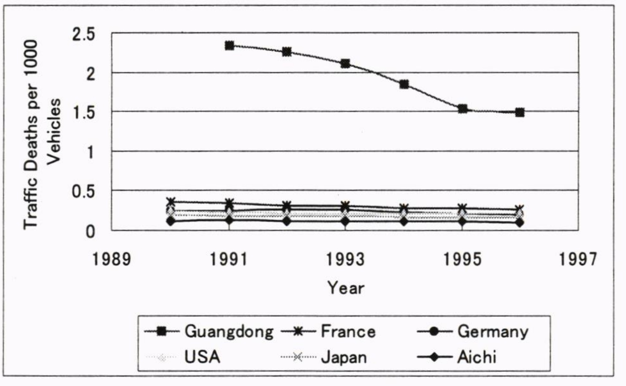

Figure 7. Comparison of Traffic Fatality Accidents

In Fig. 8, the point represents the percentages of traffic death accidents in each province to the traffic death accidents in the whole country in 1991 and 1996 in the vertical and horizontal axes, respectively. The provinces above and below the lines mean that the traffic death accidents decrease and increase from 1991 to 1996, respectively. The percentages in Guangdong province are of the highest values in these two years and increased from 8.3% in 1991 to 10.4% in 1996. This increased percentage ratio (2.1%) is the biggest one among all provinces and central cities in China. In this figure, the point representing Guangdong province is much isolated from the other points in both dimensions, especially in the horizontal axis representing the percentage of traffic fatality accidents in 1996.

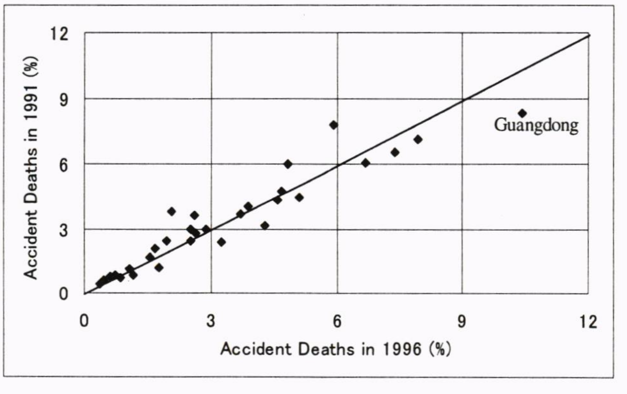

Figure 8. Share Comparison of Traffic Fatality Accidents

Based on the comparative results, the high share of traffic accident deaths in Guangdong province may be related to its high percentage of private vehicles. In Fig. 9, the points show the shares of traffic accident deaths and private vehicles in each province in 1996 in the horizontal and vertical axes, respectively. These two types of shares are in an approximate linear relationship. In 1996, the percentages of both private vehicles and traffic accidents of Guangdong province are 10.4% and 13.6%, respectively. Both are the highest value among all provinces. It should be noticed that 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.

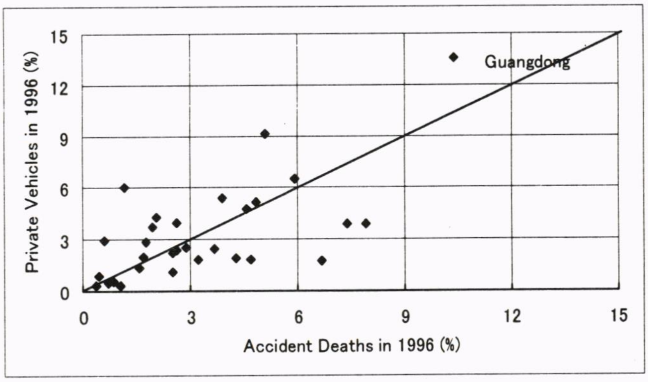

Figure 9. Share Comparison of Private Vehicle and Traffic Fatality Accidents

The geographical visual comparison of traffic accidents and numbers of vehicles among provinces of China can be carried out by taking the advantages of GIS in data visualization. Figure 10 shows the comparison of numbers of traffic accidents in each province of China. Figure 11 shows the comparison results of numbers of vehicles per 1000 population. It is clear that there are relatively high values of both traffic accidents and vehicles in the eastern provinces, and the numbers of vehicles and traffic accidents in the western provinces are relatively low. Especially, both the traffic accidents and the private vehicles in Guangdong province are of the highest values among all provinces and central cities.

