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Foreword

The chair of the Special Interest Group on Global Nonmotorized Transportation, V. Setty Pendakur, issued a call for papers on nonmotorized transportation in the People's Republic of China and in Asia and other areas of the world; he organized several sessions for the TRB annual meeting around these themes. This Record is divided into two parts to represent the fruits of these efforts. From the contents it is evident that nonmotorized transportation is of vital importance in the world transportation picture. It is further evident from the papers in this Record that considerably more attention is being paid and will be paid to nonmotorized transportation in developed and developing countries for reasons of cost, congestion, and the environment.

PART 1

People's Republic of China

Urban Transportation in China: Trends and Issues

V. SETTY PENDAKUR

China's population was 1.1 billion in 1990; it is expected to reach 1.3 billion by 2000. Its urban population was 33 percent in 1990 and is expected to grow to 47 percent by 2000. This enormous urban growth poses tremendous challenges to urban transportation planners. The five megacities—Beijing, Shanghai, Shenyang, Tianjin, and Wuhan—are planning for light rail transit/subway (LRT/MRT) systems that will cost $10 billion to $15 billion (U.S. dollars). However, China does not have the money and will depend on foreign aid and borrowing. Concurrently, planners disagree about the appropriate role of motorized and nonmotorized transportation, especially the bicycle: some wish to abolish, restrict, or redirect it, and others wish to expand its systems role. The global LRT/MRT experience suggests that such systems are expensive and take a long time to build. Forecasting systems for cost and ridership are unreliable: actual costs are more than two or three times the forecast. The urban transportation trends and issues in China are discussed on the basis of a very diverse array of data research sources. The analysis includes mode splits, costs, and reliability functions, and their applicability to Chinese cities. It proposes a strategic planning framework for Chinese urban areas, focusing on optimum modal mixes, investment and regulatory policies, and transportation system management. Although the framework has been developed particularly for China, it is generally applicable to other low-income countries in Asia.

China's population was 1.1 billion in 1990, and it is expected to become 1.3 billion by 2000. In 1990 its gross national product (GNP) was $330 per person (U.S. dollars). Table 1 shows that China had 39 cities with more than 1 million people in 1990; by the year 2000, there will be 46 of them. Of these, 23 will have between 1 million and 2 million people, 18 will have between 2 million and 5 million, and 5—the megacities—will have between 5 million and 17 million (*1*).

TABLE 1 Chinese Agglomerations, 1990–2000 (*1*)

Population	1990		2000	
1-2 Million	23 Metro Cities		23 Metro Cities	
2-5 Million	13 Agglomerations		18 Agglomerations	
	1. Shenyang	(4.8 m)*	1. Guangzhou	(4.8 m)
	2. Wuhan	(3.9 m)	2. Chongqing	(4.2 m)
	3. Guangzhou	(3.7 m)	3. Dalian	(4.1 m)
	4. Chongqing	(3.2 m)	4. Chengdu	(4.1 m)
	5. Chengdu	(3.0 m)	5. Jinan	(4.0 m)
	6. Harbin	(3.0 m)	6. Xian	(4.0 m)
	7. Xian	(2.9 m)	7. Harbin	(3.9 m)
	8. Nanjing	(2.6 m)	8. Nanjing	(3.6 m)
	9. Dalian	(2.5 m)	9. Changchun	(3.1 m)
	10. Zi Bo	(2.5 m)	10. Taiyuan	(3.0 m)
	11. Jinan	(2.4 m)	11. Zi Bo	(2.7 m)
	12. Changchun	(2.2 m)	12. Zhengzhou	(2.4 m)
	13. Taiyuan	(2.2 m)	13. Kunming	(2.3 m)
			14. Guiyang	(2.2 m)
			15. Urumqi	(2.1 m)
			16. Tangshan	(2.1 m)
			17. Lanzhou	(2.0 m)
			18. Nanchang	(2.0 m)
>5 Million	3 Mega Cities		5 Mega Cities	
	1. Shanghai	(13.4 m)	1. Shanghai	(17.0 m)
	2. Beijing	(10.8 m)	2. Beijing	(14.0 m)
	3. Tianjin	(9.4 m)	3. Tianjin	(12.8 m)
			4. Shenyang	(6.3 m)
			5. Wuhan	(5.3 m)

NOTE: m = million

URBAN QUALITY OF LIVING

Population Crisis Committee has measured the quality of living in the world's 100 largest metropolitan cities, whose populations range from 2 million to 29 million; 35 of these cities were in Asia (*2*). The livability index consists of the following components, each category having equal weight:

- Public safety,
- Food costs,
- Living space,
- Housing standards,
- Communications,
- Education,
- Public health,
- Peace and quiet,
- Traffic flow, and
- Air quality and pollution.

There may be some disagreement as to the relative weight of each component of the index, but the methodology is reasonably scientific in assessing a very complex question. Three components are important to transportation planners: ambient noise levels, traffic flow (average peak-hour traffic speeds in kilometers per hour), and air quality (air pollution measured in levels of suspended particulate matter, sulphur dioxide, and nitrogen oxide exceeding health thresholds defined by the World Health Organization).

Chinese megacities fared well in this analysis, as shown in Table 2. Out of 100 points, Shanghai scored 56, Beijing scored 55, Harbin scored 52, and Tianjin and Wuhan scored 51.

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TABLE 2 Urban Living Standards in Large Metropolitan Cities in China, 1990 (*1,2*)

City	Shanghai	Beijing	Tianjin	Shenyang	Wuhan	Guangzhou	Chongqing	Harbin	Nanjing
1990 Population in Million	13.4	10.8	9.4	4.8	3.9	3.7	3.2	3.0	2.6
Urban Living Standards Score	56	55	51	42	51	42	48	52	49
Levels of Ambient Noise (1-10)	5	4	5	6	6	6	7	5	5
Peace & Quiet Score (1-10) *	6	7	6	5	5	5	5	6	3
Traffic flow: Km/h in Rush Hour	24	41	32	26	45	30	40	42	27
Score (1-10)	3	6	4	3	7	4	5	6	3
Clean Air: Alternate Pollution Measures	16 days SO_2	272 days SPM	1900 ppm O_3	146 days SO_2	-	123 days SPM	-	-	-
Score (1-10)	7	1	5	1	-	2	-	-	-

* The Best Condition Is Score 10

Following closely were Nanjing with 49, Chongquin with 48, and Guangzhou and Shenyang with 42 each. It appears that livability index is inversely proportional to motorized traffic. Shanghai, Beijing, Harbin, Tianjin, and Wuhan have less motorized traffic and higher livability indexes than Guangzhou and Shenyang, which have substantially higher proportions of motorized traffic.

The peak-hour traffic moved at 32 to 42 km/hr in Beijing, Chongquin, Harbin, Tianjin, and Wuhan, whereas it moved at 24 to 32 km/hr in Guangzhou, Nanjing, Shanghai, and Shenyang. Air quality was the worst in Beijing and Shenyang, followed by Guangzhou and Tianjin.

URBAN TRANSPORTATION IN SELECTED CITIES

Background

The principal urban transportation modes in China are buses, trolley buses, street cars, subways, bicycles, and walking. China is the "Bicycle Kingdom." There were 300 million bicycles in 1985 but only 1.2 million cars. In 1987 China produced 41 million bicycles; the global production of bicycles was about 99 million (*3*).

In 1985 the 225 big and medium-sized cities of China had 65 million bicycles. Bicycle ownership grew 7 percent in the 1960s, 9 percent in the 1970s, and 20 percent in the 1980s. This growth has occurred with government's inability to provide adequate public transport (buses). Low personal incomes and the desire for higher mobility have produced fairly high growth rates of bicycle ownership (*4*).

Ownership of private cars and motorcycles is far beyond the means of almost all people in China. Therefore, the desire for higher personal mobility leaves them with only two options: bicycle or bus. Bus fleets have not grown consistently with population growth. During the past 20 years, increases in discretionary incomes have been accompanied by substantial increases in bicycle ownership. For example, in 1987 there was 0.6 bicycle per person in Beijing (*4*).

There were 48,000 buses and trolley buses in 322 cities in China in 1988, compared with 42,000 in 1987. These bus systems carried 24.0 billion people in 1987 and 26.8 billion in 1987. This ridership is small compared with the population base of 1.1 billion people. However, Shimazaki and Yang show in another paper in this Record that the average passenger density was 10 to 13 people per square meter in peak hours, which indicates tremendous overloading.

Shanghai had 4,600 buses, Beijing 3,000, Tianjin 1,400, and Guangzhou 1,800. This is quite low in comparison to western countries and many Asian cities. For example, Shanghai had 3.4 buses per 10,000 people, Beijing 2.8, Tianjin 1.5, and Guangzhou 4.9 (*5*).

Bicycle production increased rapidly from 13 million in 1980 to 29 million in 1984 and to 41 million in 1988. It accounted for 5 billion yuan in 1984, about 0.5 percent of the GNP. According to Shimazaki and Yang, the average cost of private vehicles in 1990 was as follows:

Vehicle	*Cost (yuan)*
Bicycle	200 to 400
Motorcycle	3,000 to 15,000
Car	80,000 to 200,000

The easy availability of locally made bicycles combined with their reasonable cost makes them an attractive transport investment. For example, in Shanghai the average household income in 1989 was 397 yuan and the expected savings were 41 yuan per month. The cost of the cheapest bicycle is 200 yuan, or 5 months' household savings (X. Lu, unpublished data, 1991). Many households own more than one bicycle.

Because the public transit system was inadequate and the government did not wish to have any more citizens waiting for hours indefinitely, in 1978 it canceled the bicycle registration tax and introduced a subsidy of 2 to 4 yuan per month for those people who rode their bicycles to work. Therefore, workers who used bicycles could receive a yearly subsidy of 24 to 28 yuan (*4*). Assuming a bicycle can be used for at least 20 years, the subsidy amounts to 480 to 960 yuan. Even at current rates, this is equivalent to 1.5 to 3 bicycles. This has encouraged bicycle ownership. In Beijing in 1986, 84 percent of the households had at least one bicycle and 52 percent had two or more. Fifty-four percent of people in Beijing ride bicycles regularly, and 78 percent of the total daily person trips are by bicycle (*4*).

Many bicycle repair shops are scattered throughout the urban areas. Parts are manufactured locally, without any import content. It is very easy to replace parts and to repair and

maintain bicycles. Renting bicycles in China is also easy. The rental shops lease bicycles by the hour, by the day, and by the month. The rental rates are 0.2 to 0.3 yuan per hour and 0.3 to 0.5 yuan per day (X. Lu, unpublished data, 1991).

All bicycles are required to be registered and carry license plates. It is nearly impossible to steal a bicycle or to sell a stolen bicycle. Because all citizens carry identification at all times, bicycle renting and parking is done with proper identification.

Bicycle travel speeds in major urban areas were reported to be 13 to 18 km/hr during the morning peak hour and 10 to 13 km/hr in the afternoon peak hour. Average bicycle trip length was 9 km for men and 5 km for women. Although bicycle parking space is scarce in some areas of larger cities, bicycle parking is not a serious problem in China (X. Lu, unpublished data, 1991). Waiting time has increased considerably during the past decade. If door-to-door travel times are considered (walking, waiting, and travel times), bicycle travel is often more efficient than bus transport (*6*).

Shanghai

Shanghai is the largest metropolis in China. It is also the administration center for the largest special economic zone, covering five provinces. In 1990 Shanghai had 13.4 million people, a number that is expected to grow to 17 million by 2000. Shanghai has more than 10,000 industrial enterprises and accounted for 6 percent of the national GNP. Heavy industry (cars, aircraft, petrochemicals, electronics, and power) accounts for 60 percent of its economic base. It has 200 scientific research institutions and 49 colleges and universities. Downtown Shanghai is the busiest shopping area in China (*6*).

Several researchers have reported on transportation modes and changes in Shanghai during 1981–1991, as shown in Table 3 (*4–10*). The share of public transit has decreased from 28 percent in 1982 to 24 percent in 1989. This is attributed to both the nonincrease in bus transport supply and the resultant increase in waiting times. Travel modes in 1989 were as follows (*7*):

Mode	*Percentage*
Walk	41
Bicycle	31
Bus	24
Other	4

According to Lam and Huang in another paper in this Record, buses and trolley buses carried 1.4 million passengers during the morning peak hour and 10 million on an average day in 1982. In 1987, they carried 10.9 million passengers a day (*6*). Bus operating speeds on major arterials have decreased slightly despite more signalization. The average operating speeds were 14 to 16 km/hr in 1980 and 11 to 14 km/hr in 1986 (*6*).

Before 1985 motorcycle ownership was frowned on. There were 2,900 motorcycles in 1978 and 16,000 in 1985. Even then, all motorized transportation (car, motorcycle, and taxi) carried only 1 percent of the total travel in 1982, growing to only 4 percent by 1989.

Bicycle population has grown considerably during the past two decades. For every 1,000 persons there were 105 bicycles in 1970 and 546 bicycles in 1990. During the same period, buses per 1,000 persons have decreased (*7,10*).

The average speed in 1985 for bicycles was 13 km/hr; for trolley buses, 15 km/hr; and for buses, 17 km/hr (X. Lu, unpublished data, 1991). In 1990 the peak-hour motorized traffic moved at 24 km/hr (*2*). There were 63 fatalities per 1,000 vehicles in Shanghai in 1985; the national average was 99 fatalities per 1,000 vehicles (Lam and Huang).

Part of Shanghai's first subway (MRT) line, estimated to cost $2 billion to $3 billion (U.S. dollars), is expected to open in 1995. To complete the entire system may take 20 years because of financial constraints (*6,7*).

TABLE 3 Travel Modes in Metropolitan Cities in China

City	Reference	Year	Share of Total Person Trips %				
			Walk	Bicycle	Bus	Others	Total
Shanghai	Shi, 1989	1982	58	13	28	1	100
	Midgley, 1991	1986	38	33	26	3	100
	Replogle, 1991	1986	38	33	26	3	100
	Powills, 1989	1986	41	31	24	4	100
	Shimazaki, 1991	1986	37	25	35	3	100
	Xuedong, 1991	1989	41	31	24	4	100
Beijing	Shi, 1989	1986	14	54	29	3	100
Tianjin	Zhao, 1987	1981	45	44	9	2	100
	Shi, 1989	1987	43	45	10	2	100
	Thornhill, 1990	1987	50	41	9	Negl.	100
Guangzhou	World Bank, 1991	1986	38	30	28	4	100

Beijing

Beijing had 10.8 million people in 1990 and is expected to reach 14 million by 2000. There are two underground railway lines in Beijing—the first, a 24-km line, was completed in 1969 and the other, a 16-km line, was completed in 1984. Together, they carried 500,000 passengers a day in 1991 (*11*). There were 3,000 buses and 600 trolleys in 1987 carrying 5.5 million passengers a day (*5*). Since then the bus fleet has shrunk because of aging and nonreplacement. In 1985, out of 280,000 motor vehicles, 260,000 were cars, jeeps, or trucks.

The bicycle is the dominant mode of transport in Beijing. In 1986, 54 percent of all trips were by bicycle, 29 percent by bus, 14 percent by walking, and 3 percent by motorized vehicle, as shown in Table 3. Fifty-seven percent of all trips were work trips, 27 percent were recreational, and 16 percent were cultural. Eighty-four percent of all households had at least one bicycle, 32 percent had two bicycles, 13 percent had three bicycles, and 6 percent had four or more bicycles (*4*).

The bicycle population grew rapidly in the 1980s. In 1978 there were 2.8 million bicycles, which increased to 3.0 million in 1980, 6.8 million in 1987, and 8.0 million in 1990 (*4*). In 1989 three of the busiest intersections were each handling more than 50,000 bicycles an hour (*4*). The average motor

vehicle speeds on Changan Street, the widest street in Beijing, were 35 km/hr in 1959, 30 km/hr in 1979, and 24 km/hr in 1980 (X. Lu, unpublished data, 1991). This is the most congested condition in Beijing.

Lam and Huang report that there were 45 fatalities per 1,000 motor vehicles in Beijing. In 1987 there were 8,134 reported accidents in Beijing. Of these, 1,975 were caused by bicycle traffic, 24 percent of the total. The fatality rate of bicycle traffic accidents was 1.7 deaths per 10,000 people, or 2.5 deaths for every 100,000 bicycles.

Recently, an automatic traffic control (ATC) system covering 92 signalized intersections in the central business district (CBD) has been put into operation. This system is estimated to have increased the intersection capacity by 20 percent. By 1993 another 250 intersections will be connected to the ATC system (*11*).

Tianjin

Tianjin had 9.4 million people in 1990 and is expected to have 12.7 million by 2000 (*1*). During the past decade, Tianjin has experienced continuing explosive growth of its industrial output, housing stock, and bus fleet, all increasing by 70 percent between 1980 and 1988 (*12*). In 1982 there were only 73,000 motor vehicles, which grew to 90,000 by 1990. These are primarily government vehicles, because private motor vehicles are rarely allowed.

In 1950 Tianjin had 14,000 bicycles and 2.4 million people; by 1980 it had 2.7 million bicycles and 7.3 million people. By 1990 there were 4 million bicycles and 9.4 million people. Because of the compactness of the metropolitan area and the predominance of bicycle transportation, Tianjin devotes only 4.8 percent of its land area to its streets and roads (*9*). In contrast, large cities use 35 percent of North America's land area for streets and roads.

Tianjin's bus fleet had 1,400 buses/trolleys in 1990 and the system carried 1.6 million passengers a day. It also has a small underground railway system, which carries only 30,000 passengers a day. The public transit system is relatively small: there is only one bus per 6,714 persons (*6*).

In 1990 the average work trip was about 45 min (*9*). At Bell Square (CBD) in Tianjin, the average traffic speeds decreased from 18 km/hr in 1983 to 11 km/hr in 1989 (*5*).

Severe congestion often persists longer than 30 min, limiting traffic flow to less than 5 km/hr. Average motor vehicle speed is approximately 16 km/hr in the central city and less than 10 km/hr in the more-congested areas. Investment in public transportation has decreased in Tianjin, from 3.6 percent of total capital construction investment in the 1950s to 0.5 percent during the 1970s. There are indications that this trend continued during the 1980s (*13*).

The quality of Tianjin's public transit service is the lowest of all major Chinese cities (*13*). Because of very narrow streets, several areas are not served by the bus system. Although the waiting times at bus stops can be as high as 45 min, walking to bus stops takes only 8 min. Peak-hour bus speeds are very low, about 11 km/hr. Bicycles often form a "wall" in front of buses at many intersections, gaining efficiency and speed for themselves (X. Lu, unpublished data, 1991).

Table 3 shows that in 1987, 50 percent of all trips were by walking, 41 percent by bicycle, and only 9 percent by public transit (*12*). Car and motorcycle trips were negligible. Walking trips increased from 1981 to 1987.

Tianjin is an old city containing many narrow and winding roads. The average road has a paved width of less than 9 m. This historical city has many bottlenecks and dead ends. Traffic flow in the central area is further inhibited by street vendors. Severe congestion often persists in the CBD, reducing motorized traffic flow to less than 5 km/hr.

Guangzhou

Guangzhou is one of the 14 open cities of China. It is also the nation's gateway to foreign trade and international interaction, as well as a transport and administrative center of south China, with strong ties to Hong Kong. Its urban pattern is broadly a combination of three linear clusters: old city, Tianhe, and Huangpu. In 1990 Guangzhou had 3.7 million people; its population is forecast to reach 4.8 million by 2000 (*1*).

From 1980 to 1990, its population increased from 3.0 million to 3.7 million (23 percent) and the number of bicycles increased from 1.0 million to 2.2 million (112 percent). Reflecting high economic growth during the 1980s as well as the open door policy, motor vehicles increased from 21,000 to 115,000, a growth of 448 percent. Private cars also increased significantly from 6,000 to 53,000 (783 percent). Private cars will increase but not necessarily at the previous geometric rates. According to Thomas et al. in another paper in this Record, reliable forecasts indicate that there will be 109,000 private cars and 3.5 million bicycles by 2000. Because of this enormous growth, conflicts between motorized and nonmotorized transportation will also increase.

Public transit carries 1.1 million trips daily: 69 percent by bus, 10.8 percent by ferry, 10 percent by trolley bus, and 0.2 percent by taxi. There was a bus or trolley for every 2,623 persons and a taxi for every 460 persons. The capacity gap for the morning peak-hour bus system is 130,000 people; this leads to overcrowding of up to 12 persons per square meter aboard the buses (*14*).

Table 3 shows transportation modes in 1986 (*5*). Bicycle and walking together accounted for 68 percent.

In 1984, 64 percent of freight was moved by road, 28 percent by water, and 8 percent by rail. In passenger movement, road transportation was even more important, carrying 72 percent of a total of 50 million trips; rail carried 16 percent, water carried 10 percent, and domestic air carried 2 percent. In 1990 Guangzhou had 1.1 billion passenger trips a year (*14*).

Traffic accidents have increased substantially, parallel to the growth in vehicle population, conflict between motorized and nonmotorized vehicles, and congestion. The number of reported accidents increased from 650 in 1971 to 1,800 in 1980 and to 4,200 in 1990. Thomas et al. report that fatalities increased from 75 in 1971 to 120 in 1980 and to 300 in 1990.

URBAN TRANSPORTATION POLICY PERSPECTIVES

Policy System and Research Findings

For the short term of 1991–2000, common or universal private ownership of cars, as it is in North America and Europe, is

probably beyond the means of almost all Chinese households (*4,6,7,9,10,13,15,16*). Cars will be owned mostly by governments and their enterprises, except in cities such as Guangzhou, Shenzhen, and Canton in southern Canton because of their special economic status and the open door policy. According to the paper by Thomas et al., in 1990 Guangzhou had the highest car ownership of all Chinese cities: 53,000 (one car per 70 people), which is expected to reach 109,000 by 2000 (one car per 44 people).

Because of the relatively low income of most people in China, bicycles are still the most popular alternative to walking and public transit (*15*). China's economic, energy, and living conditions will make it virtually impossible for individuals to own and operate private automobiles within the next 20 to 30 years (*13*). For most people, this means primarily three modes: riding the bus, bicycling, and walking.

Researchers disagree about why there is congestion now and what policies should be pursued. There is a dichotomy of conceptual and technical approaches to the current and future roles of the bicycle. As well, there are divergent views on what to do with public transit—bus and light rail transit (LRT)/MRT. By and large, Chinese authors would like to reduce, restrict, or remove the use of bicycles to general or specific areas or specific times. But others advocate accommodating the bicycle even more.

The policy analysis to date is somewhat confusing. All authors acknowledge that bicycles are very important: they are energy-efficient and pollute less, and they are universally available, economical, and versatile for all age groups (*3,4,6,7,9,13*). However, further policy extrapolation is riddled with inconsistencies and contradictions.

Zhao, while acknowledging the predominance of bicycles in Tianjin, states that the growth of bicycles has created many system-level transportation problems. He asserts that the transportation problems in Tianjin result from the inability of transportation planners to restrict the growth of bicycles. He suggests that if the bicycle transportation is allowed to develop unrestricted, the state of urban transportation will worsen (*11*).

Yang recognizes that bicycles are a very important means of urban transport in China, but he suggests that too many bicycles can cause problems. His main concern is that large bicycle volumes spill over to motor vehicle lanes, causing motor vehicle speeds to decrease and making motor vehicles wait longer at intersections (*13*).

Shimazaki suggests that too much bicycle use harms urban transit systems. He suggests heavy bicycle traffic causes inefficient use of road space and reduces motor vehicle speeds. At the same time, he acknowledges the importance of the bicycle within the system and suggests its incorporation with other modes.

Powills and Shen have documented clearly the ways in which Chinese professionals view bicycles. They state that some people argue that bicycles are ubiquitous and uncontrollable, that they are a nuisance cluttering the streets, that they are parked everywhere, and that their users tend not to obey the law and therefore their numbers ought to be diminished. Buses are more efficient, subways move more people faster, and bus/motor vehicle modes will better solve the problems of urban transit by serving longer trips. Furthermore, China must move into "more modern urban transport" (*7*).

Bicycles are considered by many in China to be archaic, inefficient symbols of backwardness—things that will give way to motor vehicles sooner or later (*16*). These are strongly held philosophical views of many Chinese professionals that lead them to extrapolate various conclusions. For example, Chen has reported that in Shanghai, the bicycle is considered to be the principal cause of the noticeable decline in public transit market share that has occurred in recent years and of the concurrent rise in the level of traffic congestion on many streets in Shanghai (*15*).

Many experts are concerned with the increasing use of bicycles. Lu has reported that the government recently published several policies to restrict the use of bicycles: to build bus-only roads and to forbid bicycles on such roads, to impose and increase bicycle registration (license) fees, and to charge an ownership tax (*6*). These policies are being slowly implemented selectively but without providing alternative transportation options to bicycle users. Some experts believe that if the bicycle is allowed to develop unrestricted, the state of urban transportation in China will worsen (*13*).

Other researchers have documented the positive aspects of bicycle use. Its energy-efficiency, total lack of dependency on foreign inputs (vehicles, parts, and repairs), economic and competitive pricing, availability within easy reach of low-income households, and versatility have all been very well documented (*3,6–10,12,16*). Lowe has advocated the adoption of the bicycle as "the vehicle for a small planet" (*3*). She has also prepared policy spectrums to reduce automobile dependence (*17*). Powills and Shen have gone further to suggest traffic control, channelization, and traffic segregation methodologies for accommodating bicycles in traffic engineering practice (*7*).

Some researchers have attributed traffic congestion, deteriorating bus systems, and decreased safety to the increasing number and use of bicycles (*12,13,15*). Only a few have pointed to the lack of required investment in public transportation systems (*7,10,17*). Extensive work by Midgley shows that the bus systems in China are inadequate and that new investment is not forthcoming (*9*). For example, if only 50 percent of the current bicycle users were to shift to the bus, Shanghai alone would require 800 to 1,200 more buses (*6*). Current policy appears to place the highest priority on increasing the bus system capacity and increasing its market share (*18*). However, this has not resulted in any significant urban bus system expansions (*14*). The availability of public transit is quite inadequate and service levels are very low; the lowest level among big cities is in Tianjin (*11*).

The sheer volume of people using the system during the peak hours is staggering. The systems are overcrowded and the service is poor. They have lagged behind for many years. As a result of severe overcrowding, many commuters avoid the buses and go by bicycle, even for long trips (*13*). Walking times are long because bus stops generally are spaced 1 km apart. Waiting time in Shanghai varies from 20 to 45 min, making walking and bicycling more efficient and economic (*7*). Commuters are optimizing their costs and benefits by walking and riding bicycles.

Private ownership of motorcycles and mopeds is restricted but possible. Motorcycles are becoming more common in large cities. Though restricted, the increasing number of motorcycles in Shanghai is attributed to the ingenuity of the local people to register them to a non-Shanghai address (*8*). However, motorcycles and cars together account for only 2 to 3 percent of all person trips.

Several studies have proposed LRT/MRT systems for megacities. Shanghai's new MRT system is to open for service in 1995. The entire system may take 20 years to complete (*6*). Guangzhou is hoping to start construction in 1993, subject only to the availability of $2 billion to $4 billion (U.S. dollars) from foreign sources, according to Thomas et al. in this Record. Plans are afoot to build LRT/MRT systems in all the megacities, but the funding must come from foreign sources. Even then, to complete these systems may take 15 to 30 years.

The urban transportation situation can be summarized as follows:

1. All cities want to build LRT/MRT systems, but there is no money;
2. The existing bus systems are inadequate and inefficient;
3. People use bicycles because they are efficient and economic;
4. Many people walk; and
5. The government wants to reduce, restrict, or abolish the use of bicycles in heavily traveled corridors.

Urban Transportation Policy Options

LRT/MRT systems are very large lump-sum investments requiring technology, equipment, parts, and training from the Organization for Economic Cooperation and Development (OECD) countries. None of the LRT/MRT systems in the low-income countries has been built without direct or indirect heavy subsidies from the western donor countries or lending and aid institutions (Manila, Calcutta, and Shanghai). For example, the proposed Lavalin LRT line in Bangkok, though justified as economically self-sustaining, will be indirectly subsidized with $400 million to $500 million (U.S. dollars) from the Canadian government and with $300 million to $400 million (U.S. dollars) from the Thai government through land use rights and tax holidays. Therefore, any question of rigorous benefit/cost analysis and user cost recovery analysis becomes irrelevant (*19*). China is no exception to these conditions or the political rules of the international aid game.

Most of the money and technology (both material and intellectual) required to build the LRT/MRT systems in Asia comes from the OECD countries. Pickrell's analysis of several LRT/MRT systems in North America indicates that LRT/MRT cost and passenger forecasts have been unreliable. Actual capital costs were 200 to 800 percent of the forecasts, operating expenses up to 200 percent higher, and passenger volumes only 15 to 72 percent of the forecasts (*20*). This is a dismal record. Thus, the same margins of error would apply to LRT/MRT systems to be built in China, because donor countries will insist that the feasibility studies be done by donor-country nationals or firms.

Kain's studies show clearly that, on the basis of cost per passenger capacity, exclusive grade-separated busways are substantially cheaper than LRT/MRT systems. For example, the Miami, Florida, busway system, which carries 200,000 passengers a day, cost $1.2 billion; the Ottawa, Canada, grade-separated exclusive busway system carries 200,000 passengers a day, and it cost only $190 million (*21*). In most cases, and until very heavy load factors are reached, busway/transitway systems are economically more efficient.

The generalized empiric reliability functions are shown in Figure 1. In general, in areas that require population, land use and economic base forecasting (trip generation, modal split, capital costs), the reliability functions are the low end. At the high end are maintenance costs, safety, traffic control,

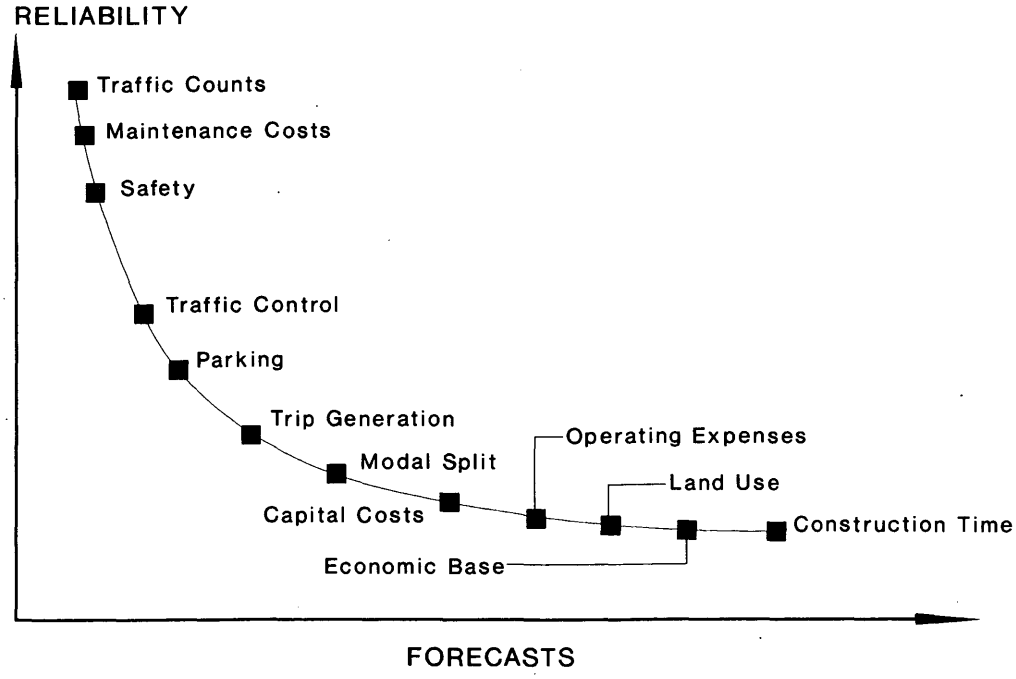

FIGURE 1 Reliability functions.

and parking. Land use and economic development are primarily government activities. Coordination should come easier. But the evidence is to the contrary.

Incomes in China are very low, and any effort at serious user cost recovery is quite complex. However, we can expect very large passenger volumes as long as the fares are kept low. Revenue prediction should be a little more reliable.

It appears, therefore, that

1. Unless there is a massive infusion of foreign aid, the LRT/MRT systems in China are unlikely to be built within 5 to 15 years.
2. Even if funded, the time required to complete the LRT/MRT systems will most likely be about 10 to 30 years.
3. Equal capacity exclusive busways are more cost-effective and may take only 10 to 15 years to complete.

So what do we do in the meantime?

Transportation planning strategies, for Chinese cities, will differ depending on city size, trip lengths, corridor volumes, economic base, and individual discretionary incomes. There is adequate evidence to show that motorization has much to do with discretionary incomes and government regulations on their availability and purchase. Furthermore, bicycle and walking trips are related to incomes, trip lengths, city size, and the level and cost of public transit service (*22,23*). These strategies will also differ from the short term to the long term. Barret's studies have shown that the long- and short-term strategies will be different in the developing and the developed countries (*24*).

LRT/MRT should be provided for, but the transportation system management strategies should dominate planning with appropriate choices of modal mix for various population groups and 5- to 15-year horizons. These should also include non-transport methods (urban planning) to reduce trips, trip lengths, and energy-efficiency and to retain environment-friendly transportation systems. A generalized model is shown in Figure 2. Even though this model has been developed specifically for China, it is generally applicable to low-income countries.

The large volume of bicycle and walking trips will remain for at least 5 to 15 years in China. The strategy should be to accommodate these modes efficiently while making new investments in bus fleets (over 5 to 10 years) to cater to unsatisfied pent-up demand and to growth in demand. It is likely that applying very simplistic draconian measures to restrict bicycle and pedestrian modes in China without sufficiently comfortable and cheap alternatives will fail in practice.

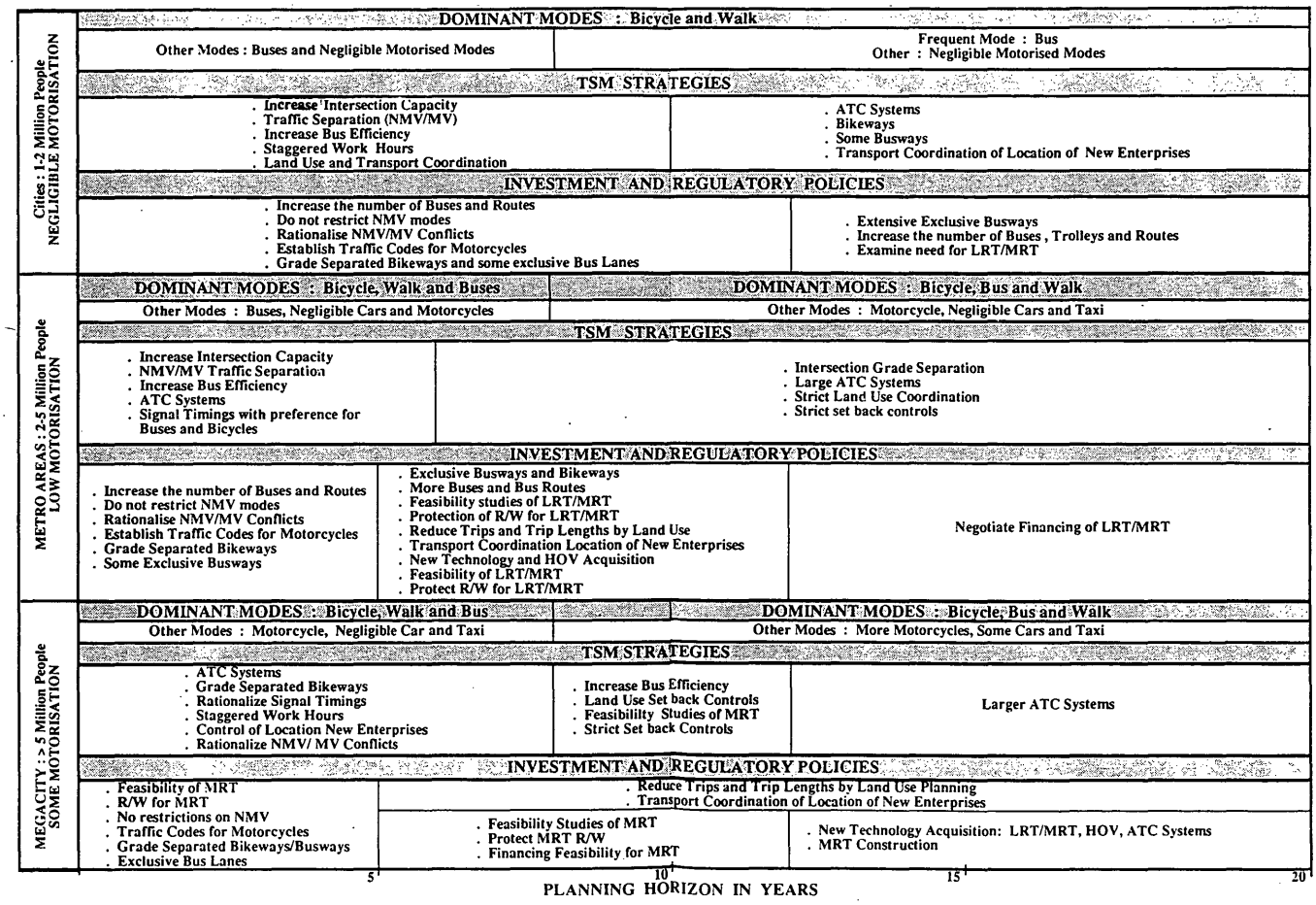

FIGURE 2 Urban transportation planning strategies in China.

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Urban Transportation Planning and Traffic Management in China

WILLIAM H. K. LAM AND HAI-JUN HUANG

As traffic congestion in Chinese cities worsens with the growing use of motor vehicles and the increasing conflicts between motorized and nonmotorized modes on the roads, economists, planners, and politicians throughout the country pay more attention to traffic management and transportation planning. It is noteworthy that although many alternatives have been suggested for expanding the transportation system and various measures have been investigated for discouraging bicycle use, very few of them have been put into practice. This testifies to the extreme difficulties of regulating nonmotorized transportation in China; the recommended plans might not be compatible with the financial resources of the community. The range of possible traffic management and transportation modeling techniques suitable for Chinese conditions is reviewed. These techniques mainly include land use and transportation planning, travel demand forecasting, signalized junction design, and area traffic control systems. The applicability of these techniques in China is discussed, and those currently used in Beijing and Shenzhen are summarized.

Good transportation planning by itself will not solve most of the urban congestion problems in China. Appropriate traffic management schemes will be required to harness the advantages of measures that offer the best solutions to the anticipated transportation problems while minimizing their adverse effects. Transportation planning methodologies and traffic management measures in developing countries differ from those in countries with the most advanced economies. It is therefore desirable to develop a basic list of development priorities based on transportation planning and traffic management techniques appropriate to different contexts in China. The essential parts of such a technique include the development of the following:

- Methods for devising alternative plans and development programs on the basis of an optimization analysis of land use and transportation systems.
- Simple methods of forecasting future travel demand, which should not require complex data bases and extensive surveys.
- Computer-aided design of signalized junctions and of area traffic control (ATCs) systems, particularly when experienced traffic engineers are scarce.
- Acceptable and effective measures that would alleviate the problems of heavy pedestrian flows and minimize the conflicts between bicycles and motorized vehicles.

Some of these techniques can possibly be adapted from existing procedures in Hong Kong, but caution must be given to the cultural and political differences between China and Hong Kong. Emphasis should be placed on encouraging simplicity, minimizing the manpower invested, and tailoring the efforts to the travel environment of China. This paper examines the range of possible transportation planning methodologies and traffic management techniques suitable for conditions in China. The applicability of these techniques to China is discussed.

First, the urban transportation problems and the planned solutions are briefly reviewed so as to give the background of the unique traffic characteristics in China. Two Chinese cities have been selected for discussion: Beijing and Shenzhen. Their locations are shown in Figure 1. This review is followed by investigations of different transportation planning and traffic management techniques appropriate for China, especially those with Hong Kong "connections." Finally, the techniques currently used in Beijing and Shenzhen are summarized.

BEIJING

Beijing is an ancient city that is more than 1,000 years old. It was the capital of many dynasties, including the Liao, Jin, Yuan, Ming, and Qing dynasties, up to the People's Republic of China.

The Beijing metropolis has a total area of 16 800 km^2. The city is divided into 19 districts, and the total population is more than 10 million. The population of the Beijing urban area is about 6.2 million; the urban area tapes up only 2700 km^2, and the built-up areas take up about 400 km^2.

Zheng has reviewed the transportation network in Beijing, in which the total length of roads in the Beijing urban area exceeds 3000 km and covers 27 million m^2 (*1*). The roads in the center alone account for 780 km in length, covering 6.9 million m^2. Figure 2 illustrates the main road system of Beijing, in which three road categories are classified, namely, main trunk routes (including axis routes, ring routes, through routes, and radial routes, for a total length of 640 km), secondary trunk routes (i.e., the main roads in the districts, for a total length of 490 km), and local roads in small districts (about 560 km). There are 40 grade-separated interchanges.

Beijing has a large population of bicycles, and pedestrians are extremely crowded on the streets. With the rapid increase in bicycle use and the continuous growth in vehicular traffic, it is necessary to separate pedestrians from vehicles and fast-moving vehicles from slow-moving bicycles. At present there are about 400,000 motor vehicles and 7 million bicycles in Beijing.

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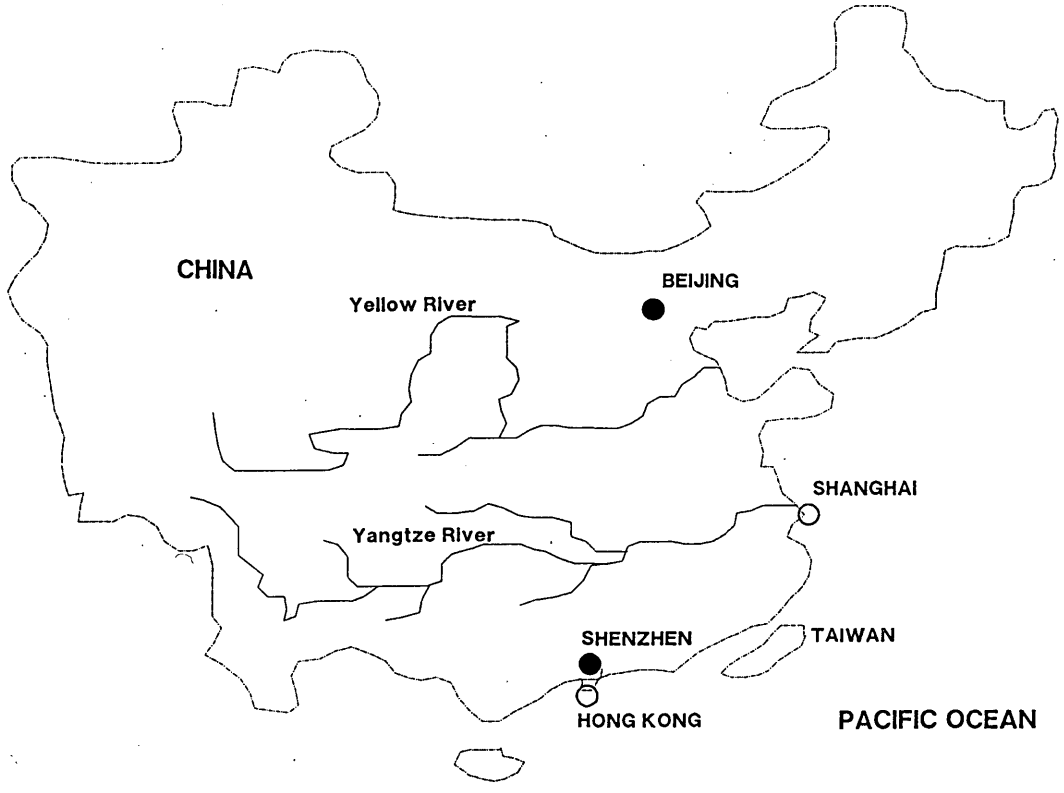

FIGURE 1 Locations of Beijing and Shenzhen.

By the end of 1991, there were two underground railway lines in the Beijing urban area; their total length is only 40 km. The first line is a straight line from Fuxingmen to Shijingshan. The second line is a circle line under the second Ring Road. The two lines carry more than 1 million passengers a day.

The long-term plan for the underground railway network of Beijing consists of eight lines. Three straight lines run from north to south. One line runs northwest, crosses the center of Beijing, and then runs to the northeast. One line runs from the southwest, crosses the center area, and then runs to the southeast. The final one is a circle line under the third Ring Road. According to the long-term plan, the total length of the Beijing underground railway will be 250 km. In view of the long-term planning in Beijing, a systematic planning approach would be required for determining the development strategy for the next decade.

Land Use and Transportation Planning

The newly developed areas of Beijing are more than 10 times the size of the old city district. With the continuous expansion in the developing areas, attention has been given to land use and transportation planning. In the middle of 1990, a team of planners and engineers from Beijing came to Hong Kong to learn the Land Use and Transport Optimization (LUTO) model that is being used for strategic planning in Hong Kong (*2*). The LUTO model is a computer analysis system that enables the simultaneous selection of land development areas and new transportation links by optimizing an objective function consisting of land development costs and transportation costs, as conceptualized in Figure 3.

However, the transportation planning process should be based on community development goals and objectives. The recommended plans must be compatible with the financial resources of the community. Taking these into account, the LUTO model has been applied to the developing areas in Beijing so as to determine the road and railway development programs and the preferred land use plans. Nine tasks have been completed for setting up Beijing's LUTO model:

1. Analyze past trends of investment in the development of Beijing and identify the likely investment from now to 2010.
2. Collate and review all development plans and proposals, including all committed major development works and potential new links.
3. Derive additional population in Beijing to be rehoused by 2010 and set up a land cost model.
4. Collate socioeconomic data required for calibration of and forecasting with the travel demand model.
5. Calibrate the travel demand model and build the transportation networks such as road, bike, public transit, and rail networks.
6. Set up the maximum networks and infer the likely transportation management policy (control of bikes, truck routes, and public transit fares).
7. Develop a cost model of the potential new roads and the proposed railway lines.

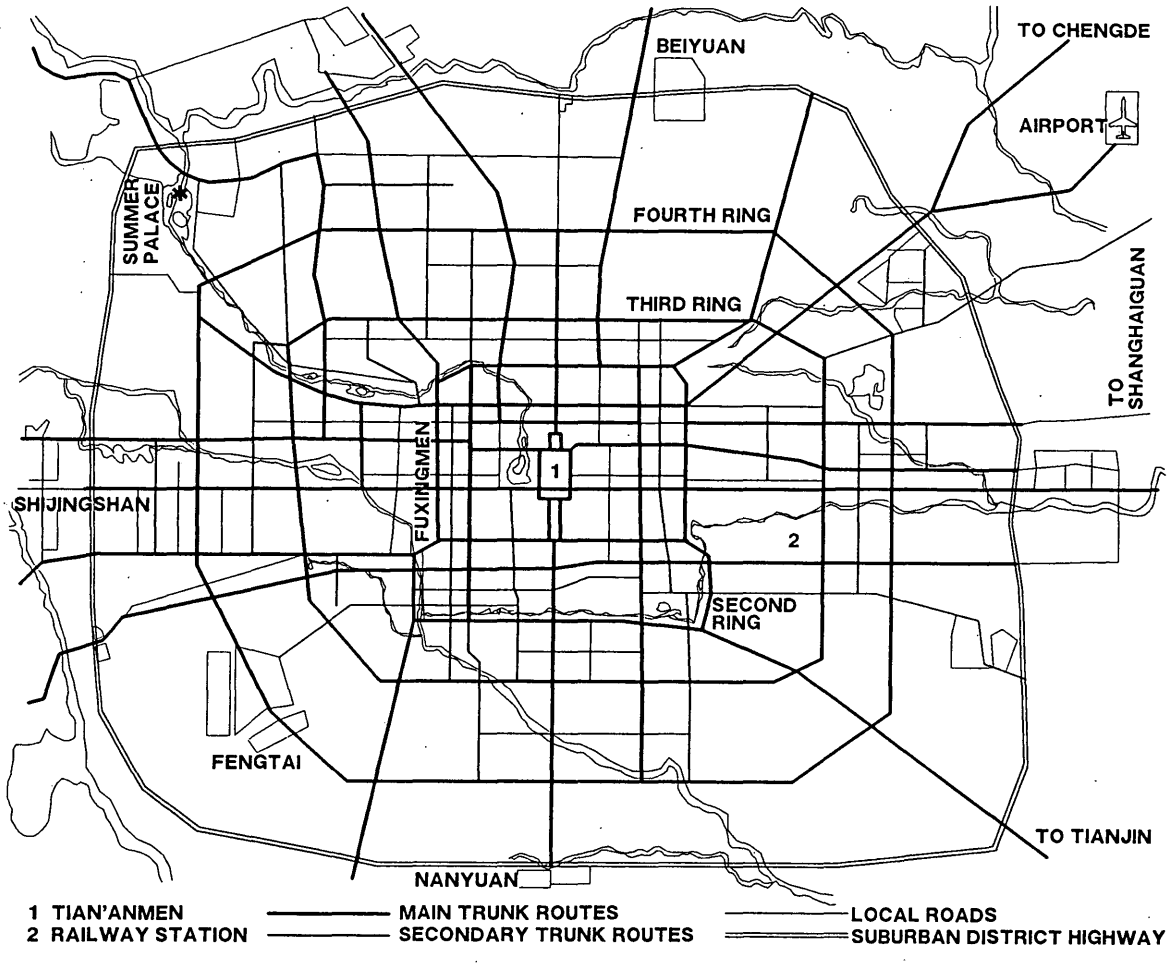

FIGURE 2 Road system of Beijing.

8. Review planning objectives of recent studies and recommend objective functions to be used in the LUTO model.
9. Install the LUTO model on a personal computer and test the programs.

A practical optimization model for the integrated land use and transportation planning has been developed in Beijing; it considers various development objectives and financial constraints of the community. Its application to the long-term planning in Beijing has shown the existence of significant common components in the alternative growth patterns that optimize the usual quantitative planning goals. Thus, a systematic approach for strategic planning becomes possible, whereby the development strategy would be built of the common components of the alternative LUTO-derived patterns.

Traffic Management Measures

To solve the growing traffic problems in Beijing, the government has continuously expanded the road system. Apart from this, making good use of existing roads leads to efficient traffic management measures in solving Beijing's road congestion. In recent years, the following measures have been adopted:

1. Control the increase in vehicles according to plan and proportion. A "passing certification" is used to prohibit about 32 percent of the goods vehicles from entering the city during the day. Large amounts of goods that have fixed loading and unloading locations may be transported into the city only at night.
2. Give traffic management priority to buses in order to reduce the pressure on the arterial roads and to ensure the efficiency of the bus operation.
3. Promote transit services as one of the effective measures to attract more passengers and limit the increase in bicycles on the road. The transit system is being improved and expanded; transit transfer centers are being introduced so that passengers who have arrived by different modes can be collected and then effectively distributed over the transit lines expected [see paper by Wei and Ren (*3*)].

There are 39 and 53 signalized intersections in the east and center of Beijing, respectively, which have been controlled automatically by the ATC computer. Compared with the past, the delay for motor vehicles decreased 24 percent and that for bicycles, 15 percent; the capacity of intersections increased 20 percent. By the end of 1992, 250 intersections within the third Ring Road will also be equipped with signal controllers connected to the ATC computer center.

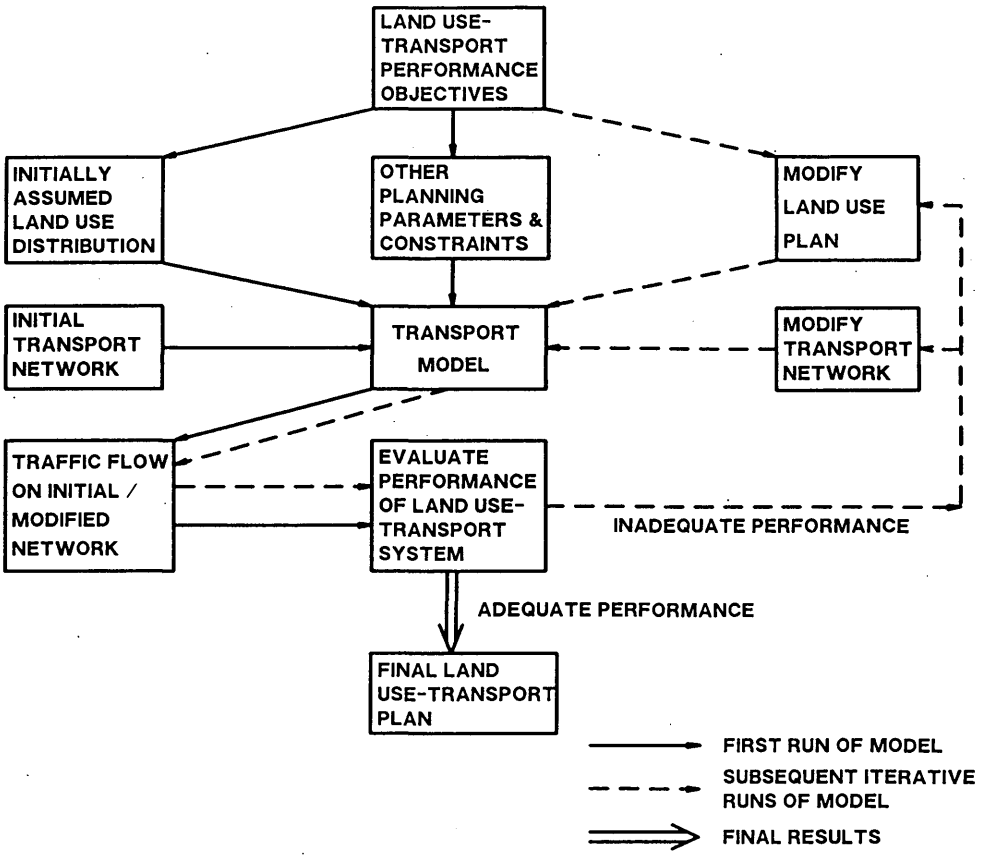

FIGURE 3 Conceptual outline of land use and transportation optimization process.

Moreover, traffic peak times are being staggered. On the basis of studies of passenger concentrations, the working hours for more than 220,000 staff from more than 450 companies can be staggered. This would somewhat help the rush-hour traffic problem.

SHENZHEN

Shenzhen is one of the special economic zones in China; it is just adjacent to the border of Hong Kong. The whole area of the city is 32.6 km^2; the registered population is more than 640,000, and the temporary or transient population is about 300,000. Local highway construction has proceeded quickly: 117 roads account for more than 420 km being completed. There are more than 45,000 motor vehicles and 300,000 bicycles in this city. Because Shenzhen has undergone rapid population growth and economic expansion since 1979, traffic problems have arisen especially in the urban area.

The traffic problems of Shenzhen can be portrayed as crowding, blocking, and noise. In the urban area, a shortage of public transit facilities is obvious: there are only 4.3 buses per 10,000 residents (compared to 8.9 in Beijing and 8.6 in Shanghai). Too many bicycles, particularly at road intersections, is one of the immediate causes of the various traffic problems at junctions.

At present, the local government still continues in land use planning and transportation network improvement. The distribution of commercial centers has been readjusted, and some major trunk routes have been upgraded. Grade-separated interchanges are being constructed, and a light rail transit line is also proposed to connect to the new Huangshi International Airport. Public transit is being improved to attract more passengers and to limit the number of bicycles on the roads.

After investigating measures to alleviate these traffic problems over the past decade, the Traffic Engineering Science Institute of Shenzhen (TIS) has obtained some valuable results, namely, an efficient data collection framework, simplified travel demand methods, a computer-aided design for isolated signalized junction, and an ATC system.

Efficient Data Collection Framework

The origin-destination (O-D) matrix is a spatially disaggregated measure of the quantity of travel within a defined study area. It is based on a zonal decomposition of the study area and simply expresses the quantity of travel between any pair of zones in the form of a matrix. Insofar as it can express travel demand, the O-D matrix is a fundamental input for most problems with planning and management of transportation systems.

Nowadays, a roadside interview survey is one of the commonly used methods in China to estimate the O-D matrix and to collect the relevant traffic information because it is more flexible and less labor-intensive. However, attention

must be given to the selection of roadside interview stations, sample selection of vehicles, and design of questionnaires. Most of the problems arising from the use of the roadside interview survey are related to the procedure of expansion of survey data. This is because trips may pass through more than one survey station, so some trips may be sampled more than once. If the survey data from different stations are added without proper adjustment, the long-distance trips will be overrepresented.

The TIS, through a joint research project with the Civil and Structural Engineering Department of Hong Kong Polytechnic, conducted a comprehensive roadside interview survey in Shenzhen; it has served as a basis for testing the simplified travel demand model. The objectives of the survey were to determine (a) the origins and destinations of motorized trips generated in Shenzhen, and (b) the choice of routes of motorists traveling within and through the urban areas of Shenzhen.

The survey was carried out over two 2-hr peak periods (9:00 to 11:00 a.m. and 3:00 to 5:00 p.m.) from December 15, 1987 (Tuesday), to December 17, 1987 (Thursday) because most peak-hour trips in Shenzhen are made by company cars for business or commercial purposes. Forty-four stations were selected for roadside interviews. A synthetic network of 23 zones and 328 links was adopted. Figure 4 shows the study area and the interview stations.

In the study, a methodology for estimating an O-D trip matrix from roadside interview surveys was formulated, and a framework for processing roadside interview data relating to trips crossing multiple screenlines was suggested and shown to be practical and useful; see Lam et al. (*4*). In the survey, collecting O-D and route information by tracing the exact path taken on street map, with the assistance of field surveyors, was an effective and reliable way to determine O-D matrix and link choice proportions.

There were 13,330 motorists surveyed and 13,250 valid questionnaires for subsequent data processing. Out of a total of $2 \times 23 \times 23 = 1{,}058$ estimates for both a.m. and p.m. peak O-D matrices, only 14 of them have variances greater than 1,000 (standard error = 32 trips). For these 14 estimates, the average of their coefficients of variation is only 0.1386, indicating that the estimates are quite reliable and accurate as far as sampling errors are concerned.

Simplified Travel Demand Methods

Estimating an O-D matrix directly from traffic counts offers great economic advantages because it eliminates expensive surveys, burdensome data editing, and subsequent analysis. Because link flows are relatively inexpensive to obtain and are regularly collected for various purposes (e.g., ATC system

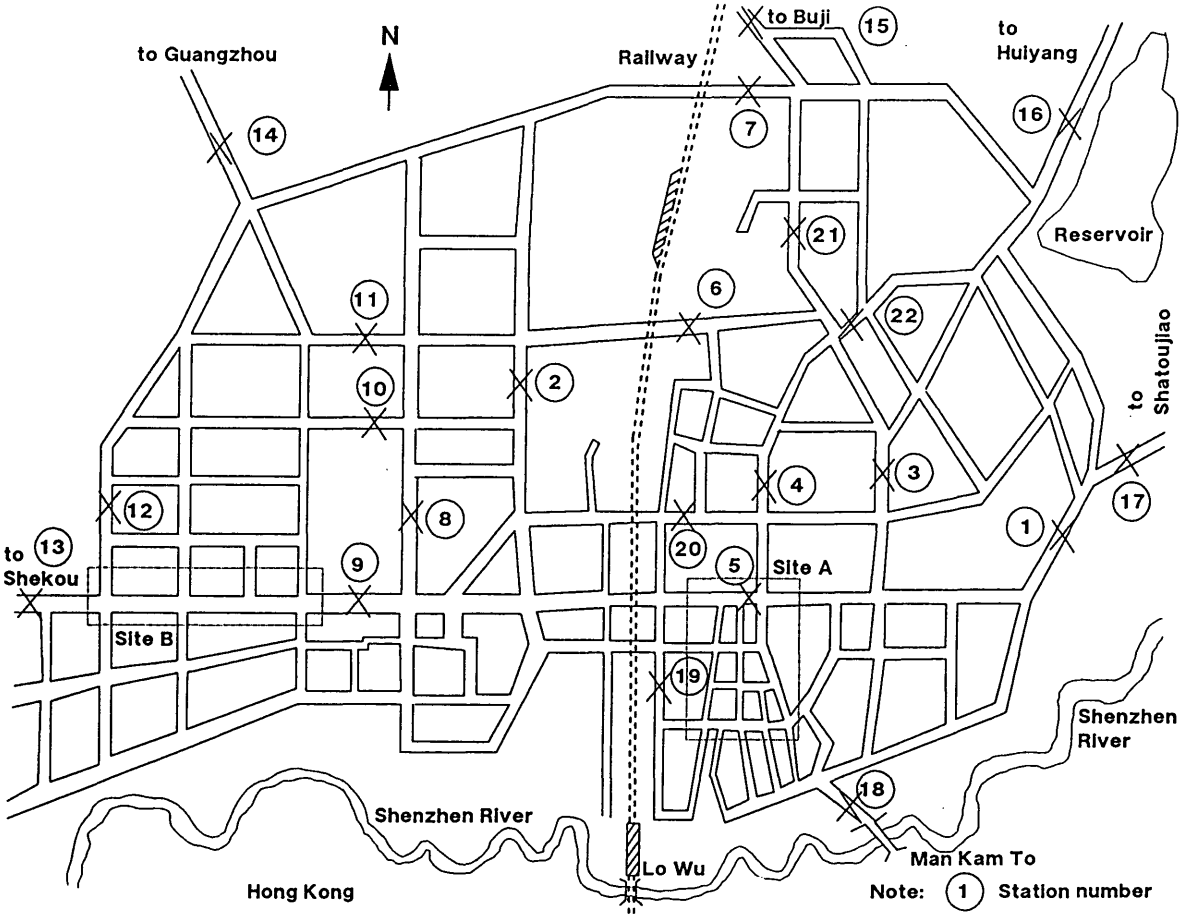

FIGURE 4 Locations of roadside interviews in Shenzhen.

and accident studies), and because the automation of traffic counts has been introduced in most of economic centers in China, the possible application of such an O-D estimation model is attractive. This method is suitable for the design and evaluation of traffic management schemes.

The model derived by entropy maximization (EM) is one of the O-D matrix estimation techniques commonly used in developed countries. Examples of various applications have been given in papers by Hall et al. (*5*) and Beagan and Bromage (*6*). However, the accuracy of the EM model in developing countries has not yet been well defined.

Lam and Lo have examined how data information affects the EM model performance and estimated the effects of information variability on model accuracy (*7*). Empirical results from Shenzhen indicate that the use of a better prior estimate of the trip matrix can dominate the EM model accuracy, especially when the link-flow information is limited. If no prior information is available, then the increasing number of links with flow information would improve the O-D estimation effectively. Moreover, the better the link choice information, the further reduction in the prediction error is found. It is concluded that the EM model would be useful for short-term planning when there is no significant change in the network.

However, for long-term planning, a combined trip distribution-assignment model for multiple user classes that was introduced by Lam and Huang would be appropriate to be used in China because the model can also be calibrated by traffic counts only (*8*).

Computer-Aided Signal Design

The designs of lane uses and stages for signal controls at isolated junctions are usually undertaken by experienced traffic engineers. The development of computer software for the designs of lane uses and stage sequence is valuable in developing countries, especially in places where there are only a few experienced traffic engineers. Much research on designing signal stages and timings has been conducted, but very little has been done for the optimal design of lane uses or lane configurations at junction approaches. Lam et al. have developed an integrated model for both lane use and signal stage designs; this model can maximize the capacity of an isolated signalized junction and coordinate the signal plan of individual junction for ATC in Shenzhen's road network (*9*). It is found that integrated design performs better than optimal stage design where a suboptimal or poor lane-use configuration is fixed in the latter.

Integrated Design of Lane Uses and Signal Stages

In the preceding study, a mixed-integer linear programming model for the integrated design of lane use and signal stage has been suggested and shown to be practical and useful in China, where experienced traffic engineers are scarce. The linking of the individual signal plan to the ATC system is also conducted with some fine-tuning improvements in the computer program (TRANSYT-7F) for minimizing the overall delays, stops, and fuel consumption.

The performance of traffic signal control plans can be measured by a number of indexes, namely, *Y*-value (i.e., flow factor) among the selected junctions, number of traffic movements having a high degree of saturation, average vehicular delay, total uniform stops, total fuel consumption, speed, and performance index. The results of the evaluation tests on two selected sites in Shenzhen (see Figure 4), with respect to these measurement indexes, indicate that the integrated design of the lane use and signal stage can minimize the *Y*-values but maximize the ultimate reserved capacities of the road junctions. In comparison with the existing signal plan in Site A, the integrated design performs better in terms of all the measurement indexes. In Site B, the integrated design does not outperform the expert's manual design in all measurements of system efficiency. However, it can produce results that are at least comparable to those designed by experienced traffic engineers. Moreover, manual design depends much on the designer's experience; hence, junction conflicts may sometimes be overlooked whereas integrated design has all kinds of conflicts as built-in constraints.

There is indication that both integrated and expert's manual designs make use of all-red for pedestrian phase. This is because the junctions in Shenzhen are generally wide, so patching pedestrian movements with traffic movements may not be advantageous.

Application of ATC in China

ATC is the centralized control of traffic signals on an areawide basis by means of computer. Usually the traffic signal controllers on street are linked to the central computer in the control center by data transmission cables. The degrees of sophistication of an ATC system vary from the fixed time plans (developed by TRANSYT) based on available traffic data to the fully responsive system calculated on-line (by SCOOT or SCAT).

Although the TRANSYT family of programs continues to be one of the most widely used computer programs in the world for ATC, improvements are still required for modeling local traffic conditions in different countries. Willumsen and Coeymans (*10*) studied the effects of the TRANSYT applications in Santiago, Chile, and discussed special research undertaken to model traffic conditions in developing countries.

The TRANSYT program has been used to develop signal timing plans in Hong Kong since 1977. In China its application is relatively new, although SCOOT and SCAT are being used in Beijing and Shanghai, respectively. Wong has discussed the process and results of developing signal timing plans using TRANSYT-7F in Shenzhen (*11*). As a result of model calibration, a platoon dispersion factor of 0.45 was found most appropriate for all time periods. Both the model and the field results indicated improvements in total travel time, total delay, number of stops, and average speed; thus, TRANSYT-7F is an available tool in developing signal timing for Chinese cities.

CONCLUSION

In summary, it is clear that rather than indiscriminately importing technologies that are relatively successful in more

advanced countries, China has committed itself to identifying ways to maximize the effectiveness of transportation planning and traffic management interventions. In some cases, this can be achieved by adapting transportation methodologies used in Hong Kong. However, it should be emphasized that variations and adjustments are required to reflect the unique nature of the transportation system in China. Traffic solutions must be specific to the culture and to the individual case. A summary of those techniques for Chinese conditions follows.

First, the Hong Kong LUTO model is being used for strategic planning in Beijing, taking into account the cultural and political differences between China and Hong Kong. It is a tool for identifying the essential decisions that need to be made on the land use strategy so that maximum flexibility can be achieved. This point is particularly important in Beijing's planning in view of the rapidly changing planning environment.

Second, a major problem often faced in China is the lack of data. An efficient data collection framework and simplified travel forecasting method have been developed for Shenzhen and are generally applicable to the situations in China.

Third, with the unique characteristics of road users and traffic composition, such as the huge number of cyclists and the mixture of the high- and low-speed vehicles on the road, the traffic parameters in Chinese cities are very different from those in other parts of the world. With reference to the latest application of computer technology and methods for automating ATC systems, a suitable computer-aided signal design method applicable to Shenzhen's traffic conditions has been developed and should be valuable in developing countries, especially where experienced traffic engineers are limited.

Fourth, there has been a strong growth of the licensed vehicle fleet in most of the economic centers of China. To alleviate the growing congestion, the government pointed out that the old cities should be redesigned and at the same time ATC systems and various traffic restraint measures should be implemented so that the serious traffic problems can be solved.

Finally, to minimize the conflicts between bicycles and other motorized vehicles in large cities of China, separated facilities are being introduced and effective traffic management measures have been applied. More important, public transit should be improved to attract more passengers and to decrease the number of bicyclists on the streets.

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Policy Implications of Increasing Motorization for Nonmotorized Transportation in Developing Countries: Guangzhou, People's Republic of China

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Increasing motorization in developing countries may have positive or negative implications for urban mobility, mainly because of potential conflicts with the predominantly nonmotorized transportation in these countries. The potential for improved planning to avoid conflicts between these two increasingly important types of travel modes is considered. The most common difficulty in planning to reduce conflicts between motorized and nonmotorized transportation lies in the phenomenal growth in automobile ownership that has occurred in the last 10 or 20 years. Urban planning in Guangzhou (formerly Canton), China, located near Hong Kong is used as an example of planning to accommodate this phenomenon. Pooled accident data for 1989 and 1990 are used to illustrate the complex relationship between various types of collisions and traffic accident severity. Most traffic accidents in Guangzhou appear to reflect relative probabilities associated with purely random occurrences (unplanned and undesired outcomes). Some types of accidents, including those involving two automobiles or two motorcycles, were more severe, as measured in terms of the ratio of personal injury to fatality accidents, than was expected, relatively speaking, on an a priori basis. This suggests that drivers of automobiles and motorcycles in Guangzhou are less well prepared for the worst types of accidents than are pedestrians or bicyclists, and that this lack of preparation is independent of any conflicts that may arise between motorized and nonmotorized traffic. The random component of accident severity nonetheless predominates overall, with the end result being that pedestrians and bicyclists are much more likely than those in automobiles or on motorcycles to be injured or killed when traffic conflicts leading to collisions between motorized and nonmotorized modes of travel do occur. Methods to reduce conflicts between motorized and nonmotorized modes of travel under increasing motorization may include education, experience, or the construction of physical barriers through grade separation. Because of the high cost of grade separation, however, it has been used only sparingly in most developing countries. There are some exclusive bicycle lanes in China, as well as some separated bicycle parking facilities, but not many. Other strategies of possible use in developing countries include the identification of truck-free areas or time periods and the creation of automobile-free zones in commercial or residential areas. In terms of controlling the rate of growth in automobile traffic and determining where such growth should occur, improved zoning regulations for automobile parking and the use of fees and licensing for road access may be used. In terms of safety, improved driving rules and better lane marking are important considerations. Travel demand management, in the form of comprehensive land use plan elements and zoning regulations that encourage employer actions to promote alternative modes of travel, might be considered.

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The level of motorization continues to increase rapidly in developing countries around the world, and this does not by any means exclude the People's Republic of China. China has undertaken a massive road building program as part of its overall economic development strategy, with the total mileage of the national highway system increasing from just 75,000 km in 1949 to well over 1 million km in 1988 (*1*). This yields a total increase over 39 years of more than 1,250 percent, or an average increase of about 7 percent a year in the total length of the national highway system. In the 1970s, increasing emphasis was placed on the construction of higher-quality divided highways; in the 1980s the first grade-separated expressways in China were built.

The result of this frenetic construction activity has been the beginning of a national network of paved, signalized, and latterly exclusive right-of-way highway facilities. The main purpose of this exercise has been to move goods by truck from one city to another more efficiently and effectively, with greater speed and timeliness, providing a higher level of service and more flexibility in the operations of major industrial producers in China. As an indirect consequence of the development of this new national highway system, private automobiles slowly are becoming more attractive to those who can afford them in China. With the increasing liberalization of the economic system, more and more inhabitants of China will gain both the ability and the desire to purchase more sophisticated and more expensive consumer goods, including private automobiles, vans, and motorcycles.