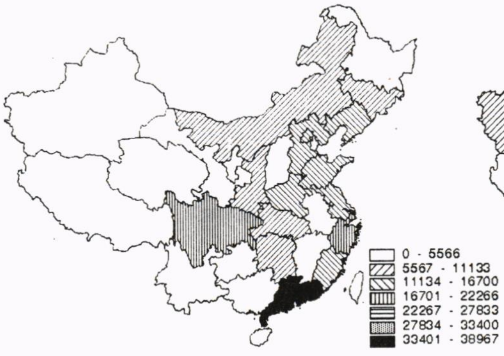

Figure 10. Geographical Distribution Numbers of Traffic Fatality Accidents

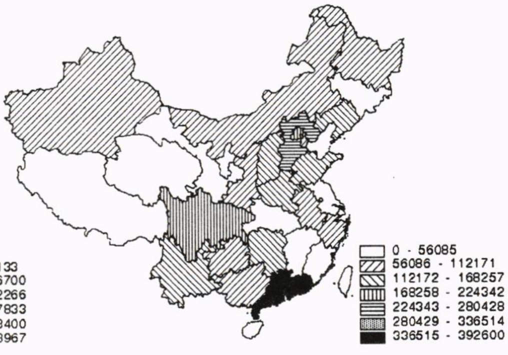

Figure 11. Geographical Distribution Numbers of Private Vehicles

Figure 12 shows the shares of private vehicles and traffic death accidents in Guangdong province to the whole country in several years in the horizontal and vertical axes, respectively. This figure also proves that a higher share of traffic death 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.

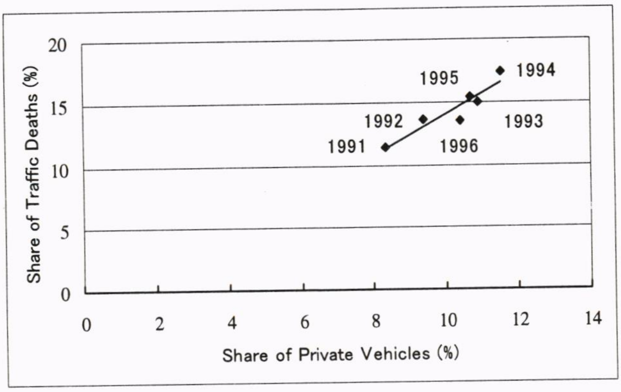

Figure 12. Changes of Shares in Private Vehicle and Traffic Death

3.2 Traffic Congestion and Traffic Noise Pollution

It is estimated that the traffic congestion wastes almost 1.4 billion gallons of fuel and 1.2 billion person-hours of time each year in USA, which cost about 10 billions US$ (Schulz 1994). These wastes are further projected to increase to about 7 billion gallons and 7 billion person-hours by the year 2005. Truck delays add more than 7.5 billion US$ annually to the cost of U.S. made goods. The average speeds have deteriorated over the last decades in most cities. In Guangzhou, the capital city of Guangdong province, the total road length increased from 951 km in 1991 to 1847 km in 1996. Compared with traffic vehicle increase from 104,101 in 1991 to 203,510 in 1996, the densities of vehicles on the network are almost constant as 110 vehicles per kilometer. These values are quite less than the 170 per kilometer in 1995 in Nagoya city. However, if the motor cycles are also considered, the automobile numbers in Guangzhou and Nagoya increase to 320 and 200 per kilometer, respectively. Due to the continuous increase in the high traffic volume and the lack of road facilities in the urban area of Guangzhou City, the driving speed has been decreasing drastically although some efforts has been carried out such as the construction of subways and the inner ring road.

Table 1 compares the average speeds in the urban central area from 7:00 to 18:00, which were provided by the local government agency. In 2010, the traffic speeds in both the north-south and east-west directions will decrease to around 10 km/h although the design speeds of trunk roads are higher than 40 km/h. In fact, many factors may influence the urban traffic speed including the scarce road capacity, imperfect traffic management at intersections, incomplete traffic control and management facility, the behaviors of pedestrians and drivers violating traffic regulations, jam caused by traffic accident, and illegal parking, and so on. For example, according to an authoritative investigation conducted by a local transportation planning agency in Guangzhou City, about 85% of the intersections in the urban areas are saturated and congestion at the intersections resulted in slow traffic, which was indicated in a World Bank Report titled Guangzhou City Center Transport Project (1998).