Nonmotorized traffic has its own problems in developing countries. Pedestrians and bicyclists often make up a large part of urban traffic in developing countries, and China is no exception to this rule. Ironically, because of the relatively low incomes of most of the people living in China, bicycles are much more popular alternatives to public transportation than are private automobiles, motorcycles, or even mopeds at this time. Thus, in Shanghai the bicycle is considered to be the principal cause of the noticeable decline in public transit market share occurring in recent years, and of the concurrent rise in the level of traffic congestion on many local streets in

China's largest city (*2*). There is a high level of dependence on bicycle transport in Guangzhou (Table 1).

Public transit may take many forms in developing countries, including the traditional subway, elevated, light rail, and large bus systems so often found in developed countries, as well as a wide variety of paratransit services based on rickshaws, jitneys, taxis, minibuses, and the like, which are more varied as well as more common in developing countries (*3*). In China the highest priority is still being placed on increasing the capacity and maintaining the overall urban market share of public transit in large cities (*4,5*). This is not unlike that of urban transit officials in more capitalistic developing countries such as Brazil (*6*).

Increasing motorization has resulted in concerns being expressed in China over where to park all of the private vehicles now being bought or otherwise brought in to use all of the new roads that have been built in the past 20 years (*7*). Given the rapid population growth in urban areas, often accompanied by even faster growth in vehicle ownership and travel, developing countries often exhibit much worse traffic congestion than do older or more established cities in the developed world. Responses to the problem of traffic congestion in developing countries might include one or more of the following:

1. Do nothing—let the market prevail;
2. Implement travel demand management strategies;
3. Improve traffic safety conditions;
4. Develop new transportation facilities;
5. Regulate land use through zoning; and
6. Carry out general urban development policies.

This paper is concerned with identifying recent trends in travel, in reviewing past planning practices, and in making certain recommendations for improved future planning with respect to transportation in a particular city of China, Guangzhou.

TABLE 1 Guangzhou Modal Split, 1984 and 1989

	Mode Split	
Mode of Travel	**1984**	**1989**
Non-motorized		
Walking	40.0	35.6
Bicycling	29.9	29.8
Motorized -- public transit		
Buses	19.5	17.2
Vans	1.2	3.2
Ferry boats	2.2	2.0
Motorized -- other vehicles		
Private auto	5.0	6.0
Taxicab	1.8	4.3
Motorcycle	0.4	1.3
Other	0.0	0.6
Total	100.0	100.0

Source: Guangzhou Urban Planning Bureau. Information for 1984 gathered from an original comprehensive regional origin/destination study, including a 3% sample of the total population, or 18,584 households and 60,911 persons surveyed. Estimates for 1989 are extrapolated from 1984 travel data, using 1989 vehicle registration data.

RECENT TRENDS IN GUANGZHOU

Private ownership of the means of urban transportation in Guangzhou and indeed in all of China is limited primarily to bicycles and motorbikes. Except for a few dozen automobiles owned by individuals, motorized vehicles are generally owned by the government, government agencies, joint venture groups, or other government-sponsored or government-permitted groups. This situation is likely to change as restrictions on private ownership continue to be relaxed. In China the trend toward privatization of economic activities is not nearly as far along as it is in some other countries struggling with centrally planned economies, but it appears to be proceeding more rapidly in southern China, where Guangzhou is, than in many other parts of the country. Privatization generally is still referred to in China as a relatively small but rapidly growing component of the "planned commodity economy."

Vehicle Registrations

The number of motorized vehicles in China has increased dramatically in the recent past. In Guangzhou alone the number of bicycles more than doubled and the number of motorcycles increased more than 40 times between 1980 and 1990. During the same period, the number of motor vehicles increased by almost 10 times (Table 2). The result of this increase has been a significant increase in traffic congestion and a growing number of conflicts between motorized and nonmotorized modes of transportation. Conflicts occur most often at intersections, at which bicycles and pedestrians, often with little or no regard for the danger involved, cross paths with motorized vehicles.

Observations of lifestyle, income, modernization programs, and local expressions indicate that the current reliance on the automobile will increase, especially for intercity transport. The government cannot continue to rely on water and rail transport for short-distance hauling and, in fact, is no longer doing so. Truck-induced traffic congestion is observed in and around many of China's urban areas. Furthermore, automobile use in Guangzhou is increasing rapidly for very similar reasons, just as automobile use in Western countries increased in the past because of the added convenience and flexibility of private automobiles. (Most "private" automobiles, as referred to in the West, are in fact owned and operated by the central government, government agencies, or local government offices. This does not by any means change the fact that publicly owned automobiles can and are used for many types of private activities, in China as in the rest of the world.) The automobile provides an air-conditioned ride, an important factor in the hot and humid climate of Guangzhou, as well as the ability to get to many places that are simply not accessible using public transit routes. Automobile rides are generally more comfortable and, except in areas of extreme traffic congestion, much faster than either bicycles or public transit for most trip purposes.

TABLE 2 Actual Number of Vehicles in Guangzhou, 1980 and 1990

Type of Vehicle	Actual Number of Vehicles 1980	1990	Change 1980-90 (%)
Bus	1,825	6,644	264.1
Car[a]	5,971	26,977	371.6
Truck[b]	13,153	51,534	291.8
Motorcycle	3,593	157,677	4,288.4
Bicycle	1,039,426	2,669,130	156.8

Source: Guangzhou Urban Planning Bureau.
[a] Includes cars, vans and taxis.
[b] Includes large, medium and small trucks.

Highway Safety

With the increase in automobile traffic in Guangzhou, regrettably, yet inevitably, has come a concomitant increase in the number of accidents involving property damage, personal injuries, and even fatalities. Whereas the total number of traffic accidents and fatalities increased dramatically between 1971 and 1990, the number of personal injuries related to traffic accidents grew much more slowly (Figure 1). The total dollar cost of traffic accidents increased by more than 700 percent between 1983 (when such records were first made public by the city) and 1990. The total annual number of traffic-related accidents in Guangzhou increased by 134 percent, and the number of vehicles, including bicycles, increased by only 118 percent between 1980 and 1990.

The more rapid increase in the number of traffic accidents may indicate increasing traffic congestion, as well as the lack of familiarity of many members of the general population with the particular abilities as well as the limitations of motorized forms of transport. These accident statistics may not reflect accurate measurements of true exposure, but nonetheless can be used as crude estimates of the relative risk of traffic accidents (*8*). A separate analysis was conducted of traffic accidents in Guangzhou in 1989 and 1990 by the type of incident, including collisions between each of the following pairs: vehicles and (a) other vehicles, (b) motorcycles, (c) bicycles, and (d) pedestrians; and motorcycles and (a) other motorcycles, (b) bicycles, and (c) pedestrians.

All other types of collisions, including multiple-vehicle collisions and any collision in which the travel mode of an involved party was not known, were excluded from the analysis. The seven specific types of two-party collisions identified in this analysis accounted for fully 72 percent of all traffic accidents reported in Guangzhou in 1989 and 1990 combined but only 53 percent of the personal injuries and 42 percent of the fatalities sustained during the same 2 years. Other types of collisions were much more likely to cause personal injury, especially death, than the seven types considered here. More than half of all traffic accidents, but only 10 percent of personal injuries and traffic fatalities, involved collisions between two motor vehicles (Figure 2).

The greatest number of traffic fatalities was associated with collisions between vehicles and bicycles, followed by collisions between vehicles and pedestrians (this excludes the "other" category). The ratio of accidents to injuries was similar to the ratio between accidents and fatalities across all types of collisions considered, including the "other" category (Figure 3). The ratio of personal injuries to deaths was lowest for collisions between vehicles and pedestrians, indicating that these types of collisions were the deadliest of those studied. The highest ratio of injuries to deaths was for collisions between motorcycles and bicycles, indicating that, although these types of collisions often resulted in personal injury, death was a much less frequent occurrence, relatively speaking.

Two-vehicle collisions resulted in personal injury or death relatively less frequently than did any other type of two-party

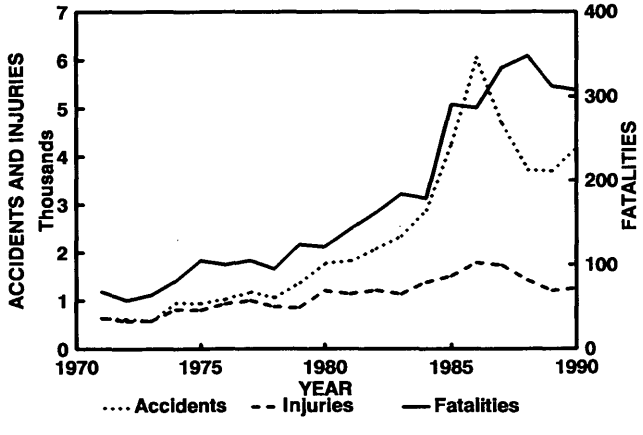

FIGURE 1 Traffic-related accidents, injuries, and fatalities in Guangzhou, 1971–1990.

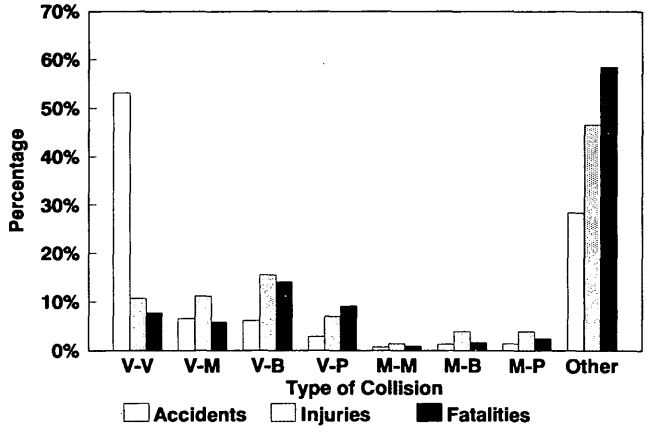

FIGURE 2 Distribution of traffic accident impacts by type of collision in Guangzhou, 1989–1990.

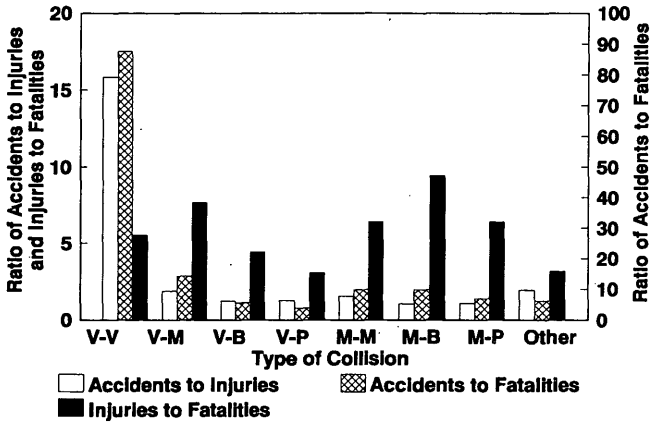

FIGURE 3 Relative severity of traffic accidents by type of collision in Guangzhou, 1989–1990.

collision. However, when some form of bodily injury was involved, it led to death in two-vehicle collisions more often than in any of the three types of two-party collisions involving motorcycles, but not vehicles (Figure 3). Only collisions between vehicles and bicycles or vehicles and pedestrians had lower ratios of personal injuries to deaths, indicating greater accident severity. These results suggest that the increase in deaths relative to personal injuries in Guangzhou between 1971 and 1990 may be due somewhat to an increase in the likelihood of traffic collisions involving larger vehicles, itself the natural result of increasing motorization. The ratio of cars to motorcycles involved in traffic accidents may have grown as well.

Because of data limitations, hypotheses such as these could not be tested explicitly in this analysis. Fridstrøm argues that traffic accidents should be treated primarily as random events, since they are usually not the result of intentional motivation (*9*). For Guangzhou, disaggregate discrete choice models probably would not provide better results in causal modeling than would aggregate statistical models and may in fact provide worse results, offsetting possible concerns regarding the "ecological fallacy" in inferential analysis. Under these conditions, our results should be fairly robust, at least at the aggregate level.

Monotonic decreases were expected in the relative frequency of traffic accidents, grouped by accident severity and type of collision, throughout the entire range of possible traffic conflicts. This was found to be true for most types of collisions, suggesting that the occurrence of traffic accidents in Guangzhou is primarily random in nature, and that the severity of accidents that do occur reflects the degree of inequality between the two colliding parties, as measured in terms of relative differences in mass and velocity (Figure 3).

The oscillation of peaks involving ratios of the most severe forms of traffic accidents—namely, those involving personal injuries and fatalities—is somewhat shocking in this regard. It may be that adaptive behavior on the part of the general population of the city to increasing motorization has resulted in the avoidance of some close calls, whereas more spectacular traffic accidents that result in death are not being avoided as successfully. It appears that as motorization has increased in Guangzhou, motorized travelers have developed their ability to avoid hitting others more rapidly than their ability to avoid being hit. This could be due to a lack of experience on the part of new drivers, compounded by the low starting point and rapid rate of motorization, with few local cultural antecedents to provide greater resiliency in the process of adaptation to changes in travel behavior and risk associated with motorization.

Urban Growth

Despite official government policies aimed at severely restricting urban growth, the population of Guangzhou rose from just more than 3 million in 1980 to almost 3.6 million in 1990, an increase of greater than 18 percent. This rate of growth is projected to continue at least until the turn of the century, when the city's population is expected to be well over 4 million. A concomitant increase in the rate of motorization that occurred during the last decade would then result in more than 2.7 million vehicles in the city. However, the rate of vehicle growth appears to be growing at an increasing rate. Our best estimates, assuming no stringent government action to curtail growth, range from 3.0 million to over 6.8 million bicycles and from 280,000 to 7.3 million motor vehicles on the road in Guangzhou in the year 2000 (Table 3). To counteract this trend, the city government has decided to limit the number of new motorcycle licenses and issued only 6,000 a year.

In addition to the registered population, there is a large floating population in Guangzhou. The floating population consists of nonregistered rural migrants who flock to the city in search of better employment. Among other things, these migrants increase the demand for transportation, contributing to traffic congestion and increasing the number of potential conflicts between motorized and nonmotorized transportation. Although it is government policy to control migration, people continue to move into the city from outlying rural areas, with or without official approval. Only recently has any attempt been made to measure the travel demand characteristics of this rather elusive population group for comparison with the travel behavior of more established social groups within Chinese urban areas (*10*).

Except for the floating population, local government is in a good position to limit the effects of commuting on traffic congestion, because to a large extent housing is provided directly by the local government. The government determines the location of housing on the basis of official employment records (*11*). Some factories provide housing on-site, which reduces the number of trips made by workers. In other instances, workers' housing may be located at some distance from their place of employment, requiring lengthy commutes. Policies relating to on-site housing at places of employment apparently have limited the contribution of commuting to urban traffic congestion in the past. Future policies regarding on-site housing will require further study to predict the impact they may have on traffic volumes and congestion within the city. Far less stringent but perhaps equally effective controls on the location of housing may be observed in nearby Hong Kong, where much-more-prevalent private homes are built on land leased from the government (*12*).

TABLE 3 Estimated Number of Vehicles in Guangzhou, 2000

Type of Vehicle	Estimated Number of Vehicles[a]		
	Low[b]	Medium[c]	High[d]
Bus	7,689	11,547	24,191
Car[e]	31,220	48,618	127,224
Truck[f]	59,640	90,609	201,910
Motorcycle[g]	182,478	314,545	6,919,497
Bicycle[g]	3,088,959	4,325,526	6,854,326

[a] Assuming no additional governmental limitations.
[b] Projected based on the number of transport vehicles per capita in 1990.
[c] Projected based on the ratio between the increase in population between 1980 and 1990 and the increase in the number of each form of transportation between 1980 and 1990.
[d] Projected based on the percentage increase in the number of transport vehicles in Guangzhou, 1980-1990.
[e] Includes cars, vans and taxis.
[f] Includes large, medium, and small trucks.
[g] In some cases, a particular method of projection may result in a figure that exceeds the projected population in the year 2000. The methodologies in question do not account for any decrease in the rate of increase that may occur as the market for one mode of travel becomes saturated, or as other modes of transportation from time to time become available or otherwise improve their competitive position.

Most personal income in China is controlled by the government and, by Western standards, is quite low per capita. However, there has been some relaxation of government controls on private sources of personal income to allow increased economic development to occur. The current policy on personal income allows limited buying and selling of private goods by individuals. Farmers are major recipients of increases in personal income under these relaxed rules. Farmers often spend extra personal income to buy private vehicles, which are used on the farm but may also enter the city from time to time, increasing the level of urban traffic congestion. Increases in personal income allow many more discretionary items to be purchased, including bicycles, motorbikes, and motorcycles. This has resulted in a large increase in the total number of private vehicles using public roads in Guangzhou.

Physical Factors Affecting Transportation

The flow of traffic is limited severely by frequently narrow street widths within developed parts of the city. Major streets often are fairly wide, but intersecting streets just as often are quite narrow, especially in the oldest parts of the city. Even in areas of more recent development, narrow streets are still being constructed with some regularity. Exacerbating the traffic problems associated with the all-too-common overly narrow streets is the lack of setbacks from property lines in much of the construction occurring today. Structures quite often are built right up to the street line, which can and often does necessitate the removal of entire buildings to widen roads at a later date.

PAST PLANNING ACTIVITIES

A 4-day symposium on traffic congestion and safety was held in Guangzhou in 1986 (*13*,p.52). Transportation officials from cities and provinces throughout China met to discuss traffic jams, speed degradation, and the rapidly increasing number of accidents occurring in Chinese cities during the early 1980s. These officials agreed that the following coping strategies might best serve to address these issues in the short term:

1. Improved traffic controls, such as a greater number of one-way streets, determined according to local traffic patterns.
2. Improved traffic regulations and facilities for cyclists.
3. Better equipment for traffic police, such as walkie-talkies to communicate problems to headquarters, and an incentive system to motivate traffic planners to do a better job.
4. Banishment from city streets of slow-moving vehicles, such as horse-drawn carts or tractors.
5. Better research and reporting of traffic volumes in cognizance of the fact that traffic jams tend to occur in specific locations at specific times. (Bridges and railway crossings were frequently cited as sources of recurring traffic congestion. Traffic jams sometimes involved hundreds of vehicles in lines of 1 mi or more, particularly in larger cities such as Beijing, Shanghai, Guangzhou, Wuhan, Shenyang, and Hangzhou.)

These generalized policy observations have since been developed into much more specific planning recommendations for the city of Guangzhou.

Land Use Planning

The current Guangzhou Comprehensive Plan includes provisions for a wide variety of improvements to the regional transportation system. Some of the more important transportation provisions within the comprehensive plan include the following:

1. *Circumferential highways.* The highway element of the comprehensive plan shows several ring roads, the first of which is already under construction and partly open to traffic.
2. *Express highways.* Several toll facilities are included in the comprehensive plan. The road to Foshan, a city approx-

imately 20 km west of Guangzhou, is now open. A toll road linked to Hong Kong and Shenzhen is under construction.

3. *Subways.* The transit element of the comprehensive plan calls for the construction of a subway system focused on the city center. The feasibility study has been completed. Construction is projected to begin in 1993, subject to the availability of funding, some of which is still pending. The subway is expected to be 35.91 km long at build-out and will include 31 rail stations on two separate lines.

4. *Parking.* The traffic circulation elements of the comprehensive plan includes provisions for dozens of new parking lots and bus stations spread throughout the city, a few of which have already been built. The city has also adopted a few parking regulations. Unfortunately, these do not cover all existing categories of land use. Additional parking regulations are currently under development. Differences between current and proposed motor vehicles parking regulations are considerable (Table 4).

5. *Design standards for streets.* The city has adopted design standards for new streets under the comprehensive plan. These standards relate to the grading, cross section, width, and separation of motorized and nonmotorized traffic on new streets, which vary in stringency for different categories of streets.

6. *Tunnels.* The comprehensive plan includes provisions for several new tunnels, one of which is under construction beneath the Pearl River.

Zoning Regulations

Until relatively recently, there was little need for the establishment of local land use zoning regulations anywhere in China. The central government retained ownership of all land and could address development issues directly, in any manner that would best suit national goals and objectives. Local autonomy and variations in local preferences were not considered to be relevant. The construction of new towns, the development of joint ventures, the encouragement of increased levels of foreign investment, and the reinstitution of private control of land on a limited scale all have increased the need for land use zoning regulations or other similar types of local controls on development. The national government recognizes the need for such local controls and has recently passed legislation authorizing—indeed, requiring—the development and implementation of various types of local land use zoning instruments. Guangzhou, like all Chinese cities, does not have its own comprehensive zoning laws fully in place at this time. Instead, the city, in conjunction with its technical advisor, is in the process of developing a more detailed set of zoning regulations. These new and more comprehensive zoning regulations will include some or all of the following:

1. Plans for traffic circulation, including greatly expanded parking requirements;
2. The creation of specific area planning land use districts;
3. Allowances for mixed use development;
4. Incentives for the provision of pedestrian ways and streets;
5. Permission for higher-density land uses near subway stations; and
6. Density controls and the regulation of traffic generators.

The proposed zoning regulations are far more comprehensive in scope, including motorized vehicle parking requirements for several types of land uses that are not covered by local legislation at the present time (Table 4). These new zoning regulations, which are still under development, are based on realistic projected increases in both population and vehicle ownership levels (Table 3). Design requirements for off-street parking and loading also will be included.

Traffic Regulations

The city of Guangzhou has some fairly basic traffic regulations in place at this time. Drivers currently are required to

1. Undergo testing in order to be licensed,
2. Travel on the right-hand side of the road,
3. Travel within designated traffic lanes,
4. Abide by both general and posted speed limits, and
5. Obey all posted traffic signs and signals that control the flow of traffic.

In Beijing, separate traffic signals for automobiles and bicycles are common. In Guangzhou, this is not yet normal practice. Drivers are permitted to turn right without stopping

TABLE 4 Motorized Vehicle Parking Requirements in Guangzhou

Land Use	Parking Ratio
First class hotels	Total number of guest rooms X 6 (m^2)
Ordinary hotels	Total number of guest rooms X 3 (m^2)
Restaurant, tea houses	Total floor area X 0.2 (m^2)
High class office buildings	Total floor area X 0.2 (m^2)
Ordinary office buildings	Total floor area X 0.1 (m^2)
Shopping center	Total floor area X 0.06 (m^2)
Financial and international trade complex	Total floor area X 0.2 (m^2)
Hospitals	Total number of beds X 2 (m^2)
Exhibition buildings	Total floor area X 0.2 (m^2)
Cinema, convention center	Total number of seats X 0.7 (m^2)
Gym and stadium	Total number seats X 0.7 (m^2)
Interesting and historical spots	Total area of land X 0.015 (m^2)
Parks, landscape spots	Total area of land X 0.006 (m^2)

Source: Guangzhou Urban Planning Bureau.

at red lights in Guangzhou. There are a few areas of the city in which on-street parking is restricted or one-way traffic has been implemented. The city has set maximum noise levels for motor vehicles, on the basis of national standards. There is some separation of motorized and nonmotorized traffic. Major streets generally have separate bicycle lanes, although motorbikes and other small motorized vehicles often are observed using these lanes, which technically is not allowed. Bicycles sometimes are observed using lanes designated for motorized vehicles only. In some cities, animal-drawn vehicles have been observed using motor vehicle lanes, even though animal-drawn vehicles are prohibited from entering the city proper in all of the major cities.

FUTURE PLANNING ACTIVITIES

Recommendations to help the city adjust to projected growth in private vehicles of all types were made in two major cat-

TABLE 5 Land Use Management Recommendations

Technique	Current Status	
	Under Study	Partly in Place
Encourage more intense use around subway stations	o	
Provide for mixed land uses	o	o
Plan land uses such that these are closer to the population from which they draw	o	o
Plan/design roads specifically for automobile traffic	o	
Provide incentives for the construction of pedestrian ways	o	
Require that design review include consideration of pedestrian ways	o	

TABLE 6 Traffic Control Recommendations

Technique	Current Status		
	Under Study	Partly in Place	In Place
License drivers			o
Increase traffic enforcement	o	o	
Facilitate carpooling	o		
Restrict the hours of truck operations in downtown areas	o	o	
Limit the availability of parking	o	o	
Require in-structure or off-street parking and/or loading areas	o	o	
Provide bicycle parking areas	o	o	
Require curb cuts and setbacks: control distance between & location of access points	o		
Separate traffic lanes	o	o	
Separate traffic signals for different modes of transport	o		
Separate streets at-grade		o	
Separate street segments for pedestrians, bicyles, and motorized vehicles	o	o	
Control street access	o	o	
Resolve intersection conflicts	o		
Create auto-restricted zones	o	o	
Require and set development impact fees	o	o	
Allow private construction and operation of roads	o	o	
Establish and/or increase toll facilities, licensing fees, use permits, and/or gasoline taxes	o	o	
Land lease--allocate % to roads	o	o	
Adopt tax increment financing	o		
Increase public awareness through education	o	o	

egories: land use management (Table 5) and traffic control (Table 6). The specific recommendations range from siting land uses in relationship to the population being served, to traffic signalization improvements, increased use of one-way streets, and the creation of reserved bicycle parking areas. These recommendations were made for the following reasons:

- To promote the use of alternative modes of travel;
- To reduce conflicts between motorized and nonmotorized transportation;
- To identify and control required transportation infrastructure;
- To improve traffic flow, regulations, safety, and management; and
- To establish appropriate transportation pricing strategies.

These recommendations are in various stages of implementation: some are under study and others are in place partly or wholly throughout the city. In general, much work remains to be done in this area; the problem, which is still fairly new, is difficult to acknowledge as being likely to increase in scope dramatically in future years.

CONCLUSIONS

Increased motorization more than likely is coming soon to China. In a sense, it is already there, at least in nascent form. On one hand, the overall level of motorization probably will remain low in China, at least by Western standards, for a very long time. On the other hand, the rate of growth in motorization is likely to remain high in China because of latent demand and a low initial starting point. Failure to recognize both the significance and the persistence of this trend, and to deal with it constructively, may result in severe problems in several areas, including the following:

1. Inappropriate land use patterns to accommodate future growth in both motorized and nonmotorized traffic;
2. Increasing dangers of personal injury and death to pedestrians and bicyclists, resulting from an increasing number of unavoidable traffic conflicts; and
3. Perhaps somewhat paradoxically, an even higher rate of growth in motorization than might otherwise occur, as a result of nonmotorized travelers' switching to faster and more convenient motor vehicles for a very different reason—safety.

China can avoid many of the most common mistakes that have occurred in the earliest stages of motorization by learning from and building on previous experience of countries such as the United States, Japan, and the European Community and taking those steps deemed to be necessary to mitigate the negative social, environmental, and energy impacts of automobiles. The first step is to improve traffic controls in anticipation of increased travel demand, so that traffic congestion does not lead to a loss of economic efficiency or reduced quality of life. The second step is to try to reduce the explosive rate of expansion in motorized transportation now being observed. Increasing motorization can be accommodated well only if it occurs at a gradual pace, to allow for the development of adequate infrastructure and to allow society time to make the necessary adjustments in lifestyle considerations and learning curves.

It is entirely feasible that China could go its own way in this matter, if it should choose to do so. It would appear that learning from the past experiences of others can produce ample rewards in terms of minimizing the many mistakes that are more likely to occur in an era of rapid change. Taking action at an early stage in the urban transformation process known as increasing motorization is very important for Guangzhou. By taking careful steps to promote appropriate mixed-use land development and to encourage demand management and supply enhancement strategies in the area of urban transportation planning and decision making, Guangzhou is at the leading edge of creating a more livable urban environment for both motorized and nonmotorized forms of transportation in developing countries such as China.

It is unlikely that the People's Republic of China will achieve levels of motorization equivalent to those in Western countries for decades. Yet, motorization is almost bound to occur, and at a relatively rapid pace at that. It is vital that transportation policy in China reflect the fact that nonmotorized transportation will remain important for many decades. Motorized transportation in China must be accommodated to nonmotorized transportation, rather than the reverse, if livable cities are to be created and maintained under these circumstances. Innovative and cost-effective solutions to the grade-separation problem, such as improved training and education on traffic safety, will most likely be important, given that diversity and complexity in urban travel markets is likely to be maintained for a lengthy period of time in China under current conditions.

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Bicycle Use in Urban Areas in China

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The bicycle is the most important personal mode of transportation in the urban areas of China. Currently, the domestic production of bicycles is not only extensive but also increasing very rapidly. In 1988 more than 310 million bicycles were in use. The causes of the intensive use of bicycles and their effects on urban transportation are identified, and measures to overcome these problems are analyzed on the basis of data from various sources. Several reasons for such intensive use of bicycles include (a) poor public transit service, (b) the relative cost of private modes of transportation, (c) adequate size and shape of cities, and (d) the bicycle's standing as a major industry in China. Hence, the importance of bicycles as an urban transportation mode is expected to increase. With the intensive use of bicycles, several related problems were noted: one is the high rate of traffic accidents involving bicycles, and another is the traffic congestion due to heavy bicycle traffic. Several measures to overcome these problems are being studied in China, such as reducing bicycle usage through the intensive construction of subways and properly managing bicycle traffic on the basis of basic studies related to the characteristics of bicycle flow.

The major modes of transportation in the urban areas of China are buses and bicycles. Bicycles, in particular, are the most important personal mode of transportation in China. However, the overabundance of bicycles has caused various adverse impacts to urban transportation. To mitigate these impacts, several countermeasures are being undertaken. This paper first briefly reviews the status of the bicycle traffic in China and then introduces the major countermeasures being considered.

OUTLINE OF BICYCLE TRAFFIC IN CHINA

Currently, there are more than 300 million bicycles in China (*1*). Since 1980 the annual rate of increase of bicycle ownership has been more than 10 percent. The number of bicycles in Tianjin is more than 7 million, which is 33 times the number of cars. In 1987 the ratio of passenger transport by bicycle reached 81 percent of the total daily trips in Tianjin; public transit accounted for the remaining 19 percent (*2*). In 1989, 37 percent of the total trips in Shanghai were made by walking, 35 percent by public transit, and the remaining 25 percent by bicycle. In Beijing, the ratio of trip by public transit is only 57 percent. These are the three largest cities in China; they have relatively higher levels of service of public transit than other cities. Hence, it follows that the bicycle is the most important mode of transportation in China.

The modal choice ratio of the bicycle is greatly related to the trip distance and physical condition of users. From the origin and destination survey conducted in the city of Nanjing, the relationship between trip time distance and modal choice ratio is as shown in Table 1 (*3*). In Nanjing, with a trip distance within 10 to 30 min, the ratio of the bicycle is the highest of all modes, which exceeds 50 percent. It is said that the average modal choice ratio of bicycle is about 35 percent in Japan (*4*). The ratio is even lower in European countries. Judging from these ratios bicycle usage is very intensive in China. Table 2 shows the relationship between modal choice ratio and ages of users (*3*). In Nanjing, which is a typical large city in China, almost half of the people between 15 and 49 years old use bicycles very often, but most people younger than 14 and older than 59 make trips by foot.

There are both merits and demerits in the wide usage of bicycles. Saving energy and reducing exhaust gas are examples of benefits, but increasing traffic accidents is one of the demerits. The ratio of bicycle-involved accidents reached 30 to 50 percent of the traffic accidents in urban areas and 40 to 70 percent of the fatal traffic accidents in China. In 1989, for example, bicycles in Shanghai were somewhat responsible for about 32 percent of the traffic accidents and 37 percent of the fatal traffic accidents out of the total of 7,527 traffic accidents. Moreover, the number of car-bicycle collisions in Shanghai was 2,254, which was more than the number of car-pedestrian collisions (1,272) in 1988. The latest figure shows that the number of car-bicycle collisions was 1,087 and the number of bicycle-pedestrian collisions was 686 from January to September in 1989 (*5*).

TABLE 1 Relation Between Trip Time Distance and Transportation Mode in Nanjing

Distance (Min)	Walk %	Bicycle %	Public Transport %
≤10	52.6	44.0	2.0
11-15	39.0	55.7	3.7
16-20	35.5	52.8	9.2
21-25	27.5	52.5	17.3
26-30	21.9	50.9	23.7
31-35	13.6	36.0	43.7
36-40	11.6	35.6	45.4
41-45	8.0	32.7	50.6
46-50	8.2	24.9	58.2
51-55	6.0	19.9	64.4
56-60	7.0	6.2	62.9
>60	7.6	14.4	15.0

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TABLE 2 Relation Between Age of User and Transportation Mode in Nanjing

Age	Walk %	Bicycle %	Public Transport %
6-14	84.2	8.1	6.0
15-19	35.8	43.6	19.0
20-24	16.5	54.2	25.8
25-29	13.0	58.0	24.6
30-39	15.0	58.5	21.1
40-49	28.7	47.4	20.1
50-59	42.9	36.5	17.0
>59	61.3	20.7	15.7

REASONS FOR POPULARITY OF BICYCLE USE

Low Level of Service of Public Transit

In 1988 about 48,000 buses and trolley buses were used for the public transit service in more than 322 of 431 cities in China (*6,7*). The number of buses increased 14 percent a year from 42,000 in 1987. Buses, the major mode of public passenger transportation, carried 26.8 billion people in 1988. The ridership increased by about 2.8 billion in 1987. Although ridership looks very large, it is small in comparison with its population of 1.1 billion people. The low level of service of public transit is characterized by its average passenger density of 10 to 13 people per square meter in peak hours. Accordingly, the average ridership of public transit is very small; it was about 20 percent in Tianjin in 1987.

Subway systems serve in Beijing and Tianjin only. The total number of subway coaches is 274, and the passenger volume is about 31.9 million a year (*6,7*).

The number of taxis is very small—only 13,223. This is much lower per capita considering that there are only 0.93 taxis per 1,000 people in Shanghai, 1.18 in Beijing, and 2.56 in Guangzhou (*8*,p.12). In addition, taxis are used mainly for foreigners and tourists, not for daily transportation.

Economic and Financial Background

Because bicycle production is a major industry in China, the increase of bicycle production is highly encouraged by the government. Bicycle production accounted for about 5 billion yuan in 1984, which is approximately 0.5 percent of China's gross national product (*9*). The number of bicycles produced was 13 million in 1980, 28.6 million in 1984, and 41.2 million in 1988 (*1*).

During the oil crisis from 1949 to 1965, the Chinese government encouraged walking and riding bicycles because of the shortage and high price of petroleum. Since the accident rate of motorcycles is high, the Chinese government now restricts the use of motorcycles in urban areas. The average prices of personal modes of transportation in China are as follows:

Mode	*Price (yuan)*
Bicycle	200–400
Motorcycle	3,000–15,000
Car	80,000–200,000

The typical price of an ordinary bicycle is about 200 to 400 yuan (4.6 yuan = $1.00 U.S.) The average monthly wage of workers is about 150 to 200 yuan, which makes the bicycle affordable. In addition to this, the Chinese government subsidizes $20 (U.S. dollars) a year to the bicycle commuter, although the amount depends on the city. Consequently, it is normal for bicycles to be the major mode of personal transportation in the urban areas of China.

Size and Shape of Cities

The typical trip length by bicycle is about 6 km, or a ½-hr ride in China (*10*). The area of a circle with a 6-km diameter is about 30 km^2, and the area of most Chinese cities is less than this. This is one of the reasons that bicycles can be useful for personal transportation. Likewise, bicycles are also important in large cities, considering that most of the large Chinese cities have only one central business district, in which almost all the commuters gather. The commuting pattern looks like the diagram shown in Figure 1. The area for this case is about 113 km^2, but the area of most of large cities is less than 100 km^2. This is the reason that bicycles are useful even in large cities. Accordingly, a bicycle trip can easily cover the commuting areas in most Chinese cities.

Easiness of Bicycle Use

From Table 2, more than one-third of people between ages 13 and 59 use bicycles. Moreover, more than 20 percent of people—even those older than 60—use bicycles. This is partly because bicycles are very easy to handle. It is said that people between 13 and 70 years old can ride a bicycle after a week of practice.