Table 1. Changes of Average Speed in the Central Area of Guangzhou

	North-south direction (km/h)			East-west direction (km/h)		
	1992	2000	2010	1992	2000	2010
Morning peak time (7:00am-10:00am)	16.1	13.4	7.7	16.6	15.3	11.1
Daily time (10:00-15:00 & 18:00-19:00)	18.4	15.0	8.2	18.0	16.3	11.9
Evening peak time (15:00-18:00)	15.9	14.1	8.9	16.2	16.1	12.2

An integrated management system is being developed for managing the vehicles, traffic, transportation, and transportation infrastructure in the urban area. GIS makes it possible to analyze the available data by taking into consideration their geographical distributions. Figure 13 shows a window of the geographical analysis on the population and population density in each district of Guangzhou City. The polygons of all districts are presented with different patterns of background. Both Baiyun and Haizhu districts have more inhabitants than the other districts. However, as shown by the bars, the population density in the Yuexiu district is the highest one. The average traffic flow in the Tianhe district was investigated to be at the top among all eight districts in Guangzhou City as shown in Fig. 14 in numbers of vehicles per hour. However, due to the relatively narrow roads in the central districts of Guangdong including the Liwan, Yuexiu and Dongshan districts, there are higher traffic flow volumes per unit road width as shown in the form of bars.

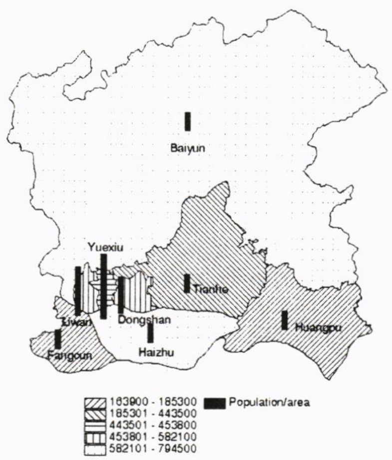

Figure 13. Visualization of Population and Population Density in Guangzhou City

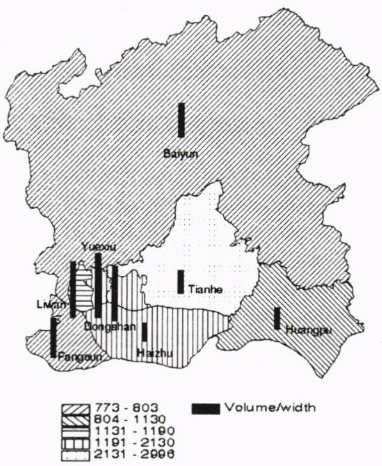

Figure 14. Visualization of Traffic Flow Volume in Guangzhou City

Furthermore, geographical analysis results on the urban noise are shown in Fig. 15. The left part of the figure represents the values of three parameters of L10, L50 and L90 in decibel (dB), which are the noise levels exceeded within an hour up to 10%, 50% and 90%, respectively. The right part is the average noise level within continuous twenty-four hours.

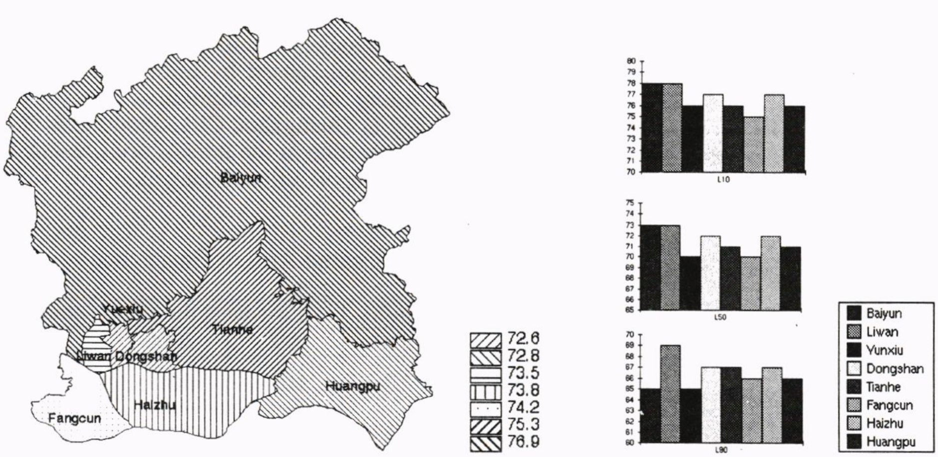

Figure 15. Geographic Distribution Analysis on Urban Noises (unit: dB)