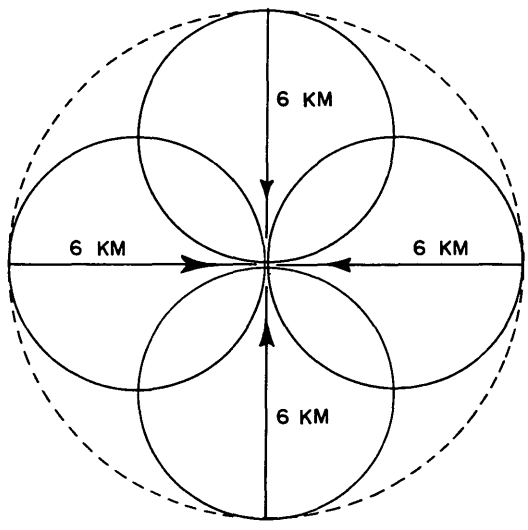

FIGURE 1 Schematic diagram of bicycle trip pattern in large Chinese cities.

EFFECTS OF BICYCLE TRAFFIC ON URBAN TRAFFIC CONDITION

The heavy bicycle traffic has caused various problems for urban traffic. Traffic accidents involving bicycles are the issue for which the influencing extent is the smallest but the most serious. Inefficiency of road usage is the issue for which the influencing extent is the largest. There are many issues between these two; major ones follow.

Traffic Accidents Caused by Heavy Bicycle Traffic

Figure 2 shows a schematic diagram of traffic flow at a crossing when the traffic signal is green. As bicycles mingle with cars, the chances of collision become great. When lanes for cars and bicycles are not properly separated, serious traffic accidents sometimes occur because bicycles suddenly turn left to cross a road. The ratio of accidents of this type is about 30 percent in Shanghai (*5*).

Reduction of Vehicle Speed

At Drum Building Square in Nanjing, the average vehicle speed decreased from 18.14 km/hr in 1983 to 11.17 km/hr in 1989, which corresponds to the increase of volume of bicycle traffic from 163,142 bicycles in 1983 to 277,469 in 1989 (*11*). Similarly, at Sanjie Street crossing, the average car speed decreased to 8.78 km/hr in 1989 from 15.59 km/hr in 1983, which also corresponds to the increase of bicycle traffic volume in 8 years from 114,410 bicycles to 203,528.

Inefficiency of Road Use

Compared with buses, bicycles do not fully use road capacity. The 1988 data obtained by authors in Guangzhou give the following facts. During peak hours, the average speed of bicycle is 5 to 8 km/hr with a required road area of 3.8 to 5.1 m^2/bicycle. During off-peak hours, the speed is 13.8 km/hr with a required area of 8.1 m^2. This means that eight bicycles are equivalent to one large bus in terms of required road area. Because the number of bicycles in Guangzhou was 1 million in 1988, bicycles require the same area as 125,000 buses. As for the traffic capacity, a large bus in China can accommodate 160 passengers. A million passengers can be transported by only 6,250 buses. Although these are rough estimates, we can deduce that bicycles are very inefficient in terms of road usage. This fact could possibly lead to more investments in road construction in urban areas.

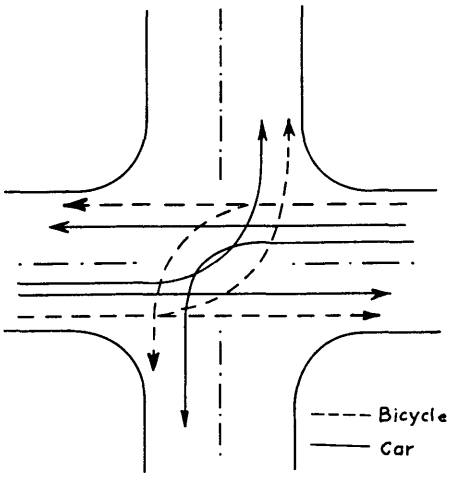

FIGURE 2 Schematic diagram of traffic flow at crossing when traffic signal is green.

EFFORTS TO MITIGATE ADVERSE EFFECTS OF BICYCLE TRAFFIC IN CHINA

China is one of the world's leading bicycle users. The development of mitigation measures that influence bicycle traffic is one of the most crucial issues in China.

Separation of Car and Bicycle Flows

Figure 3 shows a typical cross section of a road in an urban area. It is considered that physically separating cars and bicycles is the best way to reduce accidents between them. Separation is tried even at a flyover in China. Figure 4 shows the plan of the flyover, at which lanes exclusive for bicycles are installed in Beijing (*12*).

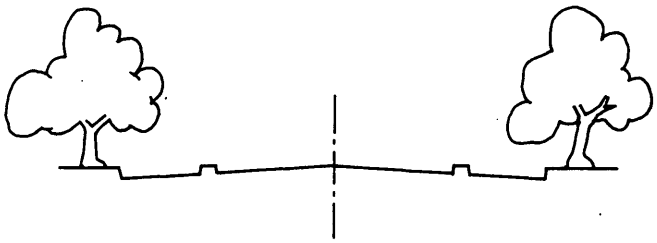

FIGURE 3 Standard cross section of road in urban area.

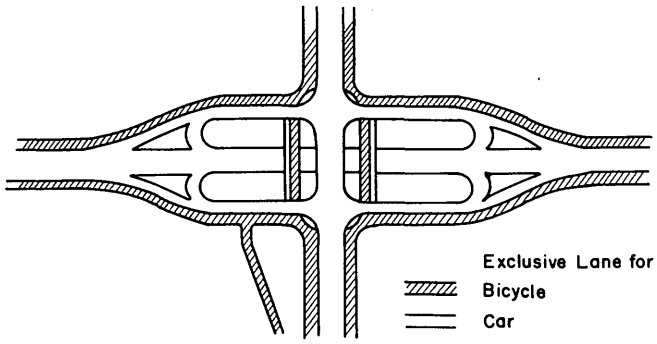

FIGURE 4 Plan for flyover with exclusive lane for bicycles in Beijing.

Level of Service of Public Transit

There is an adequate mix of transportation modes depending on the scale of cities, population density, available mode of transportation, and so on. Generally speaking, the ratio of bicycle use in urban areas in China exceeds this adequate level. Chinese engineers and planners consider the importance of diverting bicycle users to public transit by raising the level of service of the public transit system. The severe shortcomings of the public transit in China are its slow speed and congestion. However, efforts to raise the level of service of public transit are being undertaken. The first concern is to increase the average speed of buses on trunk roads. The low road density in urban areas makes it difficult to build exclusive lanes for buses in China. Hence, measures based on transportation system management are considered for the major policies.

In the central district of Shanghai, bicycles are prohibited in some roads; they are also prohibited from turning left at some crossings during peak hours. The traffic congestion problem on arterial roads is solved to some extent because bicycles do not necessarily suffer from these restrictions, because they can use the secondary roads near the main road. However, this may inconvenience bicycles and increase the danger to pedestrians on secondary roads. Since the bus service is the only public transit in Shanghai now, full use of bus is the only possible measure to solve the transportation congestion problem. Substantial improvements, such as construction of new roads, are almost impossible, although the subways are now being constructed. To improve the total performance of road usage, restriction of bicycles on arterial roads is almost the only measure. As for the increase of danger to pedestrian, we can only expect a level of danger that is less with the bicycles than with the vehicles. With this restriction, the average speed of vehicles on the main roads has improved.

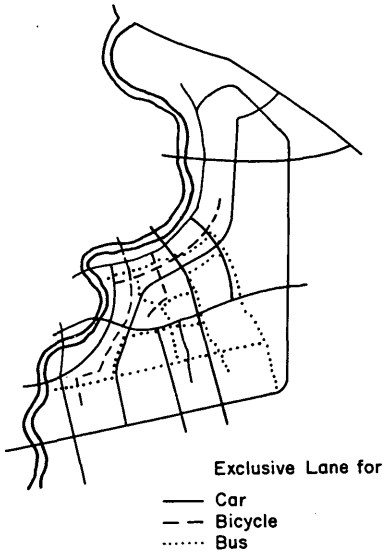

FIGURE 5 Road network system in new economic development district near Shanghai.

An increase of bus speed by 0.5 km/hr and 1.5 km/hr increases the transportation volume by 9.5 percent and the transportation capacity by 14.5 percent, respectively (*13*).

In long-range planning, construction of public mass transit systems, such as subways, is required and is now under consideration.

Improvement of Road System in Urban Area

Taking the side of long-range planning of roads, the improvement of the road system in urban areas should be considered. One major point is to consider bicycle traffic in the planning stage. Figure 5 is an example of this that shows the road network system in the new economic development district on the east side of Huanpu River near Shanghai (*14*). It is noted that an exclusive road for bicycles was planned from the beginning.

CONCLUSIONS

From the foregoing discussion, we can conclude the following:

- Overintensive use of bicycles causes urban transportation problems in China. Considering the importance of the bicycle because of the lack of sufficient public transportation, the solution to this problem is not to eliminate bicycles but to find adequate measures of coordination of bicycle and other mode of transportation.
- Overuse of bicycle in urban areas may harm the urban transportation system. The level of bicycle usage should then be kept within an adequate level in accordance with the urban development.
- In long-range planning, exclusive roads for bicycles should be considered.

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Planning for Low-Cost Travel Modes in Ningbo, China

WALTER JAMIESON AND BRENDA L. NAYLOR

Economic, social, and technological forces constitute new stresses on the transportation systems of many of China's cities. There is a need to go beyond western models of transportation planning that meet the needs of motorized traffic and recover and discover models that can more appropriately accommodate low-cost modes in mixed traffic environment. Ningbo, a city south of Shanghai, is a typical case. A joint Chinese-Canadian study there found a high level of support for bicycle use on the part of the general public, low satisfaction with public transportation, ineffectual enforcement of existing regulations, poor integration between various levels of planning officials, insufficient levels of funding for low-cost travel modes, and little awareness on the parts of officials and professionals on what to do with bicycles. Changes in national priorities are needed with more emphasis placed on existing and improved environmentally friendly and economically feasible travel modes, given China's national priorities and resources. Local strategies must broaden to include a range of network and physical changes, as well as restructured management and planning, including more integrated means of decision making, and adoption of strategic planning. Strategies suggested are not new, but they demand a new approach. Ensuring implementation will require political and professional change in attitudes and practices: Western models of transportation planning are environmentally, socially, and economically incompatible with present realities. In many aspects the current Chinese transportation system, which relies heavily on low-cost travel modes, is leading edge and could become an international model for future transportation planning.

The initial objective of the Ningbo Low-Cost Travel Modes Study was to document and evaluate the existing role for low-cost travel modes in meeting the needs of the urban population and present guidelines for low-cost modes' inclusion in the overall planning process. Urban transportation system infrastructure and operating characteristics, trip and user characteristics and attitudes, and planning and administrative frameworks in the city of Ningbo (province of Zhejiang), People's Republic of China, are profiled in this study.

The role of nonmotorized modes is considered to be as important as public transit in essential daily trips; the restriction of private motor vehicle use is advocated in mid-sized Chinese cities (*1*). Such recognition would seem to ensure continued prominence for low-cost modes, but several problems have been reported over the past decade that affect the public's and policy makers' perceptions alike:

- Alleged decreasing safety, with a perception of a rising number of accidents and deaths involving bicycles in conflict with motorized vehicles;
- Congestion on inadequate road systems leading to decreased speed of motorized transportation particularly public buses, leading to still greater numbers of bicycles in use; and
- Overlapping functions and often inappropriate design and management of the urban street.

In addition, reports in journals and newspapers and conversations with bureaucrats reveal bias against low-cost modes (*2*,*3*). Cities such as Taiwan, Los Angeles, and Houston were often cited as good city models.

METHODOLOGY

Statistical and other data were obtained from a number of sources to provide information on Ningbo's current situation. Key informant interviews with bureaucrats and policy makers revealed some constraints to particular transportation planning approaches and management measures in the Chinese urban center.

To investigate user characteristics and perceptions of the transportation system, two major surveys were conducted. The first questionnaire was administered to every worker and student (12 years of age or older) in 150 households (N = 390). Household and individual level variables detailed mode choice, satisfaction, perceptions, and trip characteristics. A second survey examined 900 women's daily travel experience and their perceptions. Data collected provided information about usual modes of travel for various activities, perceptions of advantages and disadvantages of modes, concerns about personal travel and the overall transportation system, as well as suggestions as to how to improve it. Videotaped and personal observation of travelers' and traffic managers' behavior complemented the more quantitative information, concentrating on identifying traveler behavior and compliance with regulations and enforcement officials.

NINGBO

There is no attempt in this paper to provide a fully developed political, economic, and physical context for the case study. Our intent is only to provide sufficient information to evaluate the suggested changes to the city's transportation management and planning approaches.

As illustrated in Figure 1, Ningbo is 225 km (140 nautical-mi) south of Shanghai, and 19 km inland from its harbor on the East China Sea. The city has been continuously occupied for more than 1,200 years. Situated at the confluence of two

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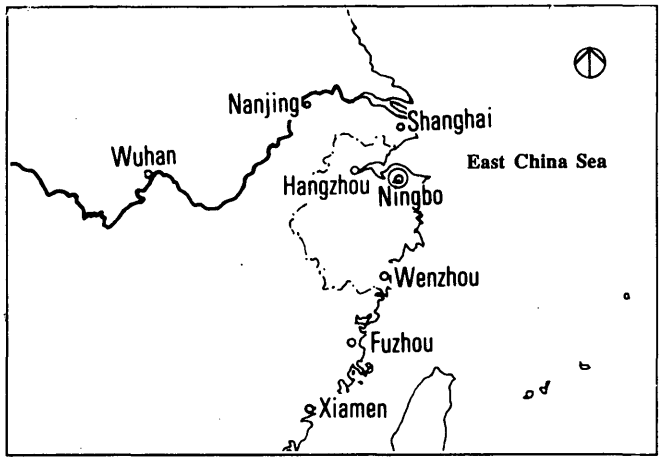

FIGURE 1 Location of Ningbo.

rivers, the city is divided into three zones: Haisu, the formerly walled feudal city, and its outlying suburbs (characterized by an organic street layout); Jiang Dong, the east river, a new residential area; and Jiang Bei, the north river, a largely industrial zone. The three zones (shown in Figure 2) cover less than 65 km^2. The organic layout of Haisu covers nearly 29 km^2 and had an urban population in 1990 of 429,368 (*4*). Haisu is characterized by a mixture of functions, accommodating residence, commercial activity, and financial, administrative, and trade offices. The newer districts house about 50 percent of the urban population and include light industrial zones as well.

Designated as one of 14 open coastal cities in 1984, Ningbo is empowered to pursue foreign investments [up to $5 million in value (*5*)] with relative autonomy. The cities so designated

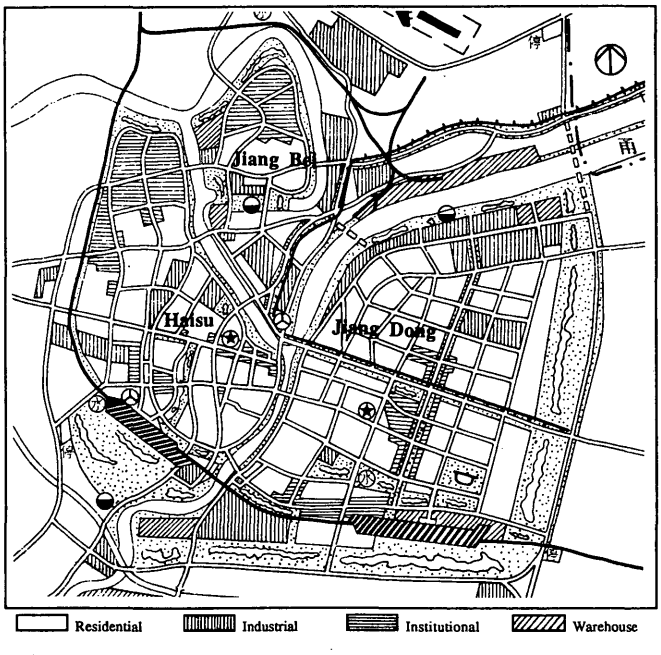

FIGURE 2 Ningbo city zones and land use designated in master plan.

are expected to act as growth poles for the surrounding region (*6,7*). Ranked 10th of 467 urban centers in China for its growth in gross industrial product (Weng, unpublished data) [up from position 16 in 1984, and 13 in 1986 (*8*)], Ningbo commands a higher-than-average degree of foreign and domestic investment in infrastructure. The agricultural sector contributes 11.4 percent of annual total value of Ningbo production; light and heavy industries constitute 60 and 40 percent, respectively, of the total industrial sector output (88.6 percent of Ningbo's total annual production value). Nonagricultural enterprises, in addition to freight handling, include textile production, food processing, shipbuilding, petrochemical and petroleum processing, and mechanical and electronic equipment manufacture (*8*).

In 1990, 72.9 percent of Ningbo household residents were wage earners, and the average family size was 3.16. Living area was 8.5 m^2/person, up from 7.2 m^2 in 1984. Expenditures on goods comprised 91 percent, and services 8 percent, of expenses, with food absorbing the largest proportion of spending, at 56 percent. There were 222 bicycles for every 100 households in 1990, exceeded only by the ownership of electric fans, at 265 for every 100 households (USEIT, unpublished data).

Since 1979 the increases in numbers of motorized vehicles and bicycles in Ningbo total 390 and 350 percent, respectively. In Ningbo there is one bicycle for every 2.4 persons and one motorized vehicle for every 98 residents. Almost all the motor vehicles are owned by work units and government departments. In 1989 heavy-duty tricycles and handcarts (commonly used in inner-city goods distribution) numbered about 10,000. Recently, policy was introduced that disallows licensing any new vehicles of these types, aimed at decreasing usage through attrition (Traffic Police, unpublished data).

One difficulty in assessing the present and future use of the transportation system is the existence of a large "floating" population, including tourists, traveling business people, visitors, temporary workers, market sellers, and shoppers. Their total numbers represent 10 to 12 percent of the registered urban population in some centers (*9*).

TRANSPORTATION SYSTEM

Road Network

Typical road sections are normally of only two types: (a) crowned road surface from curb to curb with sidewalk provided either side of the carriageway, or (b) separate laneways demarcated or fenced off for bicycles (and other nonmotorized travel), again with sidewalks provided on the outside of these lanes. Lanes and alleys typically have no separation of modes and vary in width, surfacing, and alignment (Figures 3 through 6). These normally serve mainly as access routes for local traffic and goods delivery vehicles. Nearly 60 percent (123.6 km) of the total road length of 216 km is in lanes less than 3.5 m wide; about one-third of the road length comes in roads 10 m or more wide. (Weng, unpublished data.)

There is competition between through traffic and destination-oriented traffic in the city center, and conflicts also arise from competition between different street users. Hawkers compete for street or sidewalk space with pedestrians, and cyclists and

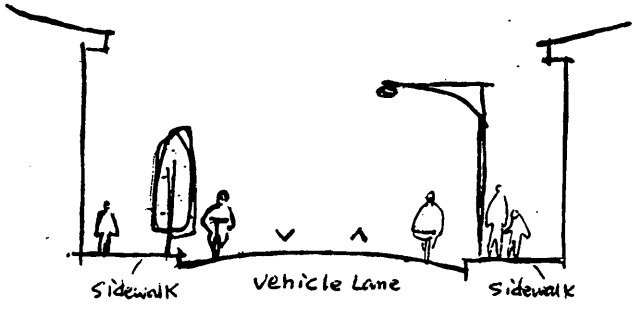

FIGURE 3 Typical street sections: Main Street with lane marking.

residents carry out domestic chores or socialize on the streets fronting their residences.

Public Transportation

Public transportation is used by only 3 to 4 percent of urban residents for regular trips. A total of 15 routes operated in the Haisu and old city zones in 1990, with the earliest run starting at 5:10 a.m. and the latest run at 9:20 p.m. However, most service finishes between 6:30 p.m. and 7:30 p.m. The floating population and visitors constitute a large proportion of passengers. Fleet size now totals 223, or 1 vehicle for every 1,900 (registered nonagricultural) residents, an increase in vehicles of 128 percent since 1978. Fares were raised in July 1990, leading to a decrease in ridership, increase in profits, and decrease in investment by local government. (Public Transportation Company, unpublished data)

Trip and User Characteristics

Modal Split

The overwhelming majority of daily commuting trips are made by bicycle, as shown in Table 1. However, mode choice does vary by sex, age, and activity: women make greater use of public transportation, and their frequency of cycling declines at a younger age.

Trip Duration

Daily commuting trip durations are distributed as shown in Table 2. City planning aims to enable most residents to reach their workplace within 30 min, and this has been largely accomplished: nearly 80 percent of commuter trips meet this standard.

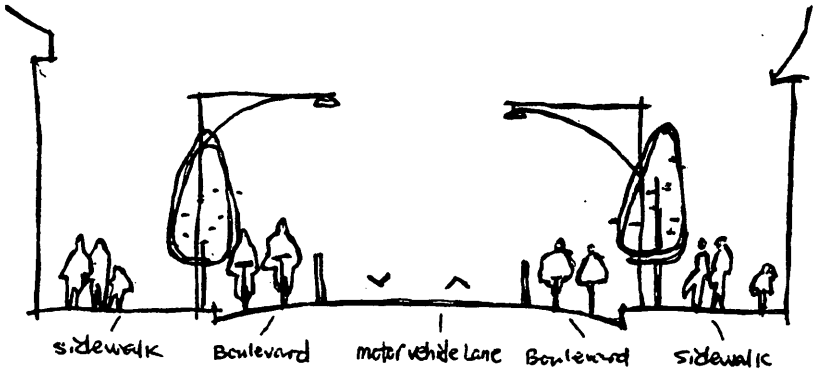

FIGURE 4 Typical street sections: Main Street with separating fence.

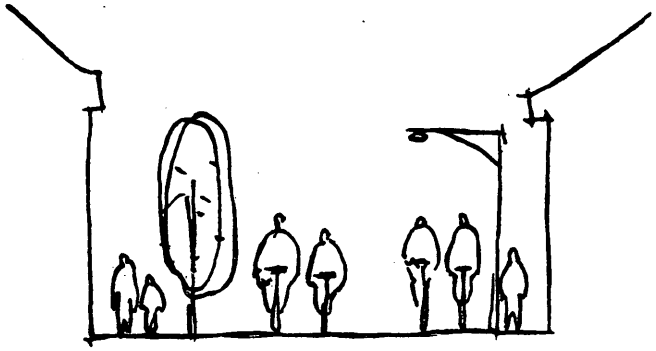

FIGURE 5 Typical street sections: Service Road 1.

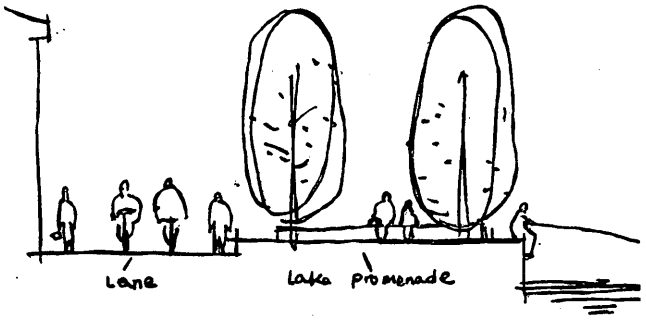

FIGURE 6 Typical street sections: Service Road 2.

TABLE 1 Modal Split for Various Activities, Two Surveys

	Commuters						
	Full Sample			Women Only Sample[b,c]			
Mode (%)	Total[a]	Male[a]	Female[a]	Work	Shop	Escort[d]	Visit
Walk	11.5	8.1	15.6	17.9	60.3	17.2	12.5
Cycle	82.3	86.3	77.7	75.9	38.7	82.8	70.1
Bus	4.0	2.8	5.6	4.8	1.1	--	17.5
Unit Bus	1.8	2.4	1.1	1.3	--	--	--
Motorcycle	0.3	--	--	--	--	--	
N	390	211	179	756	672	181	887

[a] Ningbo Commuters Survey, June, 1990
[b] Ningbo Women's Travel Survey, July, 1990
[c] refers only to those reported carrying out the activity
[d] escort child to school/care

TABLE 2 Trip Duration: Total Sample by Sex and Mode

	By Sex (%)		By Mode of Travel (%)			
Time (min)	Male	Female	Walk	Cycle	Bus	Unit Bus
t<20	23.7	13.4	46.7	16.5	0.0	0.0
20≤t<30	38.4	43.0	35.6	43.9	6.2	0.0
30≤t<40	18.5	21.8	6.7	22.7	6.2	14.3
40≤t<50	14.7	16.2	8.9	15.6	31.2	14.3
50≤t<60	2.8	3.4	2.2	0.9	25.0	42.9
t ≥60	1.9	2.2	0.0	0.3	31.2	28.6
TOTAL[a]	100.0	100.0	100.1	100.9	99.8	100.1

SOURCE: Ningbo Commuters Survey, June, 1990
[a] may not total 100% due to rounding

Satisfaction with Transportation Modes

Saving labor and controlling time of arrival were the major reasons cited for bicycle use. Less than 14 percent of respondents to the commuter survey reported being fairly or very dissatisfied with their current modes, although riders may discount their dissatisfaction in the face of a lack of viable alternatives. Of those dissatisfied, 58 percent would change their modes (almost 40 percent of these prefer to use a motorbike), while the remainder would change their workplace or residential location (18 percent each). Five problems of cycling cited by nearly equal numbers of respondents were parking problems, frequent breakdowns, theft, weather, and road conditions.

Lack of satisfaction with the public transit system explained low ridership levels—less than 12 percent reported being fairly or very satisfied with the bus service, and a third were fairly dissatisfied. Top reasons for dissatisfaction were long waiting time (39 percent), overcrowding (33 percent), and not running on time (17 percent). In both surveys respondents indicated a desire to use the bus if routes and operating schedules were more convenient.

Perceptions of Transportation System

In the commuter study, more than 60 percent reported that the traffic situation was somewhat better than it was before (the survey question was not specific as to period of time). Only 10 percent believed the situation to be worse or much worse. This contrasts with perceptions of the women surveyed: 55 percent perceived walking and 71 percent perceived cycling to be more dangerous than they were 5 years ago. (Wording of the two questions could have influenced the responses.)

Women respondents were asked to identify Ningbo's most significant transportation problem. Congestion ranked first (40 percent); a concern for road conditions was identified by 25 percent of respondents. Public transportation ranked third with almost 15 percent.

Accidents

Less than 6 percent of cyclists reported having had an accident in the last 2 years, although in the women-only survey there was a slightly higher proportion of reported accidents (probably due to greater specificity regarding the definition of accident). Conflicts with other modes of nonmotorized transportation were most common, and conflicts with roadway obstacles were next most common. No conflicts with pedestrians were reported. Reasons that survey respondents cited for accidents included congestion and poor traffic management, as well as carelessness and high rate of speed. The Ningbo Traffic Police attributed accidents to poor traveler behavior due to lack of education, poor layout of streets, distribution of flows, congestion, and poor vehicle maintenance (Traffic Police, unpublished data).

There is no clear relationship between the rising ownership of either nonmotorized or motorized vehicles and fatalities. The number of fatal accidents fluctuates considerably; it has declined 10 percent since the 1987 peak of 51 deaths. Injury accidents have also declined, to 130 in 1990—less than half the peak of 304 in 1986.

Enforcement

Traffic police appeared to be ineffectual; it was often noted that they merely observed traffic rather than contributed to

its efficient and safe operation. Retired workers are often employed as traffic wardens, serving a community enforcement role. Usually they carry out their duties with care, and often with zeal, but few reprimands or fines were administered by any authorities. When questioned as to why greater enforcement efforts were not directed at cyclists, bureaucrats and researchers responded that it would be "unfair" to single out any individual rider, because many were probably disregarding the regulations.

PLANNING AND ADMINISTRATIVE FRAMEWORKS

National Urban Transportation Policy

In 1983 a meeting of 180 Chinese local- and national-level transportation planners and researchers from various city departments, industries, and schools investigated the role of bicycles in urban transportation (*10*). They assessed the merits, problems, and evolving trends of the bicycle, and recommended some measures to constrain bicycle and private motorized travel. Paralleling conclusions found in the national policy, these measures centered on the following:

- Renovating and constructing new transportation facilities, including channelization; providing parking lots; and redefining the route network for various modes;
- Encouraging public transportation system development by incorporating consideration of accessibility by secondary modes and using park-and-ride facilities where possible;
- Restricting private motorized vehicle use and controlling nonmotorized modes of transportation achieving a modal split based on city size. Transit is to predominate in large cities (population more than 500,000); transit and nonmotorized transportation are to share the load in medium-sized cities (population 100,000 to 500,000); and bicycles are to be dominant in small centers;
- Improving traffic control; and
- Improving transfer between inter- and intracity trips and decreasing the numbers of through travelers in the center city.

As well, other unpublished research on personal transportation in Beijing concluded that

- Travel demand management could improve the efficiency of existing facilities;
- Priority should be given to public transit system development;
- Taxes should be levied on users of private motor vehicles;
- Public education campaigns should be stepped up; and
- Further research should be carried out on research methods, effects on transportation of rising socioeconomic welfare, and land use–transportation interactions.

Ningbo Planning Framework and Environment

Ningbo's transportation system is managed by a number of departments of the municipal government, as outlined in Figure 7. The Municipal People's Congress (revolutionary committee), or a standing committee appointed by it, has final decision-making authority on plans and projects. In Ningbo the planning and building bureau proposes projects and programs, which are discussed at the committee level, with input from the urban and rural construction, taxation, and financial committees. The results of these discussions are submitted to the mayor for his or her discussion and approval or that of the Municipal People's Congress (or the standing committee of same).

Bureaus under each of the commissions "may communicate directly with the bureaus under another commission on matters on which policy decisions have already been coordinated" (*11*). New issues must move upward to the commission heads for joint discussions and agreement before any action is taken by lower levels. Even with regular formal and informal consultation, the potential for fragmented and contradictory policy setting is evident.

Land Use and Transportation Planning

In contrast to the past national promotion of mixed use of urban space, single-function zones are apparently being adopted in some cities that are looking to industrialized nations for "modern" urban plans. Ningbo plans to redevelop existing central commercial space (after this function's relocation to less-traveled streets) into a financial and administrative center, along the lines of "downtowns" in Western cities. Already, most major commercial buildings are single function, with no recognition of the opportunity to accommodate multiple functions separated vertically. New residential highrises in the central city do, however, provide retail space on the ground level, and office space on one or two floors above (Weng, unpublished data).

The employer has typically provided housing, near the workplace (*12*). Common planning considerations in new suburban neighborhood layout mean that services such as daycare, health care, general services, and markets are regularly incorporated in residential neighborhood design. Daily activity travel is minimized by such considerations, but reconstruction and change of functions in the central city will exacerbate congestion and conflict as workers, business people, and patrons converge on the new "downtown." Housing shortages and universal employment (with adult family members often employed at different work units) also have a detrimental effect on this effort to manage transportation demand.

Policy and Management Responses

Ningbo has constructed facilities and instituted a number of management approaches and measures to mitigate congestion and safety problems. These include restricting the travel of certain modes on designated routes during peak hours, relocating commercial centers to separate through from destination traffic, soliciting cooperation of key employment units to introduce staggered work hours, providing motor vehicle and bicycle parking lots, constructing bridges, increasing capacity on key routes, and completing outer and inner ring roads. In addition, consideration is being given to eliminating bicycle allowances, increasing direct subsidies to public trans-

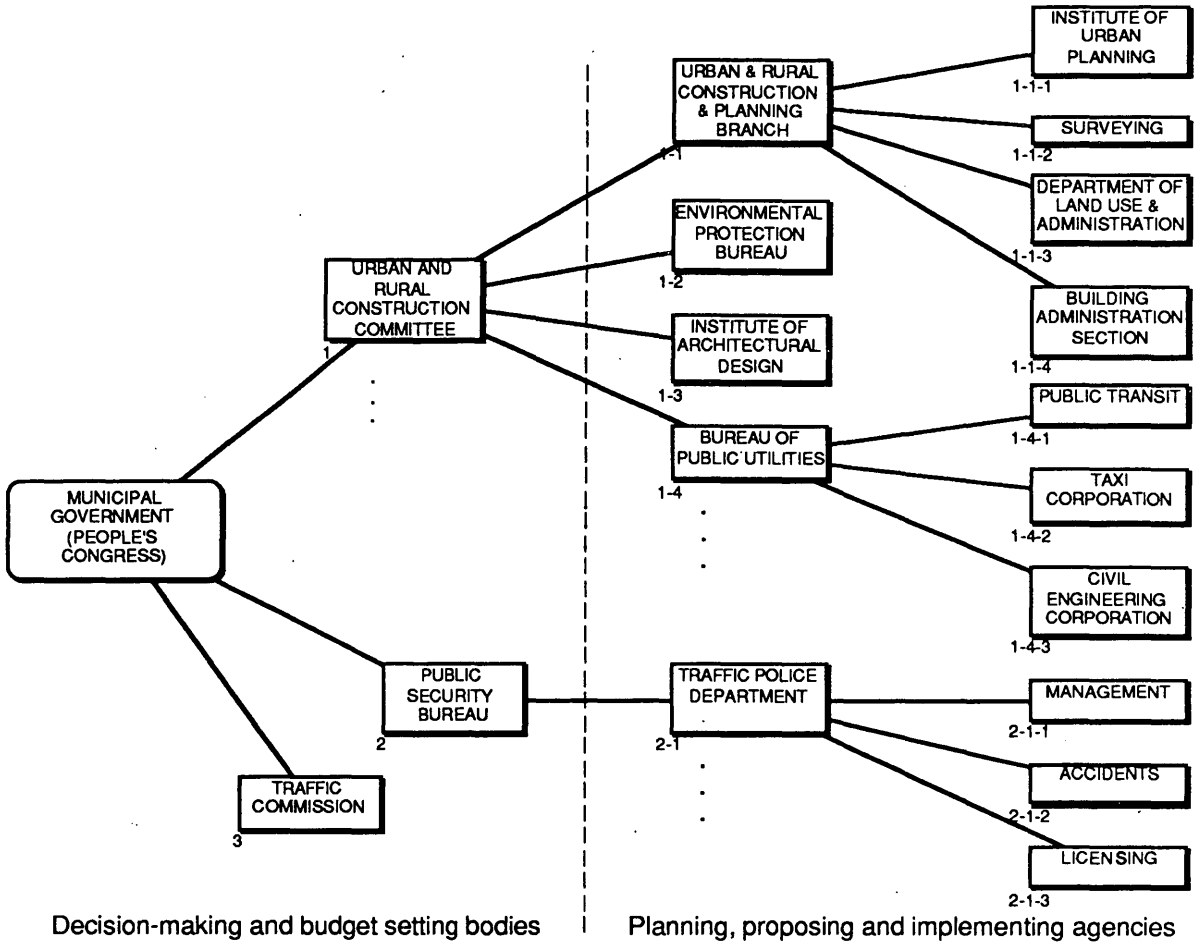

FIGURE 7 Ningbo transportation system management.

portation passengers, instituting a trolley bus system, developing new cycling regulations, and increasing the number of enforcement officials.

ANALYSIS

Key Issues

Network

The network suffers from a lack of space, a problem made worse by inefficient management. Because there is little unoccupied land in the urban center to accommodate new traffic facilities (for movement or storage), the result is the destruction of existing buildings and consequent alteration to traditional urban form. Few major roads cross the old city from east to west and from north to south, and desired lines do not match available routes, leading to the underuse of some roads and congestion on others. Most roads are very narrow, too, exacerbating conflicts between different users; current transportation policy does not employ prioritization of functions and separation of modes to good effect. Nor are intersections designed to enhance the safe movement of a mix of modes. Although both design and management measures have been adopted in Ningbo, these have been done on a piecemeal basis, and little evaluation of their effectiveness has been made.

Trip/Users

The impact of poor management measures is especially clear when examining the proportion of travel undertaken by bus. Because the buses in service cannot access smaller side streets, they are confined to running along the same few major routes. In 1990, 7 of 12 routes plied the same east-west connector in the Haisu district. Along this route, cycles are separated from motor vehicles by shoulder-high opaque barriers, and no pull-outs are provided at bus stops. Passengers disembark into the cycling lane and must cross it to the sidewalk, which is also fenced off along most of this road's length.

Of the alternatives available to the Ningbo commuter, the bicycle clearly suits the transportation network that currently exists and so is favored by Ningbo residents. Cycles can use the narrowest footpaths; they are affordable, able to maneuver around most obstacles, and not subject to delays caused by frequent stopping and starting on most routes. Thus, it is clear that use of cycles will persist and even grow.

Planning Framework

In the area of planning and administrative frameworks, the research showed that communication problems between political and bureaucratic levels as well as within the bureaucracy are a considerable impediment to planning and decision making that can deal with the extant economic and environmental imperatives. Whereas many of these problems exist in North American governments, the problem in China is compounded by animosities going back to the Cultural Revolution. In addition, there are serious gaps in the training of professionals that are also a legacy of the "Chaos," and the system of connections (*guanxi*) affects the degree of influence that policy team members may have on implementing solutions, or it affects cooperation between team members.

The newly instituted government-controlled market economy is a significant unknown. It introduces new uncertainties to the planning and decision-making framework. This change in economic structure coincides with a general devolution of authority in a number of areas (taxation, enterprise ownership, financing, policy and regulatory reform) to municipal governments, giving greater autonomy in planning (*13*).

The lack of a broad range of insufficient and easily accessible high-quality information and data contributes to inappropriate or ineffective policy decisions. Ningbo has no up-to-date land use inventory and plan, although the 1983 version is being revised. Whereas a municipal government unit is charged with undertaking social and economic research on a regular basis, the information gathering of planning agencies appears to be more sporadic and project-based.

Suggested Transportation Policy Goals

To be able to assess the adequacy and effectiveness of current and proposed policy and projects, one must have clearly articulated goals. Alternatives proposed for Ningbo derived from identification of an "ideal state" for urban transportation:

- An improved level of choice between travel modes is achieved over a range of distances, especially for the aged, children, the infirm, and so on.
- Consideration of low-cost travel modes is an integral part of the transportation and urban planning process, ensuring that the needs of the user of low-cost travel modes are met in all land use and transportation decisions.
- Low-cost travel modes continue to be developed for individuals and society, and associated acquisition, operation, and accommodation costs are appropriate to best accomplish the mix that ensures that the transportation system meets users' needs.
- Low-cost modes should remain (a) adequate (as measured by proportion of population—especially the disadvantaged—served by low-cost modes), (b) efficient (as measured by levels of service obtained on the network), (c) convenient (as measured by acceptable time to travel to work or school on the chosen mode), (d) safe (as measured by accidents), (e) healthy (as measured by air quality), and (f) pleasant (as measured by the user's perception of sensory and aesthetic environment).
- User participation and consultation is incorporated and valued as a necessary component in planning for low-cost travel modes.

Urban planners would be expected to make explicit reference to these goals in preparing proposals, officials to consult them in decision-making, and evaluators to develop criteria that indicated the degree of success in meeting them.

National Initiatives

The project team proposed a number of initiatives to improve transportation in Ningbo while maintaining the viability of low-cost travel modes. At the macrolevel, three primary approaches may address apparent problems. First, decision makers' attitudes to the low-cost modes must be critically examined and challenged. Second, some restructuring of the existing planning framework is needed to enable wider discussion and coherent, consistent policy development. Last, a set of national goals for urban transportation needs to be formulated.

First and foremost, policy makers must be convinced of the value of retaining and enhancing the role of low-cost modes in China. An awareness program for key decision makers and higher-level officials in urban planning could present the case for low-cost modes. Officials are among those most likely to benefit from increased motorization and must be reminded that low-cost modes have much to recommend them in terms of low impact on environment, broad availability to the public, and, perhaps of greatest concern, least cost to governments.

Development of specific goals for urban Chinese transportation systems should be broadly conceived, taking into account social, environmental, and economic factors. Ensuring equitable and viable choices for safe and convenient transportation services for the population, mandating preservation of traditional city forms and cultural landscapes, minimizing pollution, and limiting consumption of land, energy, and financial resources within the transportation sector would constitute a minimal set of goals.

There is also a need for leadership in redefining the role of the transportation sector in consultation with the public and flexibility in implementation at the local level. Cooperation between agencies in developing integrated approaches to development should be demonstrated and encouraged. To this end, some restructuring of the present hierarchical control may be required. Even without such restructuring, lines of communication between sections and bureaus could be established for collaboration on policy making at the preliminary stages. Such an integrated approach would enable more comprehensive planning and reduce the chances of developing counterproductive policies in different sections.

Local Initiatives

At the micro scale, educating planners and travelers and designing and managing street networks could substantially improve the urban transportation network. Measures focus on managing the existing system better through: managing travel

demand, separating modes, enforcing regulations, developing a hierarchy of routes and street functions, and designing new intersections and controls, more capable of handling the mix of modes typically found in Chinese urban centers.

To improve the quality of the daily home-to-work journey of Ningbo residents, attention should be paid to changing the modal split by improving public transportation, educating officials about the value of maintaining low-cost modes and restraining motorization, educating the general public about safe and appropriate behavior in certain situations, and revising and enforcing regulations that contribute to safe travel.

Street Management

A system of hierarchy of roads needs to reflect the priority functions of the street, developing management approaches and designs that privilege the appropriate users and discourage or disallow others. The need to accommodate socializing, marketing, traveling, and parking on the same streetscape may never be resolved adequately. But defining the primary uses of public road space and appropriate modes, activities, and designs for each class of street would go a long way toward resolving conflicts between users. Obviously, the greater the range of functions that the street serves, the greater the degree of management interventions required.

Public Transit

Management of existing transportation facilities and resources could affect large changes in traffic composition and conditions. Perhaps the largest effects could be achieved simply by optimizing the routes of the public transit system and making the hours of operation more suitable for the public that it serves. The size and type of bus in operation in Ningbo limits its use on narrow roads, which compose the bulk of roads in the old city. In contrast to other Asian and developing countries, almost no private vehicles are available on which to base a useful paratransit adjunct to the public transportation system. The Public Service Bureau may wish to investigate the opportunity to develop feeder services using minivans on designated routes. This may be more efficiently and safely accomplished if separate routes were established for motorized and nonmotorized modes.

Parking

Parking for bicycles must be improved because parking has major spillover effects as vehicles occupy pedestrian space. Park-and-ride facilities would be an important aspect of any promotion of a shift to public transit. Storage and parking requirements may be reduced as smaller or different vehicle designs increase "parkability."

Street and Intersection Design

Changing modal split and separating modes may improve flows along road lengths, but the inevitable mix of modes at intersections and crossroads also should be addressed. Alternative forms of intersections have been proposed in the project report and need to be tested and evaluated. Design of the street environment should provide facilities that are not only safe and convenient, but secure and pleasing. Attention should be paid to vegetative canopy, surface materials and design, and understreet infrastructure access.

Cycle Technology

Cycle technology is also in need of review. New technologies can improve the vehicle's sturdiness, reliability, and range of use. Gearing modifications can reduce costs in transportation facility construction, because slopes of ramps can be increased with less loss of velocity. Older users could benefit from a more stable frame construction and gearing to enable them to move with less effort and more certainty. New production technologies that can be widely disseminated would allow local entrepreneurs to adapt cycles to the conditions and terrain in which cycles operate. Regular safety inspection programs for existing vehicles would reduce accidents. Pricing policies and retrofit programs for any new technologies should be developed.

Regulation and Enforcement

Enforcement of a broad range of management-based regulations through fines and other reprimands could improve rider and driver behavior. Development of comprehensive pedestrian, bicycle, and vehicle operator regulations, with associated dissemination by public education campaigns or rider/driver education and licensing, would assist in bringing traveler behavior up to acceptable standards, reducing conflict and accidents. Budget allocations in support of such programs must be sufficient over the long term to yield results.

Planning Approaches

Consideration of the relationship of residential and employment densities to transportation should continue to play a role in urban planning and development. Development of single-function zones should be avoided as much as possible. Ningbo's intention to develop a downtown financial and administrative heart will have major implications for transportation as redevelopment removes housing and workers converge on the central area from the newly developed residential suburbs across the river.

Planners should also examine the implications of regional and local changes in economic opportunities, migration to urban centers, aging of the population, changing family structure (nuclear, one-child), and rising demand for and changing profile of amenities. Such consideration will affect the range and location of services planned (daycare, health care, shops, markets, cinemas, social clubs, etc.). Although currently accommodated in new neighborhood development, the institutionalized practice has been received "from on high" and may not account for potential local cultural and economic

changes as income levels rise and differentiation of market goods accompanies economic restructuring.

Finally, research methods and planning techniques need to be more strategic because of budget and time constraints, as well as the large number of issues requiring investigation and resolution. Multiple methods should be used wherever appropriate, using a mix of quantitative and qualitative data and broader range of available expertise and information. Strategic planning, with its explicit analysis of a range of external and internal (physical, social, fiscal, environmental, political) contributions to and constraints on decision making and resource allocation, will enhance planning processes. Strengthening the communication between relevant urban and transportation planning departments would provide multiple perspectives on urban planning issues.

CONCLUSIONS

Alternatives proposed are not particularly new. However, their adoption and application in China would signify a major shift in orientation for planners, bureaucrats, and decision makers. The preferred role of transportation in serving urban social and economic development needs to be clearly articulated in recognition of new social and environmental imperatives. Political representatives need to be informed about the relative costs and benefits of the various opportunities for modernizing their transportation systems. Frameworks for planning and decision making need to establish new communications among the professionals in each sector whose decisions have an impact on urban movements; they also need to solicit and value public input.

There is a great potential for increasing the transportation system capacity in Ningbo, and in similar cities in China, through demand management and street management techniques. Greater collaboration between researchers and practitioners within China and between China and the West will enable both to achieve greater insights into key intervention strategies, possible applications of existing approaches, and the development of new methods to ensure maximum mobility and support for development, at the least cost to society in social, environmental, and economic terms.

ACKNOWLEDGMENTS

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Bus Capacity Under Mixed Traffic Conditions

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On the basis of a field observation and analysis of traffic phenomena, models to estimate bus capacities under various traffic conditions are proposed. The bus stop is often the critical section that confines bus capacity. Two types of bus stops are introduced: one is a road section stop and the other is an intersection stop near a signalized intersection. In the latter case, buses' parking maneuvers will be affected by the queue length before the stopline of the intersection. According to these two types of bus stop, various road and traffic conditions are considered while bus capacities are calculated.

In China's major cities, besides the bicycle, the bus is an important transportation tool. In Shanghai there are 375 bus lines, including 160 lines in urban areas. More than 15 million passengers ride 6,000 buses every day (14.2 million in urban areas). Although the scheduled speed of buses is 14 km/hr, most of the buses cannot reach this speed. The majority of these buses are articulated vehicles, which are 14.05 m long and can accommodate 146 passengers each. More than 3,000 bus stops are spread along all kinds of streets in urban Shanghai. Because of the narrow streets and the interference caused by the great number of bicycles and pedestrians, bus capacity is severely affected. Therefore, bus capacity under mixed traffic conditions is of substantial importance for improving the levels of bus operation, management, and bus line planning.

On the basis of a field observation and analysis of traffic phenomena, this paper proposes the models to estimate bus capacities under various traffic conditions. The bus stop is often the critical section that confines bus capacity. For this paper, two types of bus stop are introduced: one is a road section stop and the other is an intersection stop, which is near a signalized intersection. In the latter case, buses' parking maneuvers will be affected by the queue length before the stopline of the intersection. According to these two types of bus stop, various road and traffic conditions are considered while the bus capacities are calculated.

BUS CAPACITY MODELS

In urban areas of Shanghai, there are many narrow motor vehicle lanes and walkways. In a street without separate facilities for motor vehicle and bicycle lanes, buses can park only on the bicycle lanes (curb lanes) for passengers' boarding and alighting. As a result, the travel time of all kinds of motor vehicles and bicycles that want to go through the section where the bus stops will be seriously affected. Here, capacity models of two types of stop are discussed: (a) the bus capacity models at road section stops, and (b) the bus capacity models at intersection stops.

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Road Section Stops

Usually, the road section on which a bus stop sits is the critical section that confines the bus capacity. In fact, the critical section is generally contained in a certain length of the lane. On the road section, the bus will slow down when entering the bus stop and come to a complete stop for passengers' boarding and alighting; then the bus starts and accelerates until normal running speed is reached. In this process, various other motor vehicles and bicycles that follow the bus will be influenced unavoidably. These vehicles are delayed and capacity is lowered. This influence is composed of the following two parts: (a) the bus deceleration-acceleration maneuver, and (b) the effective width of the lane, through which other vehicles go, becomes narrower when a bus stops at the stop. Figure 1 shows a typical traffic situation at a bus stop.

In Figure 1, Section I is the section on which a bus starts decelerating, and Section II is the section on which the bus completes its acceleration and reaches the normal speed. When a bus parks at the bus stop, the capacity on Section II is affected and suffers a loss. The loss is composed of $L(h)$, travel time loss caused by the vehicle that closely follows the parking bus, and $L(f)$, headway increasing losses among the vehicles following the parking bus.

Therefore, the capacity of motor vehicles (not including buses) on Section II is given by

$$Q = \frac{3{,}600 - [L(h) + L(f) * T + h\,(b)] * N}{h} \quad (1)$$

where

Q = capacity of various motor vehicles (not including buses) on Section II (veh/hr);

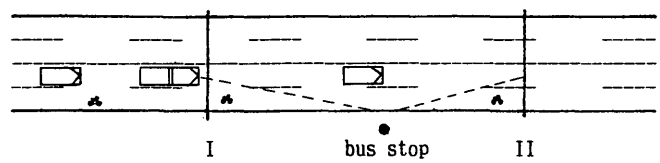

FIGURE 1 Traffic phenomenon at bus stop.

N = buses that stop (veh/hr);
T = average time taken by a bus traveling from Section I to Section II, including time spent at a bus stop (min);
h = average saturation headway of mixed motor traffic flow (sec);
$h(b)$ = bus saturation headway (sec);
$L(h)$ = time loss that results from decreasing speed of vehicle that closely follows bus (sec); and
$L(f)$ = time loss that results from increasing headways among vehicles after bus (sec/min).

If Q is the actual traffic flow rate in vehicles per hour and N is bus capacity on Section II, from Equation 1, bus capacity is estimated by

$$N = \frac{3{,}600 - h * Q}{L(h) + L(f) * T + h(b)} \tag{2}$$

In some cases, bus capacity is confined by berth capacity [similar to the model the 1985, *Highway Capacity Manual* (*1*)].

$$N = \frac{3{,}600 * n}{t(s) + t(c) * n} \tag{3}$$

where

n = maximum number of buses that can stop at the same time,
$t(s)$ = dwell time at bus stop (sec), and
$t(c)$ = clearance between successive buses (sec).

Thus, the bus capacity on a road section stop should be estimated by the lower calculating value obtained from either Equation 2 or Equation 3:

$$N = \min\left\{\frac{3{,}600 - h * Q}{L(h) + L(f) * T + h(b)}, \frac{3{,}600 * n}{t(s) + t(c) * n}\right\} \tag{4}$$

According to the result obtained by Tang, dwell time $t(s)$ can be determined by

$$t(s) = 0.41 * AN * LC + 0.73 * BN * LC + 9.3$$

where

AN = number of alighting passengers,
BN = number of boarding passengers, and
LC = passengers/146.

Here, LC is the load coefficient of a bus and 146 is the maximum number that an articulated bus can theoretically accommodate.

Intersection Stops

The bus capacity at the stop near an intersection is restricted by either the bus stop or the capacity of the stopline at a signalized intersection. The model of the bus capacity restricted by bus stop near a signalized intersection can be expressed by following equation:

$$N = \frac{3{,}600 * n * (g/c)}{(g/c) * t(s) + t(c) * n} \tag{5}$$

where g/c is the green time–cycle time ratio.

Variables $t(s)$, $t(c)$, and n are the same as those in Equation 3, but the factors affecting $t(c)$ in Equation 5 are different from the factors affecting $t(c)$ in Equation 3.

The bus capacity restricted by the stopline of a signalized intersection is given by

$$N = [3{,}600 * (g/c) * s - Q]/1.3 \tag{6}$$

where s is the mixed saturation flow rate in vehicles per hour and Q is the mixed motor vehicle flow rate (not including buses) in vehicles per hour.

The conversing coefficient from a bus to mixed motor vehicles is 1.3. The value roughly reflects the average composition of various kinds of vehicles in urban areas of Shanghai. In a certain case, this value can be calculated according to the percentages of different kinds of vehicles.

Similarly, the bus capacity at the stop near a signalized intersection is estimated by the smaller value obtained from either Equation 5 or Equation 6, that is

$$N = \min\left\{\frac{3{,}600 * n * (g/c)}{(g/c) * t(s) + t(c) * n}, [3{,}600 * (g/c) * s - Q]/1.3\right\} \tag{7}$$

PARAMETER CALIBRATION AND BUS CAPACITY CALCULATION

Road Section Stops

The bus capacity at the road section stop can be estimated from Equation 4:

$$N = \min\left\{\frac{3{,}600 - h * Q}{L(h) + L(f) * T + h(b)}, \frac{3{,}600 * n}{t(s) + t(c) * n}\right\}$$

The parameters in this equation are obtained by the statistical processing of field data. Some parameters are listed in Table 1 and the following:

Level	*Traffic Condition*	*Factor Index*
A	Poor	More than 0.52
B	Average	Between 0.36 and 0.52
C	Favorite	Less than 0.36

The factor index (FI) is introduced to describe the traffic state in a street. Vehicle and bicycle traffic along with the effects of parking buses are considered in determining FI.

$$\text{FI} = (X1 + X2 + X3)/3 \tag{8}$$

where

$X1$ = vehicle volume per hour (single direction) divided by 900, 720, or 600 allowing the width of streets to vary from 14 to 12 to 10 m;

TABLE 1 Part of Parameters

parameters	FI level	width 14m	12m	10m
L(h) (sec.)	A	7	19	26
	B	4	9	15
	C	0	2	3
L(f) (sec.)	A	32	37	43
	B	16	24	32
	C	4	7	10
stopping & starting delay(sec.)	A	26	26	26
	B	15	15	15
	C	6	6	6
t(c) (sec.)	A	15	15	15
	B	11	11	11
	C	8	8	8

$X2$ = bicycle volume per hour (single direction) divided by 3,600; and

$X3$ = average number of parking buses between Sections I and II (see Figure 1) divided by 3.

On a road stop, $X1$, $X2$, and $X3$ do not have much difference in their contribution to determine the FI; here, these three factors are considered to have a equal weight. For example, on a street 10 m wide without separation, motor vehicle flow is 300 veh/hr, bicycle flow is 2,100 veh/hr, and average bus dwell time at the stop is 30 sec. Then,

$$FI = (X1 + X2 + X3)/3$$
$$= (300/600 + 2{,}100/3{,}600 + 1/3)/3 = 0.47$$

FI pertains to Level B. Consequently, according to Table 1, $L(h) = 15$ sec and $L(f) = 32$ sec. The bus capacity at the stop is

$$N = \frac{3{,}600 - h * Q}{L(h) + L(f) * T + h(b)}$$
$$= \frac{3{,}600 - 6 * 300}{15 + 32 * (30 + 15 + 18)/60 + 6} = 33 \text{ buses per hour}$$

Here $h = h(b) = 6$ sec, the average saturation headway between successive vehicles; 30 sec is average dwell time at the stop; 15 sec is the acceleration and deceleration losses; and 18 sec is the uninterrupted travel time from Section I to Section II.

In the example, if bicycle traffic is prohibited, the FI will be

$$FI = (300/600 + 1/3)/3 = 0.28$$

FI pertains to Level C, thus $L(h) = 3$ sec, $L(f) = 10$ sec, and bus capacity changes as follows:

$$N = \frac{3{,}600 - 6 * 300}{3 + 10 * (30 + 6 + 18)/60 + 6}$$
$$= 100 \text{ buses per hour}$$

Bus capacity being up to 100 per hour, the FI should be changed as the average number of parking buses between Sections I and II varies. Then,

$$X3 = [(30 + 6 + 18) * 100/3{,}600]/3 = 0.5$$
$$FI = (300/600 + 0.5)/3 = 0.33$$

FI still pertains to Level C, and the bus capacity remains unchanged. In some cases, it needs iterative calculations while bus capacity is estimated. Table 2 gives the bus capacities under various road and traffic conditions. A bus dwell time at a stop is 30 sec. The bus capacity values in brackets are calculated by Equation 3.

In Table 2 "equivalence" means that a parking bus has the equivalent value conversing to other vehicles when the capacity on the street is concerned.

Intersection Stops

Bus capacity at an intersection stop can be estimated from Equation 7:

$$N = \min \left\{ \frac{3{,}600 * n * (g/c)}{(g/c) * t(s) + t(c) * n}, \right.$$
$$\left. [3{,}600 * g/c) * s - Q]/1.3 \right\}$$

All parameters have been defined before, except the parameter $t(c)$. Similar to the method dealing with road section stops, the FI of an intersection is also used to determine $t(c)$.

$$t(c) = \begin{cases} 28 \text{ sec} & \text{when } FI(i) \geq 0.64 \\ 18 \text{ sec} & \text{when } 0.42 \leq FI(i) < 0.64 \\ 14 \text{ sec} & \text{when } FI(i) < 0.42 \end{cases} \quad (9)$$

Here, $FI(i)$ is calculated by following equation:

$$FI(i) = 0.42 * (1 - g/c) + 0.25 * X(v) + 0.33 * X(b) \quad (10)$$

TABLE 2 Bus Capacities in Buses per Hour

width	FI level	other vehicle flow rates (veh/h) 100	200	300	400	500	equivalence
14m	A	62	55	47	39	31	12.8
	B	124	109	93	78	62	6.5
	C	(157)	(157)	(157)	(157)	(157)	2.2
12m	A	44	37	30	23	16	14.3
	B	78	65	53	40	28	7.9
	C	(157)	(157)	152	116	79	2.8
10m	A	35	28	21	14	7	14.5
	B	55	44	32	22	11	9.0
	C	(157)	133	100	67	33	3.0

TABLE 3 Bus Capacities at Intersection Stops in Buses per Hour

X(b)	motor traffic flow (veh/h) 100	200	300	400
.30	83	70	70	(38)
.60	70	70	70	(38)
.90	70	70	50	(38)

where

$X(v)$ = saturation ratio of motor vehicle;
$X(b)$ = $Q(b)/[1{,}800 * W(b) * (g/c)]$, saturation ratio of bicycles;
$Q(b)$ = bicycle traffic flow per hour; and
$W(b)$ = width of bicycle lane (m).

Maximum flow rate is 1,800 bicycles per green hour time per meter wide.

Table 3 gives some calculating results of intersection bus capacities under certain traffic conditions. In Table 3, the parameters are as follows: $g/c = 0.50$, and $t(s) = 30$ sec.

The capacity of mixed traffic flow at the stopline is 450 vehicles per hour. Values in brackets show that the stopline is a critical section to the bus capacity, that is, the bus capacity $N = [3{,}600 * (g/c) * S - Q]/1.3$.

For estimating the bus capacity at the intersection stop without bicycle interference, Equation 7 can also be used. In this case, there is no need to calculate FI(i). The parameter $t(c)$ is 14 sec.

CONCLUSION

Because of the complexity of precisely estimating the bus capacity at a bus stop, and in order to apply the bus capacity models conveniently, the road and traffic condition variables such as the width of a street, separate conditions, and motor vehicle and bicycle flows (timing factor at intersection stops) are used to classify the FI into three levels. Accordingly, the bus capacity values calculated are discontinuous. This gives practical users a scope in which to calibrate calculated capacity values against the actual traffic conditions.

Bus stops have a great deal of interference on road capacity. In streets without separation, when the traffic condition is poor, average, or favorite—that is, the FI pertains to Level A, B, or C, respectively—a parking bus has equivalent value about 15, 8, or 2.8 conversing to other vehicles, accordingly, as the capacity on the road is concerned.

The effect of the changing width of bus capacity at a bus stop is significant: add 2 m of width and the bus capacity may be doubled.

If bicycle traffic is prohibited or has a separate right-of-way, the bus capacity may be increased by 200 percent. With the variations of traffic conditions and bicycle flow rates, the effects on bus capacity caused by prohibiting bicycle traffic are varied.

The paper discusses the bus capacity only within a critical road section. The bus capacity of a whole bus line is much more complicated and needs further research.

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International Comparisons of Transportation Prices and Output

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The use of different currency converters in international comparisons can significantly affect comparisons of gross output and productivity in two sectors, nonmotorized and motorized transportation. This is illustrated for Indonesia and the Republic of Korea. Further support is provided by a comparison of bus fares in approximately 60 countries and a comparison of aggregate transportation demand in various categories in 1980 and in 1985. These comparisons also illustrate exchange rate distortions, particularly between countries whose price structures are dissimilar. The main results contrast the labor costs and value added in bicycle production in the two countries with production in the motorized sector and show the understatement of Korea's productivity in the transportation sector when exchange rates are used, relative to Indonesia. In the second comparison, transportation prices are systematically lower at exchange rates, particularly for low-income countries, and both price and income elasticities in the aggregate demand analysis are affected by the conversion method.

Transportation demand prices are often compared on the basis of data using a cross section of countries. For example, during the oil crisis in the Middle East, the press commonly compared gasoline prices in different countries. These types of comparisons are useful, but they can also be misleading if done incorrectly.

Transportation costs and expenditures in national currency units are usually compared using exchange rates. This paper discusses an alternative purchasing power–based converter that is preferable in many applications. The derivation of the purchasing power converter is discussed, and illustrative applications in international comparisons in the transportation sector are provided.

The first example is a binary comparison of productivity in the Republic of Korea and in Indonesia. Estimates of the real value added at factor costs for the motorized and nonmotorized sectors are shown, using manufacturing census data on the production of passenger vehicles, motorcycles, and bicycles in 1985. Labor costs and output per employee in each sector are then discussed when real and nominal values are used. The second example uses price data on several transportation categories for 60 countries in 1980 and 30 countries in 1985 to analyze the relationship between transportation use, final demand prices, and income. The differences between exchange rate conversions and relative price comparisons will also be discussed for each of the categories. The final section describes the methodology and its application in the production and in the expenditure approach in international comparisons.

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COMPARISONS

Motorized and Nonmotorized Transportation Equipment Manufacture

The output quantities and unit values for Japan, Korea, and Indonesia are used to calculate the price relatives, or parities, for motorized (passenger cars and motorcycles) and nonmotorized (bicycles and carts) sectors. These are shown in Table 1 with the average annual exchange rates in 1985. Japanese numbers are based on aggregate gross values of output in the manufacturing sector, and Korean and Indonesian prices are based on the values of shipments. Korean value added, however, includes subsidies and taxes.

Since the Japan-Korea price relatives relate to 1985, the results will not reflect declines in relative prices of manufacture in Korea since 1985. As noted, one of the main difficulties with the Korean census data is the treatment of taxes. Although it is possible to reconcile partially the diverse tax treatments in different countries and sectors, this has not been attempted here. For this reason, the parities reflect internal price structure, not necessarily parities relevant to foreign trade. For an extended treatment of Korean taxes in manufacturing using input-output tables and the system of national accounts, see the paper by Szirmai and Pilat (*1*).

The overall parity, or aggregate price relative, for the three sectors between Korea and Japan is twice the exchange rate, indicating that it is relatively more expensive to produce transportation equipment in Korea than it is in Japan. The reverse occurs between Korea and Indonesia, so that if Indonesian output is converted at the rupiah-won exchange rate, it is likely to be overstated relative to Korea, compared to conversions by parities. The interesting fact about Korean manufacture in particular is that bicycle production in Korea is more expensive than it is in Japan or Indonesia relative to the other transportation sectors. Some possible explanations will be given.

In Table 2 the estimates of value added in national currencies for each sector are shown, as well as productivity in

TABLE 1 Parities and Exchange Rates

	Korea-Japan (Won/Yen)	Korea-Indonesia (Won/Rps)	Japan-Indonesia (Yen/Rps)
PARITIES			
All	7.37	0.28	0.044
Motorised	7.33	0.27	0.044
Non-Motor	11.57	0.44	0.038
EXCHANGE RATE	3.66	0.78	0.215

TABLE 2 Value Added and Productivity

	Korea		Indonesia	
	VA Won (bil)	VA/Emp Won (mil)	VA Rps (bil)	VA/Emp Rps (mil)
Motorized	1,034	12.66	369	17.98
Non-Motor	20	6.20	7	1.46

national currencies, measured as valued added per employee. Cart production was left out of the value-added estimates because carts in the Indonesia census were classified as "motor vehicle body and equipment manufacture" and totaled only 15 units. The Korea-Indonesia ratio of productivity is obtained by converting the Korean won values into Indonesian currency units by the won-rupiah parity and by exchange rate, then dividing each by Indonesia's productivity. The conversions and the Korea-Indonesia ratio are shown in Table 3.

Table 4 shows the ratios of labor costs and value added per employee among the sectors within a country, in local currency units. Labor costs per employee in Indonesia for bicycle production are nearly one-fifth of the costs in the motorized sector. In Korea, by contrast, the costs per employee in bicycle production are four-fifths of the costs per employee in the motorized sector. The labor force is smaller but more expensive in Korea, and it is therefore likely that Korean bicycle manufacture is more capital-intensive than in Indonesia. In addition, Korea's high productivity in bicycle production—more than half of the productivity in its motorized sector—is also a likely indicator of high capital intensity; Indonesia's productivity at national currencies is only about one-twelfth that of its motorized sector.

The final point to emphasize is how the exchange rate understates the productivity ratio for this Korea-Indonesia comparison. In this example, the direction of change was the same for both sectors, that is, exchange rate conversions of Indonesian output are greater than their price ratio conversions for both motorized and nonmotorized transportation equipment manufacture, although less so for bicycles than for passenger cars and motorcycles. The Korean data include establishments with 5 or more workers (a total of 71 for bicycle production); Indonesia includes 54 establishments. The total number of motor vehicle and motorcycle production firms included in Korea was 1,285 and in Indonesia, 87. The next example discusses in more detail these differences from the expenditure side. Instead of unit values derived from output values and quantities, final expenditures and market prices are used. The production approach may use prices instead of unit value estimates (*2,3*). An example of unit value estimation will be given the next section.

TABLE 3 Ratio of Korea and Indonesia Productivities

	Korea		Indonesia	Ratio	
	Rps (Parity)	Rps (Xrate)	Rps	Korea-Indonesia at Parity	Xrate
Motorized	46.20	16.15	17.98	2.57	0.90
Non-Motor	13.96	7.91	1.46	9.58	5.43

TABLE 4 Ratio of Nonmotorized to Motorized Costs and Value Added

	Labor Costs/Employee Non-M : Motor	Value Added/Employee Non-M : Motor
Korea (Won)	2.62 : 3.77	6.20 : 12.66
	(1 : 1.4)	(1 : 2)
Indonesia(Rps)	0.65 : 3.11	1.46 : 17.98
	(1: 5.0)	(1 : 12)

Transportation Prices and Aggregate Demand Analysis

Two comparisons of prices and aggregate demand are discussed in this section. The first comparison uses 1985 data on bus fares in various cities and countries taken from two independent sets of data. One set is the nominal exchange rate value for fares up to 5 km in 21 selected cities, averaged between public and private suppliers of bus services (*4*). The other set is a national average of short-distance bus rides ranging from 1 to 10 km in approximately 40 other countries (*5*). The second comparison takes 1980 and 1985 average national price levels for several categories in addition to bus services, and includes approximately 60 and 30 countries, respectively (*5*). The categories in this second comparison are

- Passenger vehicles;
- Motorcycles and bicycles;
- Tires, tubes, and accessories;
- Repair charges;
- Gasoline, oils, and greases;
- Local transportation services (up to 10 km); and
- Long-distance rail and bus services.

First, the prices of each category—bus fares in the first comparison and passenger vehicles and local transportation services in the second comparison—are plotted against consumption levels in each country, at exchange rates and at purchasing-power parity conversions. Figure 1 is a plot of the nominal bus fares converted at exchange rates against the per-capita consumption of the population, both in 1985 U.S. dollars. Figure 2 is the plot of the real fares, that is, the nominal values corrected by the country's price level. The exchange rate values increase more noticeably with income than the parity conversions, which tend to be scattered for low-income countries and then to even out as income rises. This suggests that, relative to consumption, bus fares are more expensive for low-income countries than their exchange rate values indicate.

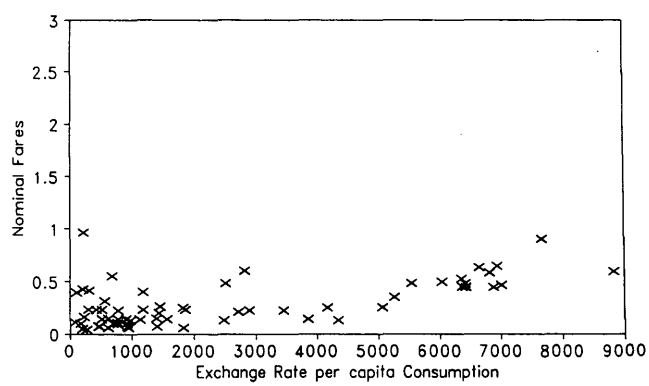

FIGURE 1 Bus fares 1985, nominal prices.

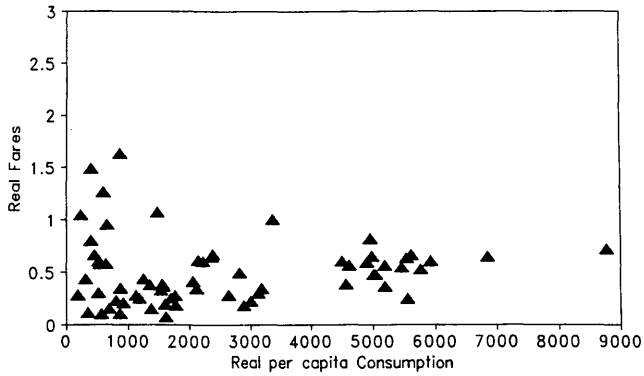

FIGURE 2 Bus fares 1985, real prices.

The exchange rate and parity conversion graphs of prices and consumption in 1980 are shown in Figures 3 and 4 for cars and Figures 5 and 6 for local services. The number that is plotted against consumption at exchange rates is the price relative to the average when all currencies are converted at the U.S. dollar exchange rate. The real prices are converted by the purchasing-power parity of the currency in a manner similar to the bus fare conversions. The difference between the two conversions is more pronounced in the car category, for which the prices are much higher at exchange rates, relative to other consumption goods, in the low-income coun-

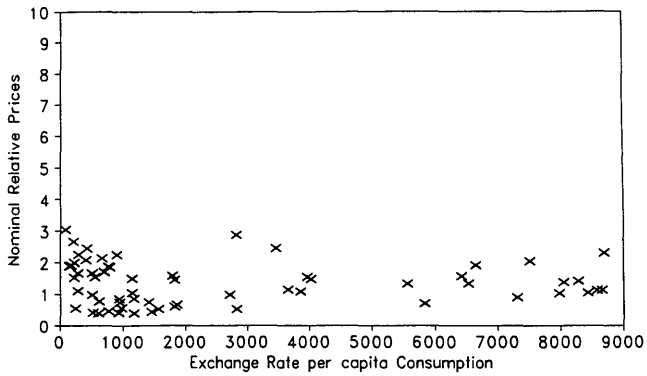

FIGURE 3 Cars 1980, nominal prices.

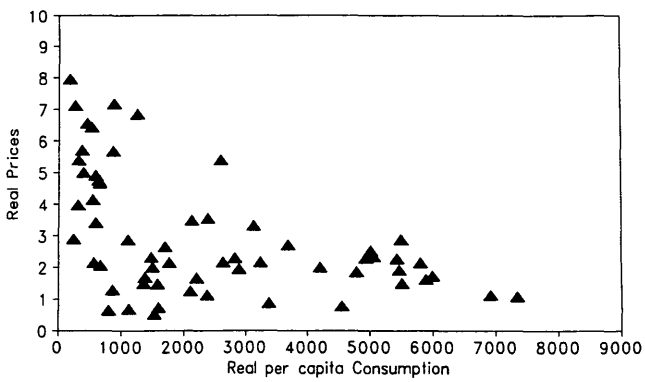

FIGURE 4 Cars 1980, real prices.