4. EXHAUTED GAS AND WASTE EMISSIONS

4.1 Urban Air Pollution

Motor vehicle emissions comprise a high proportion of total urban air pollution. For example, in the countries of the European Union in 1990, motor vehicles caused 50% of all nitrogen oxides (NO_X) pollution and over 60% of all carbon monoxide (CO) pollution. Motor vehicle pollution is perhaps an even greater problem in rapidly motorizing developing countries where emission controls are less strict and effective, and engine technology is older. For example, the contribution of motor vehicle of total NO_X and CO emissions in 1990 was 80% and almost 100% in Manila, respectively. Pollutants from vehicle engines include lead (Pb), volatile organic compounds (VOC), Hydrocarbon (HC), and total suspended particulars (TSP) in addition to CO and NO_X. Air pollution from motor vehicles increases under congested traffic conditions. The generally lower traffic speeds, intermittent stop-go operations and, in chronic congestion, frequent periods when vehicles are halted with idling engines, not only increase the amount of fuel consumed, but also the fuel is burned less efficiently by the engines. The net result is that the quantity of emission per unit of distance traveled is sharply increased. When China is at an early stage of motorization, the potential course of motorized pollution is plain to see. In Beijing, the contribution of motor vehicles to NO_X and CO pollution has already reached 46% and 30%, respectively. A monitoring program conducted in Guangzhou indicated that all HC readings exceeded the standard of 0.16 mg/m^3, generally by a factor of 8 times (World Bank Report 1998). Further, more than 70% of NO_X readings exceeded the secondary standard of 0.15 mg/m^3 and the daily averages are 2.24 times of the standard 0.10 mg/m^3; and around 12% of CO readings exceeded the standard of 10.0 mg/m3.

Environmental problems are closely relative to the energy consumption. This issue is more serious in the developing countries and regions where the fossil fuel may be the main fuel to generate energy. The primary energy consumption in China in 1991 was almost equal to that of South Korea in the early 1970s and Japan around 1950 (Imura *et al.* 1995). If the economic development in China keeps at its present pace, such gap in energy consumption will diminish rapidly in a few decades. As the energy supply in China is heavily dependent on coal, the emission of air pollution is enormous. Nonetheless, environmental pressure in industrial areas and big cities has surpassed the critical level because major production facilities and population are concentrated there. With the development of economics, the energy consumption in Guangdong province has increased drastically. As shown in Fig. 16, the yearly energy consumption in the agriculture, industry and service increased 109%, 74% and 184% respectively within the seven years from 1989 to 1996. Contained in the service sector, the energy demand in the transportation and communication sector increased from 311 tons of standard coals in 1989 to 612 tons of standard coals in 1996, which are more than half of the total energy consumption in the service sector.

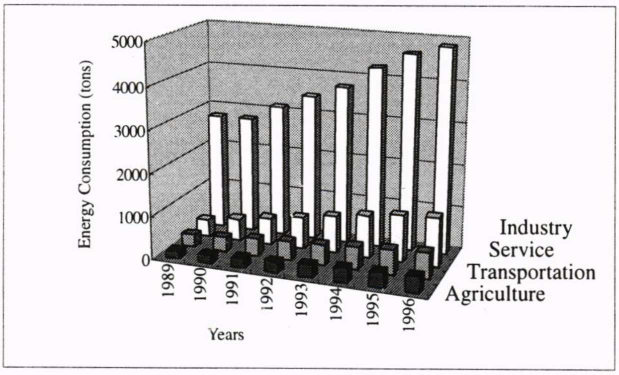

Figure 16. Increase of Energy Consumption in Each Sector in Guangdong Province

Figure 17 shows the GDP per energy consumption in the above-mentioned four economic sectors from 1989 to 1996. The economic efficiencies of energy consumption in the industry and transportation sectors are quite low compared to the agriculture sector and the service sector in average. This figure also implies that the elasticity of energy demand increase to GDP growth may change in different years.