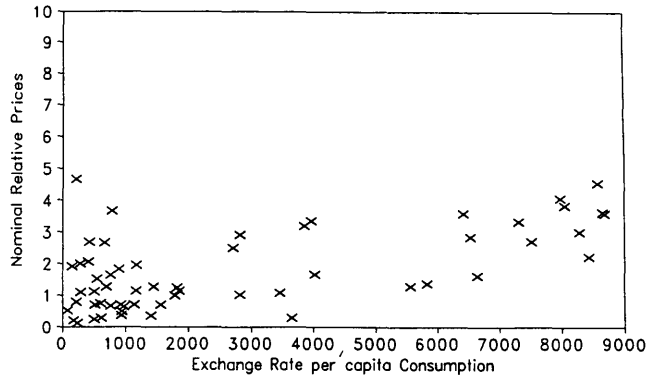

FIGURE 5 Local services 1980, nominal prices.

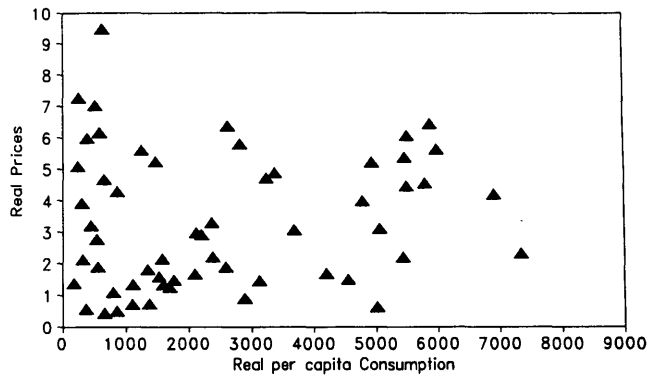

FIGURE 6 Local services 1980, real prices.

tries. The local services category shows a similar but more dispersed trend in relation to the bus-fares-only example. Prices at parities continue to be higher than prices at exchange rates, particularly for low-income countries.

Besides prices and incomes, the per-capita quantity purchases of each category, in both 1980 and 1985, are obtained from the national expenditure data described, and a crude estimating equation is specified for the comparisons. A discussion of the merits and disadvantages of this demand analysis is given elsewhere (*6*). A simple log-linear demand equation is used in this section, for each conversion method (exchange rates and at parities), and is defined as

$$\ln q_{ij} = b_{i0} + b_{i1} \ln p_{ij} + b_{ij} \ln c_j + u_{ij} \quad (1)$$

where

i = 1 category in first comparison (bus fares);
i = 1, . . . , 7 categories in second comparison;
j = 1, . . . , 64 countries in first comparison;
j = 1, . . . , 60 countries in 1980 in second comparison;
j = 1, . . . , 30 countries in 1985 in second comparison;
q_{ij} = per-capita quantity of item i consumed in country j;
p_{ij} = unit price of i in country j; and
c_j = per-capita consumption in country j.

The regression coefficients b_{i1} and b_{i2} are the price and income elasticities for each item or category heading. They are estimated by ordinary least squares regression, one equa-

TABLE 5 1985 Bus Fares

Obs=64	Intercept	Price	Consumption
EXCHANGE RATES			
coefficient	-5.167	-0.217	0.993
standard error	(1.035)	(0.184)	(0.118)
prob > |t|	0.0001	0.2446	0.0001
PARITIES			
coefficient	-4.003	-0.753	0.777
standard error	(1.159)	(0.217)	0.149
prob > |t|	0.0001	0.0010	0.0001

tion at a time, for 1980 and 1985. The first comparison is only for the bus category, and the second uses all the transportation categories in the two years. The exchange rate and parity conversions are shown in separate lines. The derivation of all the parities are described in more detail in the next section.

Table 5 shows the results for the bus fare demand analysis, with the standard errors of the coefficients in parentheses and the associated *t*-statistics below. The nominal price variable is not significant in the former, though it is of the right sign. It is mainly the income variable, consumption, that "explains" demand, and the elasticity is unity, which is high. If we look at the prices expressed relative to a country's consumption price levels, bus fares and income both significantly affect demand. The sign of the price coefficient is negative and the income elasticity is lower, suggesting that an increase in prices decreases the quantities of bus rides demanded but that higher incomes or consumption levels lead to less-than-proportional increases in bus demand.

The second demand analysis for the various categories in 1980 and in 1985 exhibit similar differences. The coefficients of each log-linear demand equation are shown in Tables 6 and 7. There are 60 observations in 1980 and 30 in 1985. The dependent variable is the per-capita quantity of each category and the independent variables (price and consumption) for each category are defined in Equation 1. Table 8 shows the adjusted R-squares for each equation, as well as the root mean square errors.

At exchange rates, the coefficients on the price variable are usually positive; when they are of the right sign, as for repair charges, they are not significant. In contrast, at parities, the coefficients on the price variable are always negative, except for passenger cars in 1980, and always smaller (have larger negative values) than at exchange rates. Income elasticities for local and long-distance rail and bus services generally follow a pattern similar to the bus fare results in Table 5—that is, they are lower at parities. They are also less than unity, suggesting that increases in income lead to less than proportional increases in the demand for purchased transportation services. On the other hand, the income elasticities for individual transport vehicles and for parts and accessories

TABLE 6 1980 Aggregate Demand Estimates

	Dep:Quantities		
(Std.Errors)	*Int.*	*Price*	*Consump.*
PASSENGER CARS			
Exchange Rates	-9.59 (1.10)	0.66 (0.33)	1.64 (0.15)
Price Relatives	-13.33 (1.80)	0.04 (0.33)	2.10 (0.22)
MOTORCYCLES & BICYCLES			
Exchange Rates	-7.11 (0.86)	0.08 (0.27)	1.15 (0.12)
Price Relatives	-9.03 (1.54)	-0.03 (0.29)	1.39 (0.18)
TIRES, TUBES & ACCESSORIES			
Exchange Rates	-7.74 (1.05)	0.52 (0.48)	1.28 (0.15)
Price Relatives	-9.39 (1.45)	-0.22 (0.43)	1.49 (0.18)
REPAIR CHARGES			
Exchange Rates	-8.79 (1.09)	-0.15 (0.26)	1.40 (0.15)
Price Relatives	-7.71 (1.35)	-1.06 (0.31)	1.33 (0.18)
GASOLINE, FUEL & OILS			
Exchange Rates	-10.10 (1.15)	0.23 (0.32)	1.67 (0.16)
Price Relative	-11.34 (2.02)	-0.57 (0.34)	1.85 (0.25)
LOCAL SERVICES (up to 10kms)			
Exchange Rates	-4.68 (0.92)	0.09 (0.18)	0.97 (0.13)
Price Relatives	-4.18 (1.10)	-0.62 (0.19)	0.94 (0.15)
RAIL & BUS SERVICES			
Exchange Rates	-2.20 (0.86)	0.33 (0.17)	0.60 (0.12)
Price Relatives	-1.50 (0.96)	-0.49 (0.18)	0.54 (0.13)

TABLE 7 1985 Aggregate Demand Estimates

	Dep:Quantities		
(Std.Errors)	*Int.*	*Price*	*Consump.*
PASSENGER CARS			
Exchange Rates	-10.08 (1.42)	0.40 (0.44)	1.75 (0.17)
Price Relatives	-17.31 (3.63)	-0.18 (0.49)	2.62 (0.41)
MOTORCYCLES & BICYCLES			
Exchange Rates	-5.85 (1.40)	0.53 (0.90)	0.98 (0.18)
Price Relatives	-5.99 (2.67)	-1.09 (0.81)	1.05 (0.29)
TIRES, TUBES & ACCESSORIES			
Exchange Rates	-8.43 (1.35)	0.93 (0.56)	1.35 (0.17)
Price Relatives	-12.41 (2.48)	-0.30 (0.60)	1.84 (0.29)
REPAIR CHARGES			
Exchange Rates	-10.61 (2.10)	-0.57 (0.47)	1.72 (0.26)
Price Relatives	-11.20 (1.76)	-1.97 (0.61)	1.88 (0.23)
GASOLINE, FUEL & OILS			
Exchange Rates	-6.71 (0.83)	0.57 (0.58)	1.34 (0.10)
Price Relative	-8.18 (2.49)	-0.87 (0.53)	1.57 (0.27)
LOCAL SERVICES (up to 10kms)			
Exchange Rates	-3.73 (2.17)	-0.45 (0.37)	0.90 (0.28)
Price Relatives	-2.00 (2.01)	-1.60 (0.38)	0.77 (0.27)
RAIL & BUS SERVICES			
Exchange Rates	0.54 (2.02)	0.14 (0.37)	0.29 (0.26)
Price Relatives	2.37 (1.83)	-1.10 (0.40)	0.13 (0.25)

TABLE 8 Adjusted *R*-Squares and Root Mean Square Errors

	1980		1985	
	*RBAR*²	RMSE	*RBAR*²	RMSE
PASSENGER CARS				
EXRates	0.670	1.437	0.670	1.451
Parities	0.670	1.450	0.814	0.936
MOTORCYCLES & BICYCLES				
EXRates	0.620	1.121	0.658	0.883
Parities	0.616	1.179	0.586	0.893
TIRES, TUBES & ACCESSORIES				
EXRates	0.626	1.296	0.752	0.981
Parities	0.553	1.340	0.686	1.028
REPAIR CHARGES				
EXRates	0.654	1.237	0.831	0.763
Parities	0.495	1.394	0.706	0.771
GASOLINE, FUEL & OILS				
EXRates	0.662	1.489	0.857	0.643
Parities	0.598	1.678	0.841	0.674
LOCAL SERVICES				
EXRates	0.584	1.050	0.408	0.819
Parities	0.448	1.110	0.363	0.793
RAIL & BUS SERVICES				
EXRates	0.492	0.949	0.194	0.777
Parities	0.235	0.989	0.243	0.750

and for gasoline and fuels are larger than unity and higher at parities than at exchange rates. Although elasticities from these demand equations should be interpreted with caution, the significant differences between the conversion methods suggest how projections based on cross-section demand analyses at exchange rates can be misleading to transportation planners.

METHODOLOGY

Production Parities

In general, manufacturing census data are aggregate values and quantities of output, and one way to obtain the individual prices is to calculate the unit value of the product. Unit values are derived from gross values of shipments or of output and from quantity data—that is, for each country j,

$$\text{unit value}_j = \text{output}_j/\text{quantity}_j$$

The other way is to match products and use their market or sale prices. The advantages of both methods have been discussed elsewhere, and in particular for production parities (*2*,*6*). One of the disadvantages of unit value estimates is that rather than price changes, differences may be due to changes in the composition of goods produced in the sector. For example, China's unit values for 1980 and 1985 in motorcycle production differ by a factor of 10. The gross-net output ratio remained approximately the same, but the quantities of motorcycles increased 22-fold. Unit values of passenger vehicles, motorcycles, and bicycles are derived from the 1987 industrial census.

For the examples in this paper, only unit values were estimated in the production comparisons. The basic approach is to match products in the industry, such as passenger vehicles, motorcycles, and bicycles, and to calculate the price relatives in each sector. The sectors may then be aggregated to obtain an industry price relative or parity. The parity between two countries for a one-product, one-sector industry will simply be the price relative of the product, that is Pa/Pb where a and b are countries. The parity for a multiproduct sector will be the price relatives for each product i weighted by the quantity or output of the product—that is,

$$PPPa = \text{sum}_i\,(Pa_i * Qa_i)/\text{sum}_i\,(Pb_i * Qa_i)$$

(at quantity weights of country a)

and

$$PPPb = \text{sum}_i\,(Pa_i * Qb_i)/\text{sum}_i\,(Pb_i * Qb_i)$$

(at quantity weights of country b)

where i is the products in the sector.

The overall *PPP* or parity for a multisector industry can be obtained in a similar fashion, by summing over the sectoral parities weighted by output in the sector—for example, summing over motorized and nonmotorized sectors to obtain the overall transportation *PPP*, as in the preceding example. The parities are used to convert the value added in one country's currency to another country's currency units, that is,

$$VA.ab = VA.aa/PPPa$$

$$VA.ba = VA.bb * PPPb$$

where

$VA.ab$ = value added of country a in country b prices,
$VA.ba$ = value added of country b in country a prices, and
$PPPa$, $PPPb$ = parity at quantity weights of countries a and b, respectively.

For simplicity, the geometric or Fisher average of *PPPa* and *PPPb* was used in the Korea-Indonesia example, and the separate country parities are not shown. This value added is then divided by the number of employees in each sector to obtain productivity per employee. Alternative denominators, such as working hours, were not available on a comparable basis for this paper.

Price Relatives

In the expenditure approach, it is generally easier to obtain price data than quantity data. Thus, instead of calculating unit values from quantity and output data as in the production example, the parities for a category such as household expenditures on transportation are obtained from price and expenditure data. The same *PPP* formulas are used in both the production and expenditure approaches. The weights are the expenditures divided by the prices, or their "notional quantities." If we had all price and quantity data for all items or categories, unit values or notional quantities would not be used. However, if only one or the other is available, together with expenditure and output values, the relation between prices, quantities, and output or expenditures must be used.

Each category or heading consists of a set of items. For example, gasoline prices include premium, regular, and diesel, and local transportation includes bus and cab rides up to 10 km. The estimating steps at each aggregation level are described more fully elsewhere (*6*). If there are detailed disaggregate prices for items such as wheelbarrows, chee-kees, and other transport and travel aids in national currencies, or the prices of purchased services such as pedal-rickshaws, the multilateral comparisons would be at the level of nonmotorized transportation categories. The matching of such products, and the price collection process for transportation services that operate largely in the informal market, are the main obstacles to a more detailed international comparison.

CONCLUSIONS

Although the data used in the examples are not strictly comparable in the case of the production approach, and not at a highly disaggregate level within nonmotorized transportation in the expenditure approach, the main goal of this paper is to illustrate the effects of currency conversions on comparisons of transportation prices and output. Exchange rates may understate the prices of low-cost transportation modes such as buses and bicycles, especially for low-income countries. In other words, although prices may seem cheap at exchange rates, they are in fact, relative to the prices of other goods within each country, more expensive. The conversions of gross output and productivity also suffer from similar distortions, that is, the exchange rate conversions will not adequately reflect the differences in costs between two countries whose price structures are dissimilar. In the Korea and Indonesia example, the exchange rate understates the productivity of Korean transportation equipment manufacture relative to Indonesian transportation manufacture. In addition, the productivity and labor costs in the bicycle manufacture sector are distinct from those in the motorized transportation sector, and the relative costs within these sectors should also be taken into account.

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PART 2

Asia and North America

Methodology for Evaluating Urban Transportation Energy-Environment Strategies: Case Study for Bangkok

MARK E. HANSON AND ROBERT W. LOPEZ

Finding and sustaining an acceptable level of environmental quality in the world's largest cities requires the adoption of major policies to address transportation investments and transportation demand management, including consideration of energy use and pollutant emissions. A methodology for evaluating urban transportation energy-environment strategies is presented. The methodology is designed to address urban development patterns, transportation system structure and modal mix, and vehicle emission and energy use characteristics. Bangkok, Thailand, is experiencing a rapid degradation of its environment and is used as a case study to demonstrate the application of the methodology. The case study develops a series of policy options to address the growing environmental problems. These policy options for responding to urban energy use and air quality degradation are compared and briefly evaluated.

The growth of global population has been the source of much attention and anxiety among those concerned about the future of the global environment. More recently, attention has focused on the massive urbanization that is a product of population growth, the increase in economic opportunity in urban areas as development occurs, and the limited ability of a fixed land base to support people in rural agriculture.

The growth in the demand for motorized travel is well understood (*1*,*2*). As urban areas expand, available land is generally at the edges of the urban area and in areas previously considered unsuitable for development. As the distance of residential and commercial locations from the city center or other subcenters increases, so does the need for motorized travel. Motorized travel, often in private vehicles, supplants traditional modes—in particular walking, various bicycle forms, water travel, and even mass transit. The need is necessitated by the decrease in population densities with distance from urban centers and by the dispersal of travel destinations.

The evolution of the form of urban areas is driven by the growth of income and accompanying increases in the acquisition of private motor vehicles and changes in travel habits. It is also influenced by public policy toward land use, housing, and transportation infrastructure. Even though the proportion of middle- and upper-income households in developing and newly industrialized countries that are able to afford automobiles and motorcycles is lower than in industrialized nations, the number of private vehicles still becomes very large as the middle- and upper-income groups grow. The number of vehicles and levels of congestion are comparable to or exceed those for major cities of industrialized countries. With the increase in motorized travel and congestion comes increases in energy use, emissions, and air pollution.

The development of Bangkok described in major recent studies—such as the *Medium to Long Term Road Improvement Plan: Main Report* by the Japan International Cooperation Agency (JICA) and the *Seventh Plan Urban and Regional Transport* (SPURT) by the Office of the National Economic and Social Development Board—follows the general development path described (*3*–*6*). In particular, these studies indicate that unless some policy measures are taken to alleviate the situation, the number of person trips, the amount of energy use, the amount of emissions, and the level of air pollution will double or triple between 1989 and 2006. In addition, unless transportation demand is managed and large investment made in well-targeted transportation infrastructure, the extreme levels of congestion will increase.

TRANSPORTATION INFRASTRUCTURE CONSIDERATIONS

Overlaid on and intimately associated with this development pattern is the transportation infrastructure. The level of infrastructure provision relative to the population density, income, and transportation pricing and other policies determines the level of congestion. For Bangkok, high population densities, rapidly increasing income levels, low fuel prices, moderate vehicle prices (except for passenger car prices, which are fairly high), and a relatively limited transportation infrastructure have resulted in severe congestion. The rapid growth in population and economic activity is pushing both the population and various urban subcenters outward, in a combination of a linear and a polynucleated or multinucleated pattern. Vehicle flow and congestion are also expanding outward.

Within this context, further growth in travel in the more central urban area will not be possible without added infrastructure. This is strikingly shown in recent data that suggest that traffic volume is decreasing in central areas while it is growing dramatically closer to the periphery (*3*). Evidence of this pattern is shown in Figure 1.

If infrastructure is added in the central areas of Bangkok, the SPURT and JICA studies agree that traffic volumes will increase so as to maintain congestion levels, except over more lane kilometers. The implication for air pollution is that it

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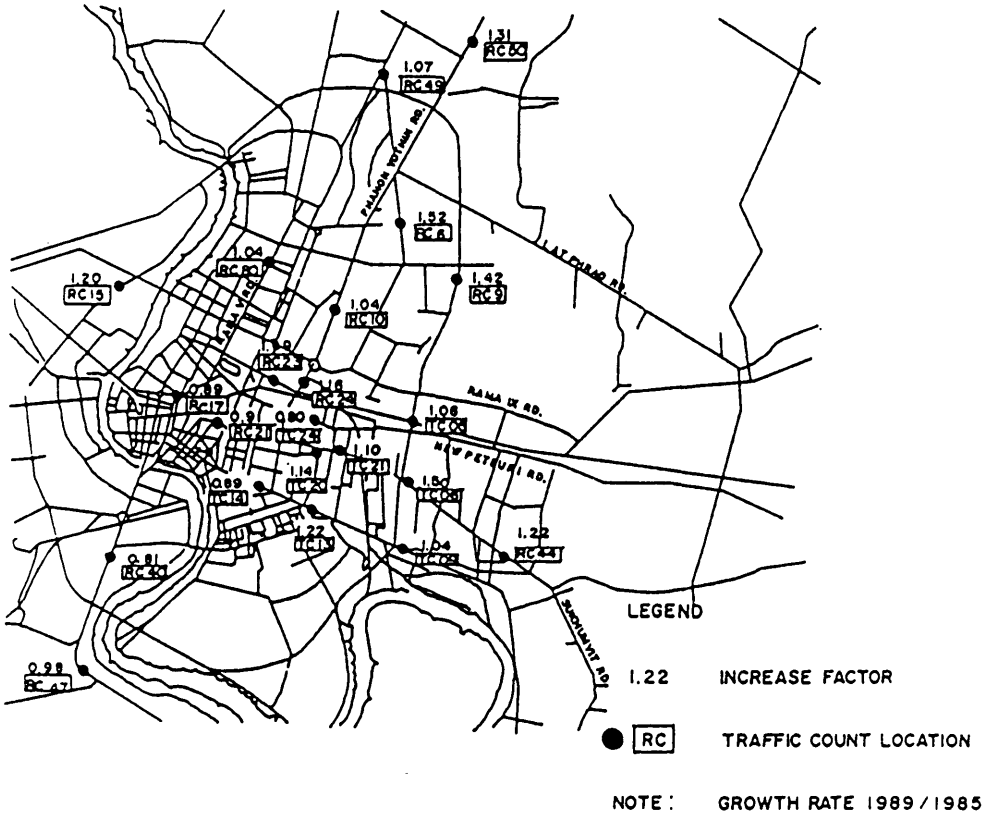

FIGURE 1 Twelve-hour traffic volume growth factor (*3*).

will increase (approximately) proportionally to the roadway lane kilometers provided and vehicle kilometers traveled. To provide, with the proposed new infrastructure, a higher level of service and prevent air pollution concentrations and energy use from doubling or more by the year 2006, demand management and other pollution control policy measures are required.

URBAN TRANSPORTATION AIR POLLUTION

Bangkok exhibits the vehicle-based air pollution problems typical of large industrial cities. Concentrations of various pollutants are high enough along major travel arteries to pose a significant concern for human health. Air pollution in the future, without some corrective measures, will encompass a much larger geographic area.

Lead, carbon monoxide (CO), ambient acid aerosols [from sulfur dioxide (SO_2) and nitrogen oxide (NO_x emissions], particulates (SPM), and products of incomplete combustion from diesel and two-stroke motorcycle engines are primary pollutants of concern from transportation. However, directly related fuel combustion residuals and fuel evaporation constituents are also concerns at much lower concentrations. These include—among others—1,3 butadiene; ethylene dibromide; and dichlorides; and gasoline's various aromatic hydrocarbon (HC) elements, including benzenes, xylenes, and toluene.

The photochemical oxidants (e.g., ozone) that result from extended reactions between ambient NO_x and HC have not yet proved to be pollutants of immediate concern in the Bangkok metropolitan area. Apparently, during the critical hot and dry months, the dominant winds flow steadily from the gulf on most days. In addition, the vertical instability typical of tropical cities at sea level assists in dispersing the reactants. Finally, the very low speed traffic conditions and high levels of HC emissions suggest a NO_x-limited chemical environment that tends to slow ozone reaction cycles.

Tetra-ethyl lead, introduced as a gasoline octane enhancer during the 1920s, is a multiple pathway toxin that causes retarded development in children and general system poisoning. Where leaded gasoline remains the dominant automotive fuel type, lead and lead scavenger exposure overshadow all other acute toxins for total population health risk.

Like exposure to lead, exposure to the combustion product CO is a localized concern. Elevated levels of ambient CO cause an extended loss of the capability of the blood to fully transmit oxygen to critical body tissues. At higher concentrations, CO can rapidly poison the system and cause death by asphyxiation. Chronic exposure levels usually cause headache, dizziness, and productivity losses associated with impaired perception, slowed thinking, and dulled reflexes.

Emissions of CO from vehicle engines are heightened under conditions of extended idling and operation distant from the engine design optimum—that is, at low speeds with frequent stops and starts. These are the conditions typical of large urban metropolitan areas such as Bangkok.

Particulate matter from motor vehicles come from three sources: engine exhaust, mechanical wear, and reentrainment (throwing of roadway dust). The smoke from diesel engines is probably the most obvious urban pollutant, but it may be

unseen particles in conjunction with the smoky exhaust that, like lead, cause the highest health hazard.

Like diesel engines, small two-stroke motorcycle engines result in significant particulate emissions. Unlike well-tuned diesel engines, the highly visible emissions are dominantly unburned HC instead of elemental carbon. Two-stroke engines emit four to eight times the HC and many times the particulates of equivalently sized four-stroke engines. Engine design and exhaust treatment modifications are available to reduce the typical high emission rates for new equipment.

In many urban areas, high volatile organic compounds (nonmethane HC) emissions have the most negative health impacts from photochemical oxidants (ozone or smog). A typical HC constituent of gasoline that exemplifies these concerns is benzene. Extended epidemiologic studies of benzene show a strong linkage to increased incidence of leukemia, a common and usually fatal blood and bone marrow cancer.

In the urban environment, acid aerosols (NO_x and SO_2) contribute to four environmental problems: respiratory problems for sensitive populations, visibility limitations, local vegetation and materials damage, and acid rain.

METHODOLOGY FOR EVALUATING TRANSPORTATION POLICY OPTIONS FOR ENERGY-ENVIRONMENT MANAGEMENT

To understand the growth of travel, energy use, and emissions, as well as to identify and evaluate various policy measures, a transportation model was developed partly on the basis of previous modeling work (*1*). An important feature of the modeling approach is that it uses the existing, extensive travel data base and models used in infrastructure planning.

In many of the largest, rapidly growing cities of the developing world, considerable work has been done in transportation studies, including origin and destination surveys, for the purpose of infrastructure planning. Such studies have frequently been associated with major loans from the World Bank and other international lenders. Despite the wealth of information that these studies provide, they are rarely used for environmental and energy studies or policy. This is the case in Bangkok, with major studies being undertaken under the auspices of the World Bank and JICA.

Several major energy and environmental policies have been adopted at either a national or urban level in developing and industrialized countries [a review of energy measures in developing countries is given elsewhere (*7*)]. To be useful in considering and comparing policy options, a model must be able to be used in representing the impact of these policies. The major energy and environmental policies of interest address technology and behavioral choices, including

- Technological change
  - –Emission standards,
  - –Fuel treatment (e.g., lead removal, sulfur removal, and reformulation), and
  - –Fuel economy standards.
- Behavioral change:
  - –Vehicle, road, and fuel pricing policies to influence vehicle choice and use;
  - –Bans of certain vehicle types;
  - –Zonal restrictions (e.g., pedestrian zones);
  - –Infrastructure provisions to encourage choice of less polluting modes;
  - –Time-based vehicle use restrictions; and
  - –Land use policies.

The greatest experience to date in large-scale policy intervention in industrialized countries has been in the area of technological change. However for developing countries faced with an enormous potential transformation from a significantly nonmotorized to a largely motorized transportation situation, addressing behavioral issues is critical.

Modeling Framework

To provide a flexible model framework for incorporating data and travel projections from existing studies and to include input from existing emissions models, a flexible spreadsheet-based model for estimating energy use and emissions was developed. The geographic basis of the model is 19 travel analysis zones identified in the JICA Bangkok study shown in Figure 2 (*3*).

Energy use and emissions are estimated for each of these 19 zones as well as in aggregate. The calculation procedure follows a conventional approach of trip generation, modal split, trip distribution, and vehicle loading. This series of calculations results in an estimate of vehicle kilometers by mode emanating from each of the 19 zones for the years 1989 and 2006. The modes treated in the model are automobiles, taxis, pickup trucks, buses, minibuses, motorcycles, motorcycles used as taxis, samlors, silors, and nonmotorized movements (walking and bicycles). Energy use and emissions by mode for each of the zones are projected using the estimates of vehicle kilometers, vehicle speed, and coefficients of energy use and emissions per kilometer. Demographic and economic projections, critical components for making future projections, are already resident in the JICA travel projections. As will be described in the discussion of policy options, long-run price

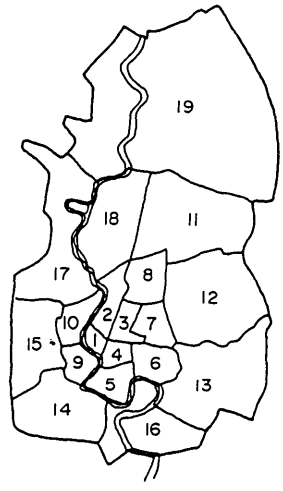

FIGURE 2 Zone division inside study area.

elasticities are treated in this study through adjustments in fuel economy. (A price response in terms of reduced travel rates could also be included, but it has not been included in this version of the model.)

It is important to note that the energy use and emissions assigned to each of the 19 zones are for personal transportation only; freight movements are not treated in this analysis. In addition, energy and emissions are assigned to zones according to trips originating in the zone even when the trip destination is outside of the zone. Thus, zonal projections may overstate or understate actual energy use and emissions occurring in the zone if the travel of residents of the zone in other zones is greater or lesser than travel by outside residents in the particular zone. Aggregate estimates, however, will be accurate to the inherent limits of the data.

The coefficients of energy use are taken from an extensive survey and study in 1987 by Diener et al. (*8*). The average fuel economy levels by mode are adjusted to approximate mean speed in each of the 19 zones by setting the speed to 8, 16, or 24 km/hr, based on JICA projections and the authors' judgment. Fuel consumption rates vary significantly with speed, as discussed in the next section.

The emissions coefficients are based on Technology Type 2 vehicle controls (i.e., very modest engine improvement and limited controls, but without catalytic converters or other add-on devices) which are based on the Environmental Protection Agency MOBILE4 model (*9*) and the California Air Resources Board EMFAC model (*10*).

Bangkok Data

The baseline information used in the model for evaluating energy and air pollution consists of

1. JICA model and travel projections (*3*) and
2. Data base and forecasting model for energy demand in the transport sector (*8*).

Given the use of the JICA report, a few observations are made on the suitability of the JICA projections as a basis for analysis. An important observation is that the JICA projections of vehicle ownership growth and the number of person trips and vehicle trips appear to be very conservative for the economic and demographic assumptions used. The number of private vehicles roughly doubles between 1989 and 2006. This outcome is a function of the logistic functions used for anticipating future ownership patterns for automobiles and motorcycles. The ownership assumptions may have been made because of the untenable levels of traffic that would result without saturation functions on ownership built into the models. For a different view on private vehicle ownership, SPURT (*4–6*) estimates that the vehicle fleet will grow by a factor of 3 to 4 during that same period.

Whereas the limits on vehicle ownership growth suppress the number of passenger trips in the JICA study, the large increase projected in average trip length may exaggerate the number of vehicle kilometers projected for the year 2006. If trip lengths remain constant, as has been the case in large urban areas in the United States (*11*), then the potential underestimate of trip numbers and overestimate in trip length may compensate each other in projecting future travel levels. No estimates of error are provided in the JICA study.

Within these limitations, we believe the JICA report is a reasonable basis for the analysis of energy and emissions levels and policies. Because JICA excludes some trips and treats trips with more than one mode as a single trip, we increased the number of (single-mode) trips to calibrate the model to estimates of vehicle kilometers and energy use.

Emissions Methodology and Data Base

Each of the policy options considered affects fleetwide emissions somewhat differently. They necessitate the capability to model expected in-use emissions for different vehicle and fuel types at different speeds and with different pollution control equipment.

No existing model is comprehensive enough to treat all the vehicles and conditions. The model used for estimating emissions for automobiles, pickup trucks, motorcycles, and light- and heavy-duty diesel vehicles is MOBILE4 (*9*). The model was applied using a 1976 U.S. emissions rate reference fleet (pre–catalytic control technology or Tech-2) and a 1990 U.S. emissions reference fleet to reflect the effect of catalytic converter controls technologies (Tech-4). These are used to represent fleet emissions characteristics before and after controls requirements.

Additional information for sulfur and particulate matter emissions and for efficiency changes at low speeds are taken from the California EMFAC7 model (*10*) and the U.S. National Acid Precipitation Assessment Program emissions inventory literature. The EMFAC7 model was developed in California to model emissions from its fleet. California has a more stringent emissions standard than the U.S. standard, reflecting the particularly difficult motor vehicle–based air pollution problems of the Los Angeles area. Alternative-fueled vehicle information comes from the emerging literature on alternative-fueled vehicles (*12,13*). These sources were used to estimate emissions for vehicles with and without specified levels of emissions controls.

An important determinant of emissions rate is vehicle speed. Thus, emissions rates were calculated at idle, 8-, 16-, 24-, and 32-km/hr average speeds using the model both with and without catalytic converters for specific vehicle modes. Estimated emissions rates under these conditions are shown in Table 1 for CO. The differences in emissions levels between the Tech-2 and Tech-4 technologies are shown by comparing the left and right sides of Table 1. (Similar tables for HC, NO_x, SPM, SO_2, lead, and benzene are available from the authors as space did not allow for their publication.)

POLICY OPTIONS AND EVALUATION

The transportation model facilitates the evaluation of a large set of energy and pollution reduction measures. A broad set of measures were considered in the study of Bangkok (*14*). Some of these, outlined in Table 2, are used to demonstrate some of the capabilities of the transportation model for policy evaluation.

The base case is in some respects a do-nothing policy: because nothing is done to constrain energy use and emissions,

TABLE 1 Emissions Factors by Fuel/Vehicle Combination

Adjusted for Average Speed of Zone in Urban Environment

(Grams/Mile)

Carbon Monoxide (CO)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	980	310	150	100	80	297	108	55	37	29
	4 Stroke Motorcycle	-	280	130	70	50	40	165	113	54	35	26
	2 Stroke Motorcycle	-	238	111	60	43	34	140	96	46	30	22
LPG:	Small 3 & 4 Wheel	-	21.0	13.0	10.5	7.5	6.0	10.5	6.5	5.3	3.8	3.0
	Taxis	-	49.0	23.3	15.0	10.0	8.0	24.5	11.6	7.5	5.0	4.0
Diesel:	LD Cars, Trucks, Vans	-	19.0	6.0	4.0	3.0	2.0	22.3	4.8	3.3	2.3	2.0
	HD Trucks & Buses	-	53.0	41.0	28.0	20.0	15.0	49.5	32.0	22.0	16.0	12.0
Nat Gas: (Compressed- CNG)	LD	-	Base Case assumes no use of CNG.					24.5	11.6	7.5	5.0	4.0
	HD	-	Base Case assumes no use of CNG.					36.8	29.1	26.3	22.5	18.0

(Grams/Kilometer)

Carbon Monoxide (CO)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	609	193	93	62	50	184	67	34	23	18
	4 Stroke Motorcycle	-	174	81	43	31	25	102	70	34	22	16
	2 Stroke Motorcycle	-	148	69	37	26	21	87	60	29	18	14
LPG:	Small 3 & 4 Wheel	-	13.0	8.1	6.5	4.7	3.7	6.5	4.0	3.3	2.3	1.9
	Taxis	-	30.4	14.4	9.3	6.2	5.0	15.2	7.2	4.7	3.1	2.5
Diesel:	LD Cars, Trucks, Vans	-	11.8	3.7	2.5	1.9	1.2	13.9	3.0	2.0	1.4	1.2
	HD Trucks & Buses	-	32.9	25.5	17.4	12.4	9.3	30.7	19.9	13.7	9.9	7.5
Nat Gas: (Compressed- CNG)	LD	-	Base Case assumes no use of CNG.					15.2	7.2	4.7	3.1	2.5
	HD	-	Base Case assumes no use of CNG.					22.8	18.1	16.3	14	11.2

TABLE 2 Transportation Policy Options Structure

Policy		Option
P1	Base Case:	new infrastructure as indicated in SPURT and JICA reports; no energy conservation or emissions controls policies
P2	Controls:	lead and sulfur removed from transportation fuels; type 4 emission controls adopted for most vehicle types
P3	Standards:	emission controls required and fuel economy standards adopted for automobiles and light trucks: from 11.0 to 8.0 liter/100 km @24 kmh
P4	Pricing:	emission controls required and fuel price is doubled due to external events or taxation policy: price elasticity assumed to be -.46 and response in terms of purchase of more efficient automobiles and light trucks resulting in 8 liter/100 km @24 kmh
P5	Area Control:	emission controls required and automobile, pickup truck, motorcycle, and samlor traffic is limited in the CBD (central business district) by means of a toll/permit system; infrastructure for rail, walking, and bicycles developed including reintroduction of pedicabs
P6	Use restrictions:	emission controls required and automobiles pickup trucks, and motorcycles are prohibited from use for two days per week

both grow dramatically between the base year 1989 and the year 2006.

Policy P2 is an emissions control policy for all new vehicles that requires, for cars, motorcycles, and pickup trucks, the use of catalytic converters common in Japan and the United States. The policy necessitates the introduction of lead-free (unleaded) gasoline for use in all new gasoline-powered vehicles. The policy also assumes the elimination of most of the sulfur from transportation fuels to allow for diesel particulate control in the form of either particulate traps or catalytic converters.

Policies P3 and P4 are energy efficiency policies that are adopted simultaneously with Policy P2. The policies are intended to result in a Bangkok automobile fleet that is slightly more efficient than the U.S. new car standards with a level of emissions equivalent to U.S. new car standards.

Policies P5 and P6 probe the use of demand management policies to improve environmental conditions and conserve energy. Policy P5 focuses on an area control initiative that is similar to the one described in JICA and that is implemented in Singapore. An important feature of this policy is the shift of infrastructure investment in this area into rail or "skytrain" technologies, pedestrian paths, and bicycle paths. Policy P6 is based on a program now in use in Mexico City, which has almost the same congestion and even worse air pollution than Bangkok.

Evaluation of Policy Measures in Bangkok

Energy conservation and air pollution reduction offer large potential benefits to Thailand. Within the context of transportation, there are important and necessary benefits provided by the transportation system. The challenge to policy makers is determining the optimal mix of transportation services, energy conservation, and environmental protection. Failure to provide necessary transportation infrastructure can choke the economy, as can failure to protect the environment, particularly in a country that has a large tourism sector.

In this section, the strategies outlined are considered in terms of

- Cost of implementation,
- Effect on energy use and travel time,
- Effect on emissions and general air pollution, and
- Other important implementation considerations.

Energy, time, and emissions comparisons are based on model results. The point of comparison is the base case or Policy P1 as described in Table 2. In using these results for policy evaluation, we stress that the results for 1989 have a range of uncertainty on the order of 15 percent. The results for the year 2006 are obviously subject to great uncertainty. The policy analyses, however, are internally consistent and provide a valid basis for comparing policy options.

Policy Options

Policy P1: Base Projection

The results of Policy P1 in terms of energy use and overall emissions in 1989 and 2006 are shown in Table 3. Energy use increases by a factor of 3 during the period. Contributing to the increase in energy use is the continuing shift to private motor vehicles due to the rapid growth in the Thai economy.

TABLE 3 Base Case Energy Use

Summary Table:	Total Energy Use (1,000 Metric Ton Oil Equivalent)		Energy Use/MM P-Km (Metric Ton Oil Equivalent/ Million Passenger-Kilometers)	
	1989	2006	1989	2006
By Fuel Type	2,181	6,520	42	53
Premium Gasoline	620	2,175	12	18
Regular Gasoline	370	1,241	7	10
Diesel	1,015	2,817	19	23
LPG	174	286	3	2
By Mode	2,181	6,520	42	53
Private Car	592	2,082	61	70
Pick-up Truck	668	2,350	65	74
MC	330	1,162	35	40
MC-Taxi	28	47	42	47
Bus-Minibus	378	576	19	20
Taxi	153	251	105	120
Samlor	15	25	40	46
Silor	16	27	39	45

Emission levels increase by more than a factor of 3 for CO, HC, and particulates and by more than a factor of 2 for NO_x, as shown in Table 4. Because of the lead reduction currently planned, lead emissions grow by only 14 percent. Emissions grow at greater levels than travel because of the greater areal extent of congestion and the greater reliance on private motor vehicles, which, as indicated, are much more energy-intensive than public transit.

Because Bangkok already exceeds World Health Organization guidelines for air pollution, certainly for street-level CO and ambient particulate matter and most likely for lead, it may be concluded from these results that air pollution by 2006 will more regularly exceed acceptable levels. Higher peak concentrations will occur over a broader geographic area and will affect a much larger exposed population. Only the adoption of pollution-limiting policies will prevent this.

Policy P2: Emissions Controls

An important strategic approach for reducing transportation polluton emissions is an emissions control equipment requirement for all new vehicles. This policy has been vigorously applied in Canada, Japan, and the United States and is being adopted in much of Europe and other parts of the world. This strategy necessitates a refinery-level modification of gasoline and diesel fuel that directly reduces acid gas and lead emissions from the motor vehicle fleet. In turn, removal of these exhaust stream contaminants allows for the use of advanced pollution control technology on motor vehicles to reduce volatile and reactive HC (including benzene and other toxics), CO, particulate matter and NO_x emissions. The strategy can be viewed as either a stand-alone option or one to use in conjunction with various demand-management or fuel switching policies.

New vehicle emission standards result in modest on-engine control equipment combined with catalytic converter investment. This control level costs $600 to $800 per typical new gasoline automobile assuming that no taxes are placed on pollution control equipment and ignoring potential efficiency gains from redesign that would reduce the cost of fuel over the lifetime of the vehicle. The fiscal implications for compliance certification can be minimized if specific engine class and control equipment combinations used in other countries are required.

This policy affects local and regional air pollutant emissions, concentrations, and deposition. The emissions modeling by 19 urban zones shows a significant air quality improvement for the regional acid gases and reactive hydrocarbons (nonmethane), along with more localized CO, lead, particulate matter, and benzene/toxics air quality improvement.

The results of Policy P2 are summarized in terms of aggregate emissions in Table 4. SO_x and lead emissions fall drastically despite the extreme growth of travel and energy use. HC also shows a modest reduction from the 1989 levels. CO shows a large reduction from uncontrolled 2006 levels due to the controls but still is twice the 1989 level. NO_x and particulates also have significantly reduced emission levels compared to the 2006 levels without controls but nevertheless show a major increase relative to 1989.

The conclusion to be drawn from this scenario is that a new vehicle standards controls policy is very effective in reducing emissions. However, even considering this effectiveness, CO and particulate matter will continue to present a serious and growing problem for air quality in Bangkok.

TABLE 4 Transportation Emissions Under Policies P1 Through P6 (in thousands of metric tons)

	1989	P1(Base) 2006	P2 2006	P3 2006	P4 2006	P5 2006	P6 2006
CO	1,075	3,830	2,081	2,081	2,081	1,835	850
HC	275	935	250	250	250	227	136
NOx	46	104	71	71	71	66	58
SPM	116	376	261	215	215	236	198
SOx	23	11	11	9	9	10	8
Pb	.501	.570	.057	.047	.047	.052	.042

Policies P3 and P4: Standards and Pricing

Policies P3 and P4 are discussed together because they are designed to accomplish the same objective of reducing energy use in the Bangkok urban transportation system. The policies are geared toward the most energy-intensive aspect of the systems—the automobiles, pickup trucks, and taxis as shown in Columns 3 and 4 of Table 3. P3 accomplishes a 20 to 30 percent reduction in energy use in these vehicles and an 18 percent reduction in all passenger transport energy use by imposing a fuel economy standard of 8 L/100 km on new vehicles. For comparison, automobiles using premium gasoline in 1984 achieved 11.0 L/100 km (*8*).

An alternative means of achieving equal savings of energy is through fuel pricing policy. If Thai drivers responded to fuel price increases in the long run by adjusting the efficiency of the vehicle they purchase (this would certainly be part of any response), then some price exists that would result in an 8 L/100 km efficiency if gasoline prices in Thailand were doubled from 8.45 to 16.9 baht per liter (the same real prices as in 1982). An elasticity of -0.46 results in a nominal 8 L/100 km efficiency. Although in our opinion it is optimistic, this elasticity is used for analysis purposes.

Either efficiency improvement strategy may prove to be politically difficult to adopt. The difficulty with the standards is that the government would have to set up a testing center for certifying vehicles and would have to find an agreement with the domestic vehicle assembly industry. A substantial penalty for noncompliance would have to be set and enforced.

As noted, the impact of a fuel economy standard (and a doubling in the price of fuel if the elasticity assumed is accurate) is an 18 percent reduction in energy use in the year 2006 compared to the case without controls (P1). Either policy would have minor direct costs to the government or to individuals, and in the case of a pricing policy, in which the underlying cost of oil is not the source of the doubling, the policy could net the government a large amount of revenue. Vehicle owners, on the other hand, would incur increased fuel cost.

Policies P5 and P6: Area Controls and Use Restrictions

These strategies are a direct policy response to a major metropolitan dilemma. The dilemma is that it is highly desirable to reduce congestion on Bangkok roads but enough roadway cannot be provided to reduce congestion levels. Congestion relief would result in shorter travel times (for a fixed set of trips), higher fuel economies, and lower pollutant emissions rates. Demand management policies could be implemented to reduce congestion.

Policy P5 borrows a policy pioneered in Singapore and now adopted in a number of cities such as Athens and Oslo, which is to charge a fee (using tolls or a sticker system) to enter the central portion of the city. The objective is to reduce the vehicle kilometers by motorized vehicles by some combination of carpooling, shifting from private vehicles to mass transit, and shifting from private vehicles and mass transit to walking and bicycles. Policy P5 sets a schedule of fees for various types of vehicles so as to result in a 40 percent decline in vehicle kilometers and an increase in average speed to 24 km/hr in an area roughly corresponding to Zones 1 and 4 identified in the JICA study.

To reduce the vehicle kilometers and provide for access, investment would be required to increase mass transit. In addition, investment would be required for pedestrian paths to provide for unserved walking demand. Some improvements in the sois (the narrow local streets that often dead-end at the canals), including bridges at selected locations, are required to provide for access to mass transit by means of bicycles and pedicabs, which would be reintroduced into this area of Bangkok. Motor vehicles would be banned on many of the sois for most hours. Finally, borrowing on the extremely successful experience of many cities in Europe over the last two decades, certain important central shopping and cultural areas would be designated as pedestrian-only zones. The overall purpose of the policy is to provide for what might be termed a quiet zone with a high level of access under pleasant conditions.

The quiet-area policy would require considerable will and vision. Because of the reduction in congestion, large travel time savings would occur within the area. The results of the quiet-area policy are a decline in energy use and CO emissions in Bangkok of 9 and 12 percent, respectively, compared with Case P2. Energy use and emissions in the targeted area, Bangkok's most congested, fall precipitously by more than 50 percent.

Policy P6 is a more drastic policy; it adopts a policy pioneered in Mexico City to ban the use of all private vehicles used in Bangkok for 2 days each week (the Mexico City experiment is for 1 day). This policy runs on a sticker system that would allocate the reduction of traffic over 7 days. The objective is to reduce the number of automobiles, pickup trucks, and motorcycles by 29 percent on any given day and increase average vehicle speed in all zones.

The impact of the vehicle use restriction policy for all of Bangkok is a reduction of 43 percent in energy use and 59 percent in CO emissions. These dramatic results assume that the policy is adopted and strictly enforced and that higher-income vehicle owners do not purchase additional vehicles to circumvent the ban. They point out the large impact of congestion on energy use and emissions. To the degree that the vehicle speed effects are overestimated (the assumption is an 8-km/hr improvement in each zone), these reductions will be overstated.

METHODOLOGICAL AND POLICY RECOMMENDATIONS

The analysis of transportation energy use and resultant emissions reveals disturbing trends for environmental conditions and the quality of life in Bangkok. Current air quality conditions in Bangkok are near failing or have failed national and international standards for health despite favorable local meteorology that helps disperse air pollutants.

Air quality may be worse in other major cities around the globe, for example, Mexico City, Los Angeles, and Cairo, but the prospects for further rapid growth in Bangkok pose an extremely serious challenge. Beyond basic environmental and health issues, there are the related issues of Bangkok's future as a tourist destination and a financial center. If recreational and investment prospects are not already dimmed by existing conditions, they are likely to be challenged by future conditions without a comprehensive mitigation strategy to address the deteriorating environmental condition.

The flexible modeling framework used and the general scenarios developed provide a basis for comparing some of the foremost air pollution management policies available to Thailand. On the basis of the results of these scenarios and additional sensitivity studies, a set of preliminary policy recommendations has been developed (*14,15*).

Before these recommendations are considered, a few observations on methodology will be made. First, where large survey-based origin-destination studies have been conducted, as in the case of Bangkok, these studies provide a major opportunity for systematically exploring energy and air pollution implications. The massive amount of route assignment data can be ignored for the purposes of exploring energy and emissions use by zone. This simplification results in an analysis that is amenable to microcomputer-based conventional spreadsheet software.

This research benefited from the availability of a recent survey of vehicle owners to establish fuel economy levels and load factors. It would have further benefited if a similar survey had been available for emissions levels from vehicles. Thus, the adequacy of the assumption of emissions levels using a U.S. pre–catalytic converter is untested. The error here, however, will tend to understate emissions levels and therefore is conservative.

The large reduction in projected emissions for 2000 brought about by emissions controls combined with the recommended refinery modifications (Scenario P2) makes this policy the highest priority for consideration. This strategy would reduce lead and sulfur emissions in Bangkok and Thailand as a whole compared to 1989 levels. Though CO emissions drop significantly from projected levels, the frequency of ambient concentrations in Bangkok above international health standards would still increase significantly relative to 1989 levels because of the enormous energy demand increase. The fact that CO emissions and ambient levels increase despite the effectiveness of controls is indicative of how large the emerging air pollution problem is becoming.

Both the Thai government and the private fuel refiners have committed to a substantial investment in the refining sector for the Seventh Plan. That effort will upgrade existing facilities and add substantial new capacity and will include most of the capital necessary for processing unleaded gasoline and desulfurizing diesel and fuel oils.

In addition to a basic emissions control policy founded on vehicle technology and fuel quality requirements, Bangkok has four main options for improving environmental quality and energy efficiency that can be considered in various combinations:

- Congestion reduction policies,
- Infrastructure capacity additions,
- Technical energy efficiency improvements, and
- A fuel switching policy.

Any policy that results in a significant reduction in congestion brings about large improvements in emissions and energy efficiency, as was shown by the striking results of Scenarios P5 and P6. The difficulty is identifying proposals that policy makers are willing to implement. Any demand management policies adopted require ongoing experimentation, management, and adjustment.

Electrically powered mass transit on separate grades is one of the most promising public infrastructure investments. These transit systems add capacity to the overall transportation system with energy-related emissions occurring at power plants. Not only can these emissions be better controlled, but the plants are located away from dense population centers. The systematic development of pedestrian paths, bridges, and bicycle ways is also promising. The advantage of these investments is that they provide for considerable mobility without the accompanying energy use and emissions. The use of exclusion zones may be necessary to return many of the sois to bicycle and pedicab use and to improve the immediate environment so as to make walking and bicycling attractive options.

Fuel efficiency improvements (at any specified level of congestion) can be made in Thailand's vehicle fleet over the long run. Because of its relative energy intensiveness, the automobile and pickup truck fleets (when used primarily for passenger movement) are the main targets for fuel efficiency improvement. Substantial fuel taxes as in Japan, Korea, and most of Europe could also be imposed to attempt to achieve a similar result as an efficiency standard on new vehicles.

Although the congestion, energy use, and emissions problems facing Bangkok are enormous, it is also evident that a large number of potentially effective responses exist. The methodology described here, using the case study of Bangkok, provides a flexible means for exploring and evaluating these and other options.

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Transportation Planning and Management in Small Towns in a Developing Country: Case Study for Sri Lanka

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The underlying reasons for the poor state of the transportation systems in small towns (also known as urban councils) in Sri Lanka are identified. Two major reasons are the lack of coordination among the various agencies responsible for different aspects of the system, and the absence of transportation planning. The lack of coordination and transportation planning can be addressed by establishing the post of "transportation planning engineer" in large urban councils. The duties and responsibilities of the proposed post and the required qualifications are outlined. Technical problems associated with road cross sections, the vehicle-transport network, pedestrian facilities, parking, and traffic control are discussed and some remedies suggested. The importance of considering the mobility of all people, as opposed to those using automobiles, is emphasized. Novel approaches to the provision of public transportation services, such as joint urban council–private sector "tram" systems are proposed.

The transportation systems in most small towns (also known as urban councils) in Sri Lanka are in a state of chaos today, mainly because of poor management, lack of financial resources, inadequate maintenance of the existing transportation system, and the low capacity of the public (bus and van) transportation systems. A small town is defined as one with a population range of 5,000 to 50,000. The lack of formal coordination among the various agencies [e.g., Roads Development Authority, Urban Council, Police, Regional (Bus) Transport Board, Private Bus Operators Council] contributes to the general disarray. Furthermore, some important users of the transportation system such as pedestrians and cyclists are not formally under the purview of any particular agency.

Besides the problem of coordination, some of the other problems associated with transportation system planning and management in small towns and possible remedies are also discussed.

TRANSPORTATION NETWORK

The transportation network in a urban council essentially consists of nodes [trip generators and attractors such as shopping areas, bus terminals, railway stations, weekend markets (pola), schools, hospitals, and industrial parks] and transportation links that connect the nodes to residential areas, to each other, and to intercity routes. In addition to roads (with sidewalks) the network includes foot and bicycle paths. The roads on the network should be classified as intercity arterials (primary), secondary, tertiary, and feeder. The classification of a particular road will depend on functions and volume.

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Intercity

Most small towns are on a Class A or B intercity route. The major function of an intercity route is the movement of traffic through the small town. Consequently, the link should have a minimum of two clear vehicular lanes that are not obstructed by parked vehicles. On-street parking during periods of light traffic can be allowed only if four lanes are available. An intercity route could also consist of two one-way links with one lane and one parking lane, each forming a complete system. Raised and fenced sidewalks of a minimum 1-m height should be provided for pedestrians. Ideally, adjacent parallel one-way service roads should be provided with adequate parking, and parking should not be allowed on the intercity link. A good example is the Colombo-Galle Road through the Kalutara urban councils shown in Figure 1.

Bypasses take business away from small towns. Consequently, bypasses should be considered only if space is unavailable for adequate traffic movement within small towns.

Primary Arterial

An arterial street services major intraurban council movements of traffic as its major function. If an arterial link coincides with an intercity link it should be configured as an intercity link. Otherwise, it should have a minimum of two lanes. One or two parking lanes could be provided if space is available. Off-street parking lots should be considered if space is not available for on-street parking lanes. An arterial could also consist of two one-way links with one-vehicular lane each and, if space is available, one parking lane each. Raised and fenced sidewalks should be provided for pedestrians in central business district (CBD) regions. In other parts of the urban council, at-grade, stabilized, compacted, drained, graveled sidewalks are sufficient. A good example is the Colombo Airport access road.

FIGURE 1 Widened section of the Colombo-Galle Road, Kalutara; note that cross section includes sidewalks, service roads, and main highway.

Secondary Arterial

A secondary arterial such as a shopping street caters mainly to people who have shopping destinations on that street. Ideally, it should have wide sidewalks for pedestrians, two parking lanes, and two lanes. However, a one-way street with only one lane and two parking lanes is acceptable. Additional off-street parking should be provided where necessary. In extreme cases, shopping streets can be converted to pedestrian-only malls with parking near the extremities of the mall and on adjacent streets.

Collectors (Tertiary)

Collectors are mixed use side streets that service local destinations as well as feed arterials with traffic. Two lanes with two at-grade graveled sidewalks are generally adequate, with parking bays provided in areas with shops, schools, temples, and such. One-way collectors should have at least one lane and one sidewalk.

Feeders

Feeder streets are side streets connected to collectors or arterials that service areas of mainly residences and an occasional boutique. Ideally, two lanes should be provided on these low-volume, low-speed roads. However, one wide lane on which two vehicles can pass slowly while moving in opposite directions is sufficient. At least one sidewalk should be provided.

Industrial Streets

Industrial streets are collectors that serve industrial regions or parks within the urban council. They should have two wide lanes that can accommodate trucks and wide sidewalks, plus bicycle lanes and sidewalks for the workers.

ROAD CROSS SECTIONS

The delays experienced by private motorized vehicles (subsequently referred to as vehicles) is perceived by most decision makers and influential citizens (all of whom are regular users of automobiles) to be a major problem. Although this is true to some extent, it is important to consider all modes of transportation (vehicles, pedestrians, buses, bicycles, carts) when establishing the cross sections for the roads in a town. In particular, it is important to consider formally pedestrian and bicycle trips since they are the most attractive from the economic, public health, and environmental points of view. It is noted that the term "cross section" includes both lanes and shoulders. Figure 2 shows a section of highway with no shoulder provision for pedestrians. In contrast, Figure 3 shows a cross section with adequate shoulders for pedestrians. Increased capacity for vehicles should not be given at the expense of the pedestrians. At the same time, lanes demarcated for use by vehicles (hereforth called lanes) should be free of pedestrians (except at crosswalks), and shoulders assigned to pedestrians should be kept free of parked vehicles.

All roads should consist of at least one lane with shoulders adequate for pedestrians. Each lane of a two-lane, two-way or one-lane, one-way road should be wide enough (usually 5 m) for a van to pass a load-carrying bicycle, with the cross section of each lane consisting of a 3.7-m vehicle lane and a 1.3-m bicycle lane. The cross section should be wider if Regional Transport Board (RTB) buses are allowed. If parking is allowed, sufficient width should be available for a parking lane and the shoulder should be physically separated. This will help prevent motorists from parking on areas designated for pedestrians.

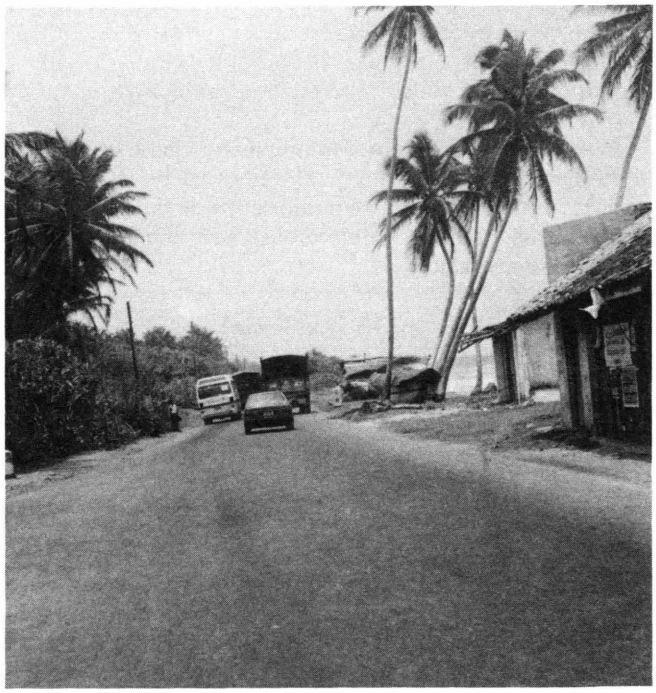

FIGURE 2 Section of Galle Road near Galle; inadequate shoulders for pedestrians.

FIGURE 3 Kandy Road; recently reconstructed with adequate lane and shoulder width.

FIGURE 4 Parked vehicles force pedestrians to walk on street in Welimada urban council.

In heavy pedestrian sections (more than 600 pedestrians per meter per hour), the lanes and adjacent sidewalks should be separated by welded steel-pipe fences with concrete foundations (*1–3*). This will prevent pedestrians from walking on lanes and vehicles from being parked on the sidewalk. In medium pedestrian sections the sidewalk should be raised, and in light pedestrian sections the road should be protected by a curb between the lane and a leveled gravel sidewalk. Figure 4 depicts the problem in which parked vehicles force pedestrians to walk on the roadway.

The available roadway width and land use should dictate the number of lanes and whether parking is allowed. For example, shopping streets should have at least one parking lane 3 m wide, and priority should be given to extra lanes over parking lanes in streets with heavy through traffic. On arterial roadways the cross section should be wide enough to accommodate a median of variable width (usually a minimum of 1 m wide). The median can consist of raised curbs.

Bus bays should be provided (minimum length of 36 m for three buses) near bus stops in the town center. Transit operators at bus stops should not interfere with the pedestrians. Cantilevered structures in place of present rectangular ones should be constructed.

CHANNELIZATION AND SIGNS

Intersections should be channelized for turning movements and traffic circles when necessary. Further, all intersections within town limits except those between local streets should be controlled with Stop and Yield signs. Occasionally, an intersection may have to be signalized.

The centerline of a two-way street should be marked with a solid yellow line. The edges of outside lanes should be marked with solid white lines. The space on the left side of the solid white line is for bicycles. A further solid white line will demarcate the separation (if any) between the bicycle lane and the parking lane. A broken white line will denote the separation between same-direction lanes.

Local directional, parking, and traffic control signs are the responsibility of the urban council, and intercity directional signs are the responsibility of the Roads Development Authority (RDA). However, a manual on uniform traffic central devices for Sri Lanka should guide both groups.

PARKING

Traveling by private automobile is not cost-effective from a social point of view when the costs of providing extra lanes, parking facilities, policing, environmental pollution, and health care are considered. Ideally, most intraurban councils' trips should be undertaken by public transportation, cycling, or walking. A good intraurban council bus service should be subsidized (when necessary) by using funds generated by parking fees, provincial and national subsidies, and other sources.

At present, the parking fee is from no charge to 1 rupee in most urban councils, irrespective of the time and the duration. A significant amount should be charged for all vehicles, including official vehicles, to park—say, 5.00 rupees per hour with a minimum of 2.50 rupees. Higher amounts should be charged during periods and at locations where parking is in short supply. Thus, parking near the market on weekends should be more expensive than parking at the edge of the town center during off-peak periods. The main idea is to discourage personal automobile use and consequently to reduce congestion caused in part by circulating vehicles. However, it is essential to provide a good alternative public transportation system.

A significant amount of employment could be generated locally by hiring parking ticket issuers such as the traffic wardens of Colombo. However, it may be more cost-effective to install locally designed parking meters. Again, a national competition could be organized for a parking meter suitable for local weather conditions and resistant to local forms of vandalization.

Double parking and parking on the sidewalk (along or across) should be prohibited. Parking lanes should be wide enough to allow angle parking by passenger vans.

PEDESTRIAN FACILITIES

The highest priority should be given to pedestrian facilities such as sidewalks, footpaths, pedestrian precincts (malls), and crosswalks. All streets should have dedicated exclusive-pedestrian sidewalks of appropriate width. The sidewalks should be raised and fenced in very heavy pedestrian corridors or in locations where parking lanes are adjacent. Parking on the sidewalks should not be allowed under any conditions.

The sidewalks should be designed with adequate space for utility posts, garbage containers, and bus stops so that a minimum width is available for walking. In particular, urban council bylaws should be strictly enforced to prevent the dumping of garbage, new construction materials, and construction debris on the sidewalks. The use of movable containers for construction debris should be encouraged. It is common for sidewalks to be blocked by raw garbage, garbage containers, and trucks loading or unloading goods. Whenever possible, back streets (unpaved service streets running behind shops) should be used for this purpose. Alternatively, the storage and collection of garbage and the loading and unloading of goods should be strictly controlled with respect to time and location.

Sidewalk vendors and stalls provide a service to pedestrians that is governed by market forces. Forcible evacuation of vendors to distant "markets" rarely solves the problem. However, priority space is for the pedestrian flow and not for vendor stalls. Streets with heavy pedestrian flows and many sidewalk vendors are prime targets for conversion to malls.

Grade-separated pedestrian crossings (tunnels and bridges) are expensive and usually unattractive, unsafe, and rarely used to their potential. Well-marked at-grade crosswalks that are policed frequently and equipped with traffic lights where necessary are usually sufficient.

Besides providing exclusive sidewalks along all streets, serious attention should be given to providing a network of pedestrian facilities such as footpaths and pedestrian malls that connect major nodes with the nearest bus terminal or bus stop, rail station, and parking lot. The essential ideas behind such a network are to provide a safe walking environment and to minimize walking distance. The footpaths should be leveled, compacted, stabilized, and well lit. Crossings of footpaths and streets should be carefully controlled with signs and signal lights where necessary. The pedestrian network should be designed to encourage the circulation of people walking and of public transportation as opposed to the circulation of vehicles seeking nearby parking. Schools and playgrounds should be connected to nearby residential areas by footpaths and sidewalks. Pedestrian crossings near schools should be located and operated with special care. Above- and below-grade crossings should be used only if absolutely necessary for capacity or safety purposes such as a crossing of an intercity route with heavy traffic by a pedestrian route. The use of the facility should be encouraged by providing well-designed, attractive structures with in-place vendor stalls if possible. It is recommended that two national competitions for type plans for at- and below-grade crossings be held.

At present, the police control crosswalks used by pedestrians. However, they should also ensure that pedestrians do not walk along the vehicular rights of way and enforce appropriate laws.

BICYCLES AND OTHER NONMOTORIZED TRANSPORTATION

Previous large-scale urban transportation studies in Sri Lanka have neglected the importance and opportunities offered by nonmotorized transportation modes such as bicycles and pedal-powered trishaws. In fact nonmotorized modes are often cited as one of the causes of traffic congestion and safety problems on urban streets. This view of nonmotorized transportation has resulted in transportation system management schemes directed mainly to the automobile, bus, and truck at the expense of nonmotorized transportation. Part of the problem as well is the view that nonmotorized transportation is associated with a backward technological society. Also part of the problem is that bicycle technology in Sri Lanka is antiquated—for example, single gearing on pedal trishaws.

Pedal Cycles

Thirty years ago, the percentage of cycle riders in small towns was much higher than it is today. Even though cycling should be encouraged in Sri Lanka for shorter-distance traveling (because fossil fuel is not available), neither government nor planners have taken any measures to encourage this mode. The sharp drop in cycling is mainly due to safety reasons. Police accident statistics clearly show that a large number of pedal cyclists have had accidents in the recent past in small towns and other places and that many of these accidents are fatal. It is proposed that roads in towns should be planned to ensure the safety of pedal cyclists as well to encourage school children and others to use this mode more frequently.

Possible solutions concerning bicycles and other slow-moving nonmotorized transportation include the separation of traffic streams into fast and slow lanes. Bicyclists may have to share the same facilities as pedestrians on narrow cross sections such as bridges. The minimum lane width for a bicycle with a carrier basket (the type typically used in Colombo) is 1.2 m, and the desirable width for a two-way cycle path is 2.0 m. In rural areas bicycles can share the shoulder with other slow-moving vehicles such as animal-drawn traffic.

To improve safety for slow vehicles, traffic regulations (such as the provision of lights or reflectors) and transportation systems management that recognize the importance of nonmotorized transportation both need to be marked.

The potential, however, for nonmotorized transportation in Sri Lanka will not be fully realized until modern technology such as multiple gearing and improved braking are used. Modern bicycle technology coupled with planning and traffic engineering that provide for slow-moving vehicles will help establish nonmotorized transportation as socially acceptable and practicable in Sri Lanka.

Draught cattle have been used in many South Asian countries for a very long time. Sri Lanka has a relatively higher per-capita vehicle ownership (about 2 percent) among South Asian countries. In the capital, Colombo district per-capita vehicle ownership is about 10 percent. However, even today nonmotorized transport is a major mode of transportation, even in Colombo.

Cycling and walking are the major nonmotorized modes of passenger transport in small towns, especially for shorter and

medium-distance travel up to 6 to 10 km. Bullock and hand carts are the two major modes of nonmotorized goods transport.

Bullock Carts

Many aspects of bullock cart operations and costing remain imperfectly known—their type and design, the number of improved versions, their daily use, cost of operation, pattern of ownership, life span, and the exact nature of freight carried. There are an estimated 44,000 bullock carts in Sri Lanka.

Most bullock carts have steel-rimmed wooden-spoked wheels attached to a wooden axle. All rely on wooden superstructures with roofs made from either coconut leaves or, less commonly, corrugated iron. In the far north and east of the country, open-sided bullock carts are more common. In Sri Lanka the average load carried by a bullock cart is about 400 kg (*4*).

In congested small towns in which there are narrow roads with many bends, the bullock carts delay motorized traffic because the roads are not planned to handle such mixed traffic. This has resulted in planners' giving low priority to this mode, even though many people use bullock carts to transport goods. The passenger-car equivalent of a bullock cart is estimated to be 6 to 8 units, and the average speed of a laden bullock cart is estimated to be 3.7 km/h. The average haul generally lasts 1 to 2 hr.

The major commodity carried by bullock carts and hand carts in urban council areas is building materials (bricks, cement bags, sand, metal, iron reinforcements, roof tiles, timber, etc.). The hiring charge for a cart is about half that of a truck for up to about 13 km. Hence, a majority of people living in urban areas hire carts to transport goods that need no careful handling.

TRAFFIC AND PEDESTRIAN CONTROL

Unless vehicle ownership is low, traffic congestion cannot really be eliminated. There is no city in the world that has both high automobile ownership and low traffic congestion. Traffic will increase to fill available capacity.

It is relatively easy to control traffic on a well-planned, well-designed transportation network. In addition to enforcing the Motor Vehicles Act on automobiles and other vehicles, the police should also actively control pedestrians who cross illegally and walk along the vehicular lanes. Bicycles should also be checked for safety features and lights.

Traffic control is needed mainly at intersections where the road space is shared by intersecting streams of traffic and pedestrians. Control options include noncontrol, traffic control signs, traffic circles, and traffic signals. If the presence of police is required at a traffic circle, then it is either poorly designed or unable to handle the existing flows.

When pedestrian traffic is low, it is counterproductive for police to stop vehicles at marked pedestrians crossings (with no signals) to let pedestrians cross. This leads the drivers to believe that they need not stop unless signaled by a policeman. Instead, the police should charge those who do not stop for pedestrians at crosswalks. If pedestrian traffic is so high that motor traffic can be severely obstructed at a crosswalk by regularly crossing pedestrians, pedestrian signals that work on, say, 1-min cycles should be installed. Grade-separated crossings should be considered as the last step. If funds are not available to install pedestrian signals, the police could control pedestrian crossings.

The philosophy behind urban traffic management is to get pedestrians and vehicles to remain in their own rights-of-way and to interact only at specific locations under controlled conditions.

PUBLIC TRANSPORTATION

The mobility of a majority of people depends on the provision of reasonable public transportation and pedestrian facilities; this includes non-automobile-owners, senior citizens, children, and many females. The urban council could negotiate with the local RTB depot and the Private Omnibus Association (POA) regarding the provision of intraurban council bus services connecting residential areas to major nodes such as shopping centers, markets, government offices, hospitals, major office buildings, industrial parks, railway stations, and main bus terminals. Routes, stop locations, bus types, timetables, and terminal locations should be discussed and negotiated. On low-demand routes the RTB and POA can be subsidized for providing minimum services.

Currently available van services to schools are disasters waiting to happen because of overloading, lack of safety measures, and poor pick-up/drop-off locations and practices. Most such services provide transportation to far-off schools outside urban council boundaries. Van service to local schools from within the urban council should be encouraged by providing good off-street parking facilities in or near schools and suggesting appropriate routes and safety features in conjunction with parent-teacher associations and school administrations. These services could be funded on a user-pay basis.

Priority should be given to bus stops over parking lanes. Bus stops should be provided in parallel bus bays only if one lane is available for through traffic. Otherwise, buses should be allowed to stop on the left lane.

An accessible, reliable, fast, safe, and inexpensive public transportation system is the key to urban transportation management. A scheme that gives priority to public transportation and pedestrians can succeed only if the public transportation system functions.

Mitric has suggested that developing countries could draw several lessons from the successful French experience in providing public transportation service in urban areas (*5*). He argues that the French system is successful because of the following:

- Existence of a coherent national policy on urban public transportation.
- Use of clear contractual arrangements among various levels of government and public transportation authorities that have been set up by groups of urban councils. The contracts "clarify relationships and mutual responsibilities; establish measurable goals; and stress partnership and negotiation."
- Maintenance of competition between various private operators as well as private and public operators.
- Decentralization, which resulted in experimentation and variety in technical matters, organizational, and tariff policies as well as in amounts of investment in public transit per capita.

- Creative funding of public transportation including local taxes and subsidies from the federal government.

The urban councils transport planning engineer, representing the public (the demand side) should negotiate with the RTB and POA (the supply side) regarding intraurban councils routes, bus stops, and frequencies. Otherwise, the public may be at the mercy of an oligopoly in which certain areas are not served. Some routes may have to be subsidized.