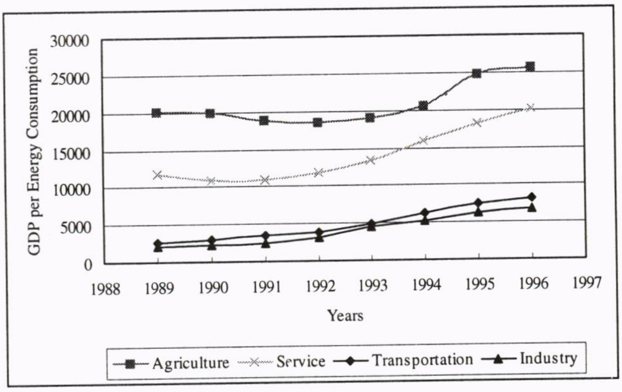

Figure 17. GDP per Energy Consumption Sector in Guangdong Province (unit: Yuan)

There are several typical ways to estimate the environmental impacts from the motor vehicles such as using the consumed fuels or according to the moving lengths. Emission factors to represent the unit emission are the key to determining the exhaust emissions and air quality. Several parameters have to be taken into consideration such as the age, mileage, emission rate of new vehicles, degradation coefficient, and temperature, and so on. According to the available data on vehicle fleet composition, traffic volume and speed, the daily and annual mobile source emissions were estimated. Those emission factors are used to calculate the emissions including CO, NO_X, and HC as shown in Fig. 18. In fact, there are more than one hundred kinds of vehicle exhaust pollutants, among which these three are the representative ones.

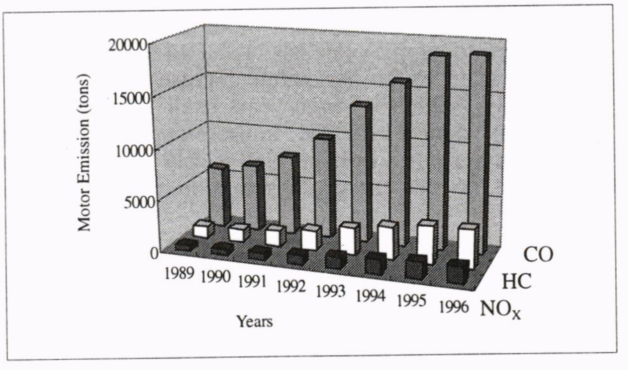

Figure 18. Emissions of Pollutants in Guangzhou City

Air pollution is the contamination of air by the discharge of harmful substances. Air pollution can cause health problems including burning eyes and nose, itchy irritated throat, and breathing problems. Some chemicals found in polluted air can cause cancer, brain and nerve damage, and long-term injury to the lungs and breathing passages in certain circumstances. Air pollution can also damage the environment and property. Trees, lakes, and animals have been harmed by air pollution. Air pollution has thinned the protective ozone layer above the Earth. Air pollution can deteriorate buildings, monuments, statues, and other structures. Air pollution also can result in haze, which reduces visibility in national parks and elsewhere, and can sometimes interfere with aviation. Therefore, the reduction of the air pollution emissions from traffic is important for the sustainable development.

4.2 Waste Emission Analyses

The industrial air and water pollution in China has been major concerns for the past two decades. A recent assessment by the Chinese Research Academy of Environmental Science has identified industrial pollution as the source of approximately 70% of China's total environmental pollution in China. Current estimates of human health damage from urban air pollution are very high for some areas. Such high levels of damage are primarily due to the rapid growth of pollution-intensive industries. The pollution intensity of output in certain key emission categories has dropped sharply since 1985, at least in factories, which are regulated by the environmental agencies. Continued rapid decline in pollution intensity will be necessary just to stay even with the pace of industrial growth. Moreover, recent findings on pollution related health damage suggest that considerable improvement in ambient quality would be necessary. In fact, it is very difficult to face with the simultaneous need to reduce pollution and increase industrial output and employment, especially in the developing regions due to the limitation of the fund, equipment, labor capacity, and technology, and so on.

By taking the advantages of GIS in data visualization and analysis, a waste management system is being under development to study the geographical distribution and relationship of waste emissions. Figure 19 shows the waste water discharged in 1996 in each province of China, which includes waste water from production and domestic sewage. Figure 20 shows the industrial waste gas emission in 1996 in each province of China. The volume of waste gas emission refers to waste gas emitted from burning of fuels and from production process in the area of the factory, and is measured by 1000 standard cubic meters each year under normal condition.

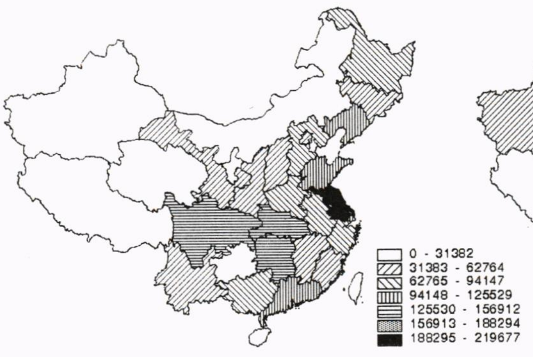

Figure 19. Waste Water Discharged (unit: 10^4 tons)

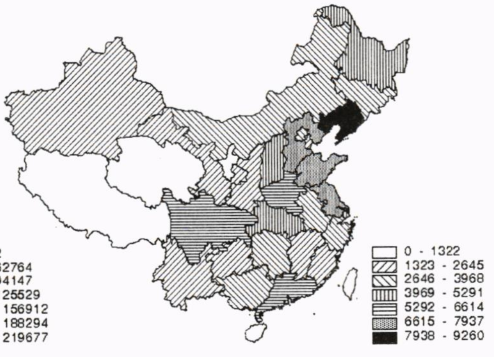

Figure 20. Industrial Waste Gas Emission (unit: 10^8 m^3)

Figure 21 shows the industrial dust emission in 1996. The industrial dust discharged refers to the total weight of solid dust discharged by industrial enterprises in the production process such as dust of refractory materials from iron plants, dust from coke-screening system or from sintering machines of cooking plants, dust from lime kilns, cement dust from building material enterprises, etc., but excluding smoke and dust discharged by power plants. A great deal of dust in the urban area is generated from the construction sites of the civil infrastructures and the particle emissions from motor vehicles.

Figure 22 shows the industrial solid waste produced in each province in China. The volume of industrial solid waste produced refers to the total volume of solid, semi-solid or high concentration liquid residue produced by industrial enterprises in their manufacturing process, including dangerous wastes, residues from melting, slag, powdered coal ash, gangue, chemical residues, tailings, radioactive residues and other residues, but excluding stripped or dug stones in mining.

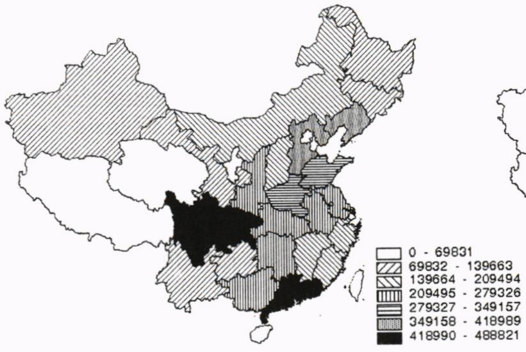

Figure 21. Industrial Dust Emission (unit: ton)

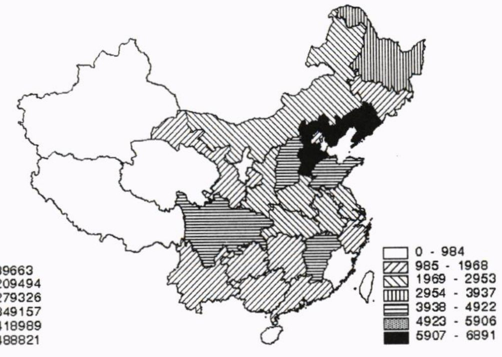

Figure 22. Industrial Solid Waste Produced (unit: 10^4 tons)

4.3 Environmental Complaining and Reparation

The China's cities are far from passive about the environmental performance of neighboring factories. During 1997, the environmental authorities received over 160,000 complaints, mostly related to air, water and noise pollution. Plaintiffs visited provincial and local regulators near 100,000 and sent more than 6700 letters. Figure 23 shows that the propensity to complain in 1996 varies widely across China's provinces. This provincial map of the propensity to complain shows that its geographic distribution is far from randomness. The incidence of complaints is generally highest in the urban and industrial centers of east China; lower in middle provinces and lowest in China's least developed regions, the western hinterlands.

According to the China's Environmental Protection law, it is specified that in case where the discharge of pollutants exceeds the limit set by the state, a compensation fee shall be charged according to the quantities and concentration of the pollutants released. A few areas began experimental implementation of the compensation fee or pollution levy shortly after passage of this law in 1979. In 1982, China's State Council began nationwide implementation by issuing the Provision Regulations for Collection of Compensation Fees for Pollutant Discharge. Almost all China's cities and counties have now implemented the levy system. About 80% of the collected funds in levies have been used to finance industrial pollution prevention and control, accounting for about 15% of total investment in these activities. Figure 24 shows the reparations for pollution accidents.

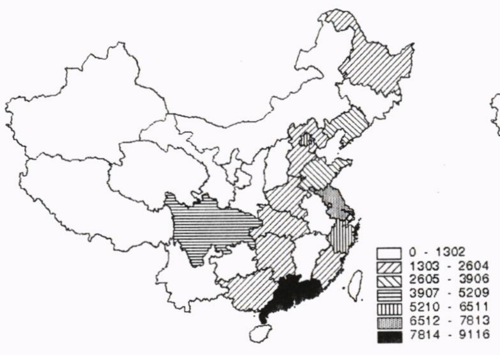

Figure 23. Letters Complaining on Environmental Pollution

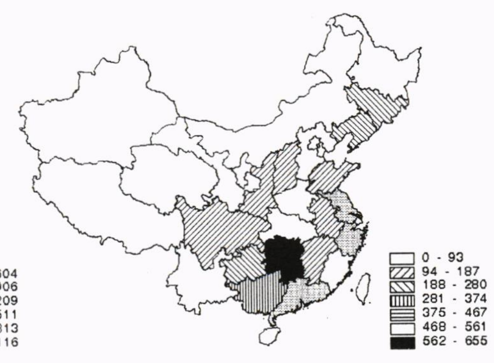

Figure 24. Economic Reparation for Pollution Accidents (unit: Yuan)

5. DISCUSSIONS AND CONCLUSIONS

Sustainable transportation infrastructure development needs the contributions from five basic components: roads, vehicle, fuels, drivers and management system. (1) Roads often bring significant economic and social benefits, but they can also have substantial negative impacts on communities and the natural environment. As we become more aware of these impacts, there is a growing demand for the techniques and skills needed to incorporate environmental considerations into road planning and management. (2) Vehicles powered by new types of energy provide an efficient way for reducing the environmental pollution due to traffics, including the synthesized natural gas vehicles, compressed natural gas vehicles, electric vehicles, hydrogen powered vehicles, hybrid electric vehicles, and solar vehicles. (3) The conventional automotive fuels including gasoline and diesel power more than 98% of the global motor vehicle fleet. Hence, cleaner gasoline and diesel fuels can play a major role in improving air quality. (4) People can contribute significantly to cleaning the air. Especially, drivers can contribute to the reduction of air pollution by making personal changes in driving habits such as to limit driving. Use of public transportation, walk, use of carpools, bike, or so forth can also contribute to the reduction of air pollution. These are the best ways an individual can help reduce air pollution. If they must drive, they had better try to follow some guidelines such as to avoid high speeds, or drive alternative vehicles or alternatively fueled vehicles such as electric vehicles. (5) Some information oriented management technologies are being developed and applied for transportation infrastructure construction management, including the automated highway system, vehicle information and communication system, advanced traffic information system and electronic toll collection, and so on.

The conclusions of this research can be stated as follows:

(1) In Guangdong province of China, more than 20% of annual infrastructure construction investment has been made for the transportation sector. Relative to this high investment rate, the urban population has been increasing for many years and the employment structure has changed with the increase of GDP per capita.

(2) Compared to the developed countries, the traffic accident, traffic congestion and traffic noise are still severe problems and need effective solutions in Guangdong province. The traffic accident fatalities per 1000 vehicles in Guangdong province were as high as 10 times of them in Aichi prefecture of Japan in previous years.

(3) The economic development, transportation infrastructure construction, and vehicle increase change the demand of energy consumption, and then increase the environmental pressure in the air quality and waste emission. In Guangdong province, the efficiency of energy consumption in transportation sector is similar to the manufacturing process, and the local government received more letters complaining on the environmental pollution from the citizen per year than other provinces in China.

(4) The GIS-based management system is an efficient approach for the data visualization and analyses on the infrastructure construction and its induced sustainable development issues according to the regional geographical distribution.

Further comprehensive research is planned to carry out for implementing a GIS-based integrated management system for the sustainable regional traffics, transportation, and infrastructure construction using information technologies.

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