In fact, urban councils have the power under Sections 57 and 59 of the Urban Council Act of 1988, individually or in association with nearby urban councils, to construct and operate "tram" systems (streetcars or light rail transit systems) and all other public transportation systems (*6*). Under Section 58, they have the power to form agreements with private sector operators to undertake such transport functions. Such services should be supported by the national and provincial governments as well as through special urban council taxes on properties and vehicles as allowed under Section 162(1) of the Urban Council Act of 1988.

Shanmugalingam has given a legal opinion to the effect that "the draft proposals (in this report) are not in any way ultra vires to the provisions of the 13th Amendment" (personal communication, 1991).

COORDINATION

The responsibility for various aspects of the transportation system in an urban council falls on several different agencies and officials. A major cause of the mismanagement of the system is the splitting of responsibility among many agencies and officials. One possible solution would be for the urban councils to take over responsibility for most aspects of the transportation system. However, this is not viable from an economic point of view given the low tax base of many urban councils. It is also an inefficient way of using resources such as highway maintenance equipment. On the other hand, some urban council administrations appear to be satisfied in not having much responsibility since transportation woes can be blamed on others.

In the following it is argued that the transportation system performance in small towns can be improved substantially by creating the post of transportation planning engineer. This engineer would be responsible for all transportation planning and management activities falling under the control of an urban council. Typically, one transportation planning engineer would be responsible for each large urban council. For small urban councils within an urban conurbation, an associate transportation planner (not necessarily an engineer) would be responsible for the day-to-day planning for each urban council and the transportation planning engineer would have overall responsibility for all urban councils within the conurbation. Among other responsibilities, the transportation planning engineer would chair a transportation coordinating committee consisting of persons from various public and private agencies responsible for various sectors of the transportation system.

Urban Council Transportation Planning Engineer

At a minimum, an urban council should be responsible for planning the transportation system within its area, to the extent possible under the Urban Council Act of 1988. It is vitally important for a transportation planning engineer to be available in-house and to be responsible to the urban councils' politicians and hence to the people. Some of the major functions of the proposed urban council transportation planning engineer are

- Planning and operating the urban council road network;
- Designating arterials, collectors, local roads, and so on;
- Designating parking lanes and off-street parking lots;
- Enforcing parking and collecting parking fees;
- Designating truck routes, loading zones, and times;
- Providing traffic signs;
- Situating bus stops, bus terminals, and bus routes (in consultation with RTB and POA);
- Providing bicycle facilities; and
- Providing pedestrian facilities.

A major function of the transportation planning engineer would be the chairing of an urban council transport coordination committee consisting of the following officials:

- Urban council transportation planning engineer (chair);
- Inspector of Police (traffic), Sri Lanka Police (local station);
- RDA executive engineer;
- RTB depot superintendent;
- POA secretary;
- Merchants association president; and
- Sri Lanka Railway station master.

This group should meet at least four times a year and whenever necessary to discuss problems, solutions, and any possible changes to the transportation system. Each official would have legal authority over various aspects, but he or she would be expected to consider the viewpoints of the others and to attempt to accommodate their concerns. At the least, all issues and concerns would be on the table and would receive a full airing of views.

Further, the transportation planning engineer would chair an honorary advisory committee of citizens consisting (at a minimum) of

- A local school principal,
- A local merchant,
- Two householders from the urban council, and
- A senior citizen from the urban council.

Input would be requested from this committee regarding any changes to the transportation system.

The transportation planning engineer and the works engineer would coordinate excavations for utilities (water, sewerage, electricity, telephone) to minimize disruptions. Essentially, no major excavations should be permitted on the road system without the prior consent of the transportation planning engineer.

Qualifications and Training

The transportation planning engineer would be a qualified civil engineering graduate who has taken courses in transportation planning and engineering and preferably a course

in urban planning. In the long term transportation planning engineers should be required to hold a postgraduate diploma in transportation planning and management. This type of diploma is planned to be offered by the University of Moratuwa beginning in 1992. Professional registration (C.Eng.) would be required.

The associate transportation planner would be any degree holder qualified in at least two of the following subjects: physics, mathematics, geography, economics, sociology, and computer science. The associate planners could be further trained by means of a series of short courses, seminars, and workshops in transportation planning and management.

SMALL TOWN CASE STUDIES

Two small towns have been selected for case studies: Nugegoda and Maharagama on Route A4. Both towns are within what may be considered the greater Colombo area. The traffic and transportation problems of each town are discussed briefly, and preliminary planning studies are recommended. These studies are currently under way by final-year civil engineering students at the University of Moratuwa.

Nugegoda

Nugegoda is on Highway A4 approximately 10 km southeast of the Colombo CBD.

Road Network

The main shopping area is on a secondary road connecting with the main highway, Route A4. The two main intersections are uncontrolled with operations at times similar to a four-way stop. There is little or no channelization. All road links are nominally two-lane facilities. Pavement surface is considered good, but excavations have not been resurfaced and many manhole covers are missing, as shown in Figure 5. The uncovered manholes pose a danger for pedestrians, cyclists, and vehicles.

Public Transportation

Public transportation facilities consist of an off-street terminal for public and private buses that is adjacent to the Nugegoda rail station. The rail line is currently underused in terms of its potential capacity, although the three trains per day are operating with high load factors. In June 1990, a total of 3,022 passengers passed through the Nugegoda rail station. The rail line has a right-of-way adequate for upgrading to light rail transit. Of grave concern is the encroachment on the rail right-of-way by small shops and squatters, as shown in Figure 6. Measures should be taken immediately to protect all transportation corridors from illegal development. Without a transportation corridor, introduction of upgraded rail or transitway systems will be difficult, if not impossible, to construct.

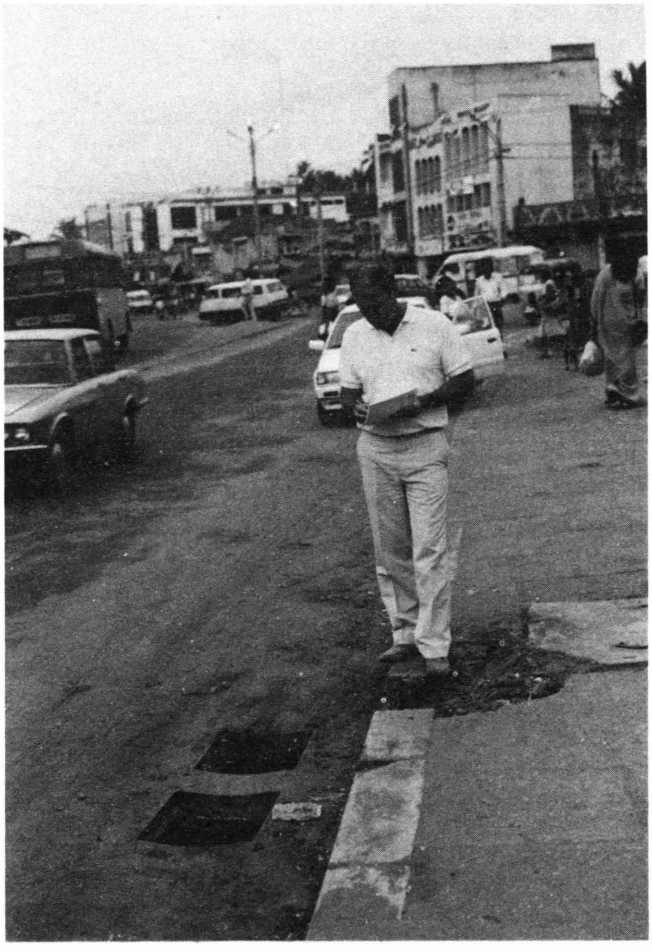

FIGURE 5 Missing manhole covers on main shopping street in Nugegoda.

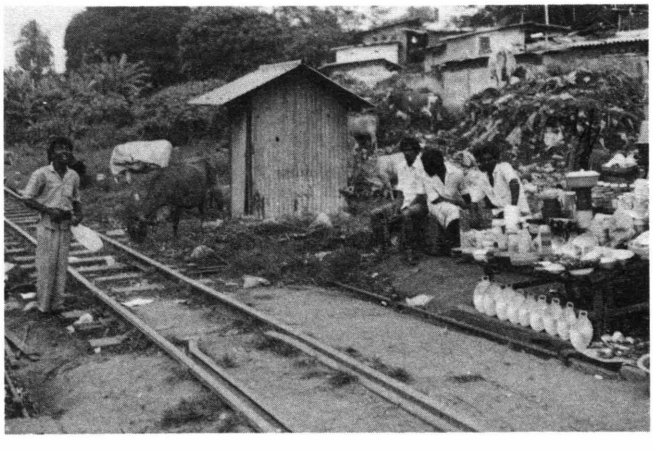

FIGURE 6 Example of encroachment on K.V. rail line right-of-way in Nugegoda.

Pedestrian Facilities

Although wide sidewalks exist in certain areas, many sections have broken pavements, forcing pedestrians to use the road. In those areas with no sidewalks, pedestrians are forced to walk on the road. Pedestrian crosswalks are in need of repainting. The open market provides a pedestrian mall free of vehicles. Pedestrians are sometimes forced to use the road if sidewalks are used for displays by shop owners, as shown in Figure 7.

It is recognized that a lack of pedestrian data has been a constraint in defining the pedestrian problem and evaluating alternative solutions. Recent techniques, however, have been developed to minimize the errors resulting from short-term counts with large variances (*1*). Using such techniques would help expand the pedestrian data base of small towns and introduce new planning techniques to the transportation planning engineer.

Parking

Off-street parking is provided at the shopping center, and parallel parking is permitted on the main shopping street west of the open market. A limited amount of parking in front of shops, although illegal, is tolerated by the police because of the problems of enforcement. Illegally parked cars, however, force pedestrians to walk on the road. Traffic wardens were observed on duty, and their efforts were diligently performed and effective. Parking for taxis is provided at the shopping center, which is adjacent to the bus and rail terminal.

Recommended Studies

1. Conduct a traffic circulation analysis.
2. Analyze two main intersections to determine if signals are warranted and their cost.
3. Review public transportation facilities including the bus and rail terminals.

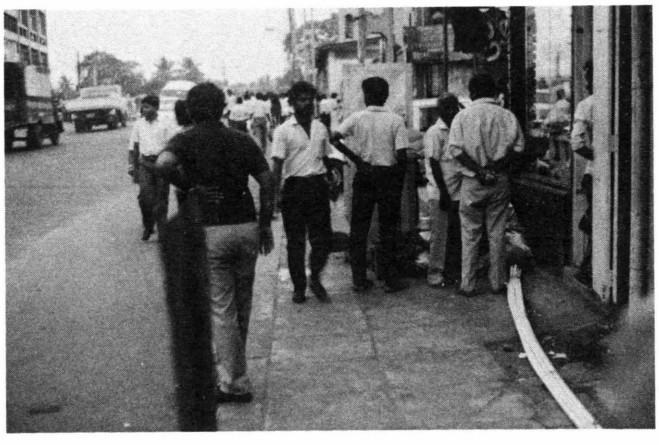

FIGURE 7 Pedestrians forced to use road where sidewalks are used by shop owners.

4. Develop an overall plan to improve pedestrian facilities. Special attention should be paid to the separation of pedestrians and vehicles, crosswalks, and adequate pedestrian walkways.
5. Develop a parking plan for Nugegoda town. The plan should show the location and number of parking stalls and where parking is restricted.

Maharagama

Maharagama is also on the main road A4, but it is several kilometers southeast of Nugegoda. Maharagama differs from Nugegoda in that the main shopping activity is on the main road and that the potential for a fully integrated transportation system is not as great.

Road Network

The main shopping activity lies on the Route A4, which also serves through traffic. The old highway parallels part of the new highway and offers some potential for a bus terminal off of the main route. The main problem with traffic circulation appears to be that the main route must serve all trip purposes and all modes, including its use as a bus terminal.

Public Transportation

The main problem is that the bus terminal lies along Route A4, resulting in buses interfering with through and local traffic as well as pedestrians.

Pedestrian Facilities

Along the main route, pedestrian facilities are very poor. However, the market area provides shopping in a mall atmosphere.

Parking

A limited amount of off-street parking is provided in Maharagama; however, many vehicles were observed parking on curbs and sidewalks.

Recommended Studies

1. Examine the possibility of separating through and local traffic.
2. Determine the potential of using the old road as an off-street bus terminal. Because this offers the greatest potential for improvement in Maharagama, a detailed public transit circulation and terminal plan should be developed. Also, as part of this project, the potential of linking the bus and rail station should be investigated.
3. Develop a plan for upgrading pedestrian facilities throughout Maharagama town center.

ACKNOWLEDGMENTS

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Bicycle-Friendly Cities: Key Ingredients for Success

ANDY CLARKE

What makes a city bicycle-friendly? How can a city become more bicycle-friendly? Seattle has twice been voted the best city for bicycling in the United States. Other cities renowned for bicycling have similar characteristics that distinguish them from cities considered less conducive to bicycling. A detailed survey of bicycle professionals has been carried out, and the criteria for judging the 10 best cities for bicycling were researched. Three key ingredients for success are identified, and their applicability to cities across the United States and elsewhere is explored.

More new bicycles are sold each year than new cars; 93 million U.S. residents enjoy bicycling, most of them adults (*1*). A recent opinion poll carried out by the Harris organization on behalf of *Bicycling* magazine reported that although only 1 person in 60 in the United States currently commutes by bicycle, that figure could rise to 1 in 5 if conditions were more favorable (*2*). *Outside Business* magazine in February 1991 rated the six "hottest" sports for the 1990s: mountain bicycling was top, and bicycle touring was fourth. Tandem cycling was first in the "what's next" category (*3*).

Interest in bicycling is high at the federal level. FHWA appointed a bicycle program manager in 1990, and the Office of the Secretary of Transportation followed suit in 1991. FHWA and the U.S Department of Transportation are involved in a 2-year, $1 million National Bicycling and Walking study. FHWA has been actively promoting bicycling through its regional and district offices with a series of publications and policy memorandums from the FHWA Administrator.

Many bicycle-specific bills have been introduced into Congress over the past 2 years; they range from general expressions of support for bicycling to proposals for guaranteeing levels of funding for bicycle and pedestrian facilities and requiring the installation of bicycle parking at all federal office buildings.

State, county, and city agencies are showing a similar level of interest. For some, bicycling is an opportunity to reduce single-occupant vehicle use. For others, bicycling is an integral part of the transportation system, or a desirable recreational and environmental policy to pursue. Cities struggling with congestion, new clean air mandates, and dwindling resources for new construction and maintenance are increasingly looking at bicycling, walking, and other transportation demand management strategies for salvation.

Whatever the reason for individual or organizational interest in bicycling, some communities are regularly portrayed as models for others to follow. A glance through the literature shows the following states and cities cited for frequent praise: California, Minnesota, New Jersey, North Carolina, Ohio, and Oregon; and Davis, Palo Alto, and San Diego, Calif.; Boulder, Colo.; Gainesville, Fla.; Eugene and Portland, Oreg.; Arlington, Va.; Seattle, Wash.; and Madison, Wis.

Bicycle Federation of America, 1818 R Street, N.W., Washington, D.C. 20009.

WHICH CITIES ARE BEST FOR BICYCLING?

These cities may not have the highest levels of bicycle use, but they are always singled out as being among the most bicycle-friendly cities in the United States (*4*). For example, in 1988 and 1990 *Bicycling* magazine published a list of the top 10 cities for bicycling (*5,6*). The results were as follows:

- 1988
  - –Seattle, Wash.
  - –Missoula, Mont.
  - –Eugene, Oreg.
  - –Washington, D.C.
  - –Indianapolis, Ind.
  - –Ann Arbor, Mich.
  - –Bloomington, Ind.
  - –Calgary, Alberta
  - –Redmond, Wash.
  - –Palo Alto, Calif.
- 1990
  - –Seattle, Wash.
  - –Palo Alto, Calif.
  - –San Diego, Calif.
  - –Boulder, Colo.
  - –Davis, Calif.
  - –Gainesville, Fla.
  - –Eugene, Oreg.
  - –Montreal, Quebec
  - –Madison, Wis.
  - –Missoula, Mont.

In the 1990 survey, honorable mentions were also given to Ann Arbor, Mich.; Arlington, Va.; Minneapolis, Minn.; Toronto, Ontario; and Calgary, Alberta.

A 1989 survey by the League of American Wheelmen rated the performance of states in relation to bicycle policies, rules, and regulations. The top five states were Arizona, California, Oregon, Ohio, and Florida (*7*): an increasingly familiar list.

This paper identifies why these communities are so identified with probicycling programs and policies, what makes them different from other states and cities, and, more important, what other states and cities can do to make themselves more bicycle-friendly.

THREE KEY INGREDIENTS OF SUCCESS

When representatives of the bicycle industry, bicycle user groups, trade and consumer magazines, and government agencies met to discuss this question in 1989, a clear train of thought emerged (*8*).

First, they acknowledged that increasing the level of bicycling—for transportation and for recreation—is a desirable social, economic, and environmental goal, but that it will not happen as long as people believe that there are too few safe places to bicycle. More people would bicycle if they felt safer doing so.

Bicycling takes place primarily on the highway system or in parks and recreation areas controlled by government. Government action—or inaction—determines the quality of the bicycle riding environment. In almost all the places where bicycling is popular—such as those places listed—the city or state has an active bicycle program. An active bicycle program usually comprises three key ingredients:

1. A full-time bicycle program manager,
2. Supportive politicians and professionals within government agencies, and
3. An active and organized citizenry, usually exemplified by the presence of a bicycle advisory committee.

Bicycle Program Manager

In 1990 the Bicycle Federation of America (BFA) surveyed more than 250 government agency staff members at the federal, state, and local levels who work on bicycle issues. More than 120 completed surveys were returned, 34 (29 percent) from people with the title of bicycle coordinator or bicycle program manager. Five more respondents had full-time positions devoted solely to bicycle issues but were not actually called bicycle coordinators (*9*).

Two-thirds of the respondents were in the engineering, transportation, or planning departments of their government agencies. This is important because the vast majority of bicycling does and will continue to take place on the highway system, which is shared with other vehicles. Locating bicycle program managers in the engineering or transportation department gives them the best access to information and input to the design and implementation of projects directly affecting the quality of the places in which people ride bicycles.

Eight of the top 10 cities for bicycling in 1990 have bicycle program managers; of the two that don't, one has just recently ended a full-time position. Seattle has a bicycle and pedestrian program staffed with six full-time positions, and neighboring King County also has a full-time Roadshare Program manager. The city and county of San Diego both have full-time positions, and the city of Boulder maintains two full-time positions.

The most productive results have come from full-time positions. Some agencies—the majority in the 1990 BFA survey—give to a staff person the title or responsibilities of a bicycle program manager but allow them to spend only 10 percent or less of their time on the job. Such an allocation of time makes it difficult to carry out many of the essential functions of a bicycle coordinator.

A bicycle program manager should review all capital improvement projects, traffic plans, development proposals, and comprehensive plans affecting bicycle access and safety. Most important, the manager should develop policies, regulations, and guidelines that institutionalize the development of designs and plans to include bicyclists as a matter of course. As employees learn to implement the policies, regulations, and guidelines, the manager should need to spend less time on the review process.

In the short term, however, a major function of managers is to ensure that the government agencies in which they work incorporate bicycling into all transportation projects and that projects are not approved if they make bicycling more difficult, or impossible.

The bicycle program manager should also be able to advise on the planning and design of specific bicycle facilities—as a part of larger highway and site designs and as independent bicycle facilities such as bicycle parking and special intersection designs. Often jurisdictions like to have specific bicycle plans, or bicycle elements in their planning documents, for which the bicycle program manager will be responsible.

The BFA survey of bicycle program specialists revealed other key functions. Sixty-five percent of respondents stated that "coordination" was a major emphasis of their work. "Information flow" was mentioned by 52 percent, and 35 percent included "communication." Bicycle program managers perform a coordinating and technical assistance function within their agencies, spreading information and advice on bicycle-related issues, both technical and general, to their colleagues.

The survey asked respondents to check the activities on which they had devoted time in the previous 12 months. The most popular answers were policy development (69 percent), facility design (63 percent), comprehensive planning (62 percent), and facility planning (61 percent). The activity most frequently mentioned by full-time bicycle program managers was dealing with the media and publicity activities. Full-time staff were more likely to be involved in highway project and site and subdivision review. In general, answers to this question were encouraging, because it would appear that bicycle program specialists spend most of their time on tasks for which they are uniquely qualified, trained, and positioned to undertake: planning, policy development, facility design, and highway project review. They do not spend a lot of time teaching bicycle safety or enforcement activities, which, although important, should be the responsibility of other departments or agencies, or even of volunteers.

Supportive Politicians and Professionals in Government Agencies

One bicycle program manager in a large highway department of hundreds or thousands of employees can get lost quickly. One of the greatest challenges of bicycle program staff, therefore, is to generate support for their activities, and to persuade, train, and require their colleagues to work toward the same aim—that of creating more safe places to ride.

In most cases, highway engineers and planners are not opposed to that idea, but they have never been given the encouragement, advice, or technical information on how to accommodate bicyclists in the highway system. A draft survey

of bicycle and pedestrian education courses in U.S. universities in 1990 revealed that only 1 percent of university engineering courses offer a separate course in bicycle and pedestrian transportation (*10*). Forty percent of respondents reported that they offer some bicycle material in their courses, but the average time given was just 1.5 h.

There are many ways in which the bicycle program manager (or other interested individuals and organizations) can start to reverse this process and make engineers and planners more comfortable with the notion of providing for bicycles.

- Circulate interesting magazines, newsletters, articles, and technical papers related to bicycling.
- Write articles for internal agency magazines and newsletters on the work of the bicycle program or on bicycle planning and engineering in general.
- Present different aspects of planning for bicyclists informally at staff meetings or over a bag lunch.
- Organize in-house training through the personnel department.
- Arrange training courses (from ½ day to 3 days in length) to be run by outside organizations.
- Encourage attendance at major bicycle conferences.

Just as important as the lack of formal bicycle-related training for most engineers and planners is that few of the regulations, guidelines, or policies within which they operate require them to consider bicycles. For example, most communities have zoning ordinances requiring a minimum number of automobile parking places in new developments. Very few require a minimum level of bicycle parking, and so no one thinks to include space for bicycle parking.

There are certain key public documents (plans, policies, and standards) that are essential to all levels of government. By changing these basic documents, a bicycle program manager can ensure that bicycling is considered at the earliest stages of all planning and development projects.

Highway Design Guides

Most government agencies involved in highway construction and design have standards, guidelines, or policies to be followed. Agencies may adopt standards used by others, such as another state, or a national professional association, such as ITE. Other agencies will develop their own technical documents, and these will be revised on a regular basis. A bicycle program manager should discover which documents are being used and when they are to be revised. At that time, they can provide comments on and additions to the document to better reflect the needs of bicyclists. AASHTO has a bicycle facilities handbook that many state and local agencies have adopted as their standard (*11*). Florida (*12*), New Jersey (*13*), Minnesota (*14*), and North Carolina (*15*) are among the states with their own design guides for bicycle facilities.

Planning Documents

All units of government engage in long- and short-range planning, and it is essential that these documents incorporate full consideration of bicycling. During the 1970s it was common for states and cities to develop special bicycle master plans, most of which are gathering dust on government office shelves. Although these special bicycle plans can serve a valuable purpose, particularly in providing direction and focus to a bicycle program, it is usually more important to have bicycle programs, policies, and projects integrated into larger community plans. As a stand-alone document a bike plan can be isolated, marginalized, or ignored by the rest of a government agency. Nevertheless, Oregon (*16*), Florida (*17*), Minnesota (*18*), and Dallas (*19*) provide excellent examples of individual bicycle plans and program documents that work.

Other Ordinances and Regulations

Bicycle program managers need to know when state implementation plans, growth management plans, street maintenance schedules, zoning ordinances, and a host of other documents are being developed so that they can add in consideration of bicyclists' needs.

Building Political Support

Ensuring that the bicycle program has frequent, small, visible successes and products—such as parking stands, pothole repairs, signal and sign repair and replacement, lighting improvements, maps, safety brochures and publications—helps maintain a high profile, both within the agency and externally. In turn, this enables politicians to show progress and to feel good about the program.

With these small successes, support can be garnered for more ambitious projects, such as including space for bicyclists in a bridge replacement project or highway improvement and in the ongoing battle for funding.

The success of this second element of an active bicycle program can be most rewarding and effective, as evidenced by many of the top 10 cities for bicycling. The city of Seattle spends up to $5 million each year on improvements for bicyclists, ranging from pothole repairs to major bridge renovations that incorporate bike lanes costing hundreds of thousands of dollars a mile.

In Palo Alto every new development (retail, business, and domestic) incorporates a minimum level of bicycle parking, both lockers and short-term parking stands. Resurfacing, patching, and locating metal plates in the street all take into account the need for a smooth surface for bicyclists. Metal plates, for example, must be surrounded with asphalt to remove the sharp edges and severe bumps.

The integration of bicycles with transit systems in San Diego; Arlington, Va.; and Montreal, Quebec, results from strong institutional and political support for bicycling. Progress in Portland and Eugene has been made possible by the commitment of funds and staff at the state level as well as at the city level. Florida has helped create bicycle programs in every metropolitan area in the state, and millions of dollars a year are spent in making state highways safe and accessible to bicyclists, according their highway design standards.

Active Citizens and a Bicycle Advisory Committee

The third key ingredient necessary to make a city or state bicycle-friendly is an active local bicycle community, including more general neighborhood activism and citizen involvement in government.

The bicycle community has developed a valuable structure for encouraging participation in government through bicycle advisory committees (BACs) or task forces. The 1990 BFA survey of bicycle program specialists revealed that more than half the respondents had some kind of relationship with a BAC, and almost all the best cities for bicycling have such bodies.

BACs are traditionally made up of volunteers, not necessarily all of whom come from bicycle groups. They provide input into the government process, work on bicycle-related issues within the community, activate other volunteers, and provide some vision and direction to the work of the bicycle program. (BACs may be structured so as to include mostly government agency personnel meeting to coordinate the efforts of different government agencies.)

Some common activities of a BAC (which typically comprises 6 to 10 members who meet monthly) include the following:

- Reviewing and commenting on planning documents and policies;
- Developing policies and guidelines on bicycle issues;
- Implementing community-based activities such as education programs, maps, publications, and bicycle events;
- Identifying the needs and concerns of bicyclists and the opportunities for bicycling in the community;
- Recommending and implementing programs involving the private and nonprofit sectors—such as bike-to-work promotions; and
- Reviewing the annual workplan of the bicycle program and developing their own list of priority projects.

The involvement of citizens through a BAC has distinct benefits. First, the decisions and actions of the BAC are more likely to reflect a balance between the enthusiasm and ideals of citizen members and the realism and attention to practical details of government employees. Second, working together educates all involved as to the views and constraints under which each must operate. Citizens, in particular, are better able to understand how government works as a result. Third, the BAC may be able to ask for, and say, things that government employees cannot. The BAC provides an official channel for citizen comment and requests. Fourth, a BAC provides continuity and permanence in the face of personnel changes. For example, in Eugene, Oregon,

> the presence of a regular committee with a body of wisdom shared by the continuing members provides a buffer against these losses [of staff]. The program need not die and have to be restarted, and replacements are more quickly trained. Under the guidance of the committee three bicycle coordinators [in 10 years] gained their stripes and two traffic engineers learned to think bicycles. (*20*)

The value of citizen involvement is certainly not confined to a BAC. Indeed, BACs are often the result of citizen pressure for government action on bicycle issues. The highly successful Florida bicycle program was created after citizens persuaded Governor Graham to form a task force, which in turn recommended the appointment of a full-time bicycle coordinator, back in 1979–1980.

In Seattle the bicycle community helped in securing passage of a $33 million bond issue for open space preservation and trail development that will finance parts of the growing bike network in the city and neighboring King County.

Citizens in San Diego have worked hard to preserve the position of the bicycle coordinator and have generated two excellent technical reports on the location of bicycle parking (*21*) and the installation of bicycle-sensitive traffic signals (*22*).

CONCLUSIONS

1. Three clearly identifiable and common ingredients make up a successful bicycle program:

   - A full-time bicycle program manager,
   - Supportive politicians and professionals in government agencies, and
   - An active and organized citizenry, usually exemplified by the presence of a BAC.

In states and cities with active and successful bicycle programs, real progress is being made toward the creation of bicycle-friendly communities in which large segments of the population will feel comfortable, willing, and able to ride bicycles for both transportation and recreation.

2. The existence of all three elements simultaneously is not necessary for success, and it is not possible to say which is the most important element. Palo Alto, for example, has not had an official bicycle program manager but has done more than most communities to improve conditions for bicyclists. The city does have good citizen involvement and a responsive government. Similarly, Montreal does not have a formal BAC, but it does have an active citizenry and the other two elements. Gainesville has not had a bicycle coordinator for 2 or 3 years, but it is still a good place for bicyclists.

3. Conversely, many communities do have one or more of the three key ingredients, but have not experienced the same degree of success as places such as Madison and Boulder. The three ingredients are not guarantees of success.

4. In all of the places best known for being bicycle-friendly, and in places with one or more of the key ingredients, there remains much to be done to fully integrate bicycling into the transportation system. They may have achieved more than Detroit, Mich., or Hutchinson, Kans., but there is still a long way to go.

5. There are no hard and fast rules about how to implement or create a successful bicycle program containing these key ingredients. Bicycle program manager positions have most often been created by transportation departments without the need for specific legislation or mandate. However, many positions so created are part time and less likely to generate substantial change. Most of the full-time and more successful positions have been created by legislation or executive order of a governor or mayor.

New federal legislation proposed by U.S. Representatives DeFazio and Oberstar would require each state to appoint a bicycle and pedestrian coordinator (*23*)—but no such mandate is possible to make whole government agencies more receptive to bicycling.

6. Highway and transportation agencies are continually having to deal with new issues and new pressures, ranging from fresh environmental mandates to telecommunity, transportation demand management programs, and intelligent vehicle-highway systems. The way in which bicycle programs have been able to develop and become institutionalized within agencies provides useful guidance and experience for upcoming issues.

This is particularly true for pedestrian issues, for which many of the problems faced by bicyclists and pedestrians are the same: institutional neglect, lack of funding, and lack of safe places to walk. The ways to overcome them may also be similar, and in a few short years most transportation agencies may have both a bicycle and pedestrian program manager working with citizen advisory groups to make U.S. communities more bicycle- and pedestrian-friendly.

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Bicycles and Cycle-Rickshaws in Asian Cities: Issues and Strategies

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An overview of the use and impacts of nonmotorized vehicles in Asian cities is provided. Variations in nonmotorized vehicle use, economic aspects of nonmotorized vehicles in Asia, and facilities that serve nonmotorized vehicles are discussed, and a reexamination of street space allocation on the basis of corridor trip length distribution and efficiency of street space use is urged. The relationship between bicycles and public transportation; regulatory, tax, and other policies affecting nonmotorized vehicles; and the influence of land use and transportation investment patterns on nonmotorized vehicle use are discussed. Conditions under which nonmotorized vehicle use should be encouraged for urban transportation, obstacles to nonmotorized vehicle development, actions that could be taken to foster appropriate use of nonmotorized vehicles, and research needs are identified.

Nonmotorized vehicles—bicycles, cycle-rickshaws, and carts—play a vital role in urban transportation in much of Asia. Nonmotorized vehicles account for 25 to 80 percent of vehicle trips in many Asian cities, more than anywhere else in the world. Ownership of all vehicles, including nonmotorized vehicles, is growing rapidly throughout Asia as incomes increase.

However, the future of nonmotorized vehicles in many Asian cities is threatened by growing motorization, loss of street space for safe nonmotorized vehicle use, and changes in urban form prompted by motorization. Transportation planning and investment in most of Asia has focused on the motorized transportation sector and has often ignored nonmotorized transportation. Without changes in policy, nonmotorized vehicle use may decline precipitously in the coming decade, with major negative effects on air pollution, traffic congestion, global warning, energy use, urban sprawl, and the employment and mobility of low-income people.

As cities in Japan, the Netherlands, Germany, and several other European nations demonstrate, modernizing urban transportation requires not total motorization, but the appropriate integration of walking, nonmotorized transportation, and motorized transportation. As in European and Japanese cities, in which a major share of trips are made by walking and cycling, nonmotorized vehicles have an important role to play in urban transportation systems throughout Asia in coming decades.

Transportation investment and policy are the primary factors that influence nonmotorized vehicle use and can have an effect on the pace and level of motorization. Japan, Germany, Denmark, and the Netherlands have witnessed the major growth of bicycle use despite increased motorization, through policies providing extensive bicycle paths, bicycle parking at rail stations, and high fees for motor vehicle use. China has for several decades offered employee commuter subsidies for cyclists, cultivated a domestic bicycle manufacturing industry, and allocated extensive urban street space to nonmotorized vehicle traffic. This strategy reduced the growth of public transportation subsidies while meeting most mobility needs. Today, 50 to 80 percent of urban vehicle trips in China are by bicycle, and average journey times in China's cities appear to be comparable to those of many other more motorized Asian cities, with favorable consequences for the environment, petroleum dependency, transportation system costs, and traffic safety.

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EXTENT OF OWNERSHIP AND USE

Bicycles are the predominant type of private vehicle in many Asian cities. Bicycle ownership in Asia is now more than 400 million and growing rapidly. Bicycle ownership in China increased more than 50-fold between 1952 and 1985, to 170 million, nearly half of which are in cities (*1*). Since then it has risen to 300 million and is anticipated to grow to 500 million by 2000 (*2*). In many Chinese cities, bicycle ownership rates are one bicycle per household or more. In India there are roughly 25 times as many bicycles as motor vehicles, and urban bicycle ownership is growing at a fast pace. Table 1 shows the number of nonmotorized vehicles in a number of Asian countries and cities.

Most of the world's 3.3 million cycle-rickshaws and goods tricycles are found in Asia. Despite recurrent efforts by some local authorities to suppress cycle-rickshaws in favor of motorized transportation, the number and use of these vehicles is growing in many cities in response to otherwise unmet transportation needs. The Indian Planning Commission in 1979 estimated that the number of cycle-rickshaws in India would increase from 1.3 million in 1979 to 2.2 million by 2001. In Bangladesh the cycle-rickshaw fleet is estimated to grow from two-thirds of a million in 1988 to more than a million by 2000 (*3*). More than three-fourths of Bangladesh's cycle-rickshaws are in urban areas. These urban cycle-rickshaws each account for an average of more than 30,000 passenger-mi and nearly 100 ton-mi of goods movements a year. Together, bicycles, rickshaws, bullock carts, and country boats account for about 75 percent of the value added, 80 percent of the employment, and 40 percent of vehicle assets employed in the transportation sector. On secondary roads, nonmotorized transportation vehicles make up about 85 percent of traffic (*4*,p.16).

The substantial variability in nonmotorized vehicle use in Asian cities is due to many factors, including topography,

TABLE 1 Vehicles in Selected Cities and Counties (*2;3*,p.69;*6;7*,p.31;*19–23*)

City	Year	Bicycles (X1000)	Cycle-Rick-shaws (X1000)	Motor Vehicles (X1000)	Popula-tion	Bicycles per 1000 Residents	Motor Vehicles per 1000 Residents
China	1988	300,000	500	1,200	1,104,000	272	1
Beijing	1982	3,773	na	na	9,231	410	na
Tianjin	1982	3,228	na	na	7,764	420	na
Tianjin	1987	4,500	na	na	8,500	530	na
Shanghai	1980	1,700	na	80	na	152	7
Shanghai	1982	2,243	na	na	11,860	200	na
Shanghai	1988	5,600	na	200	12,400	445	12
India	1985	45,000	1,700	1,500	765,000	59	2
Bangalore	1981	322	na	na	2,900	111	38
Bombay	1981	984	na	na	8,200	120	11
Delhi	1981	945	7	na	5,800	163	54
Hyderabad	1979	800	14	na	2,200	360	na
Jaipur	1979	150	9	na	900	180	na
Madras	1979	272	6	na	4,000	68	16
Indonesia	1985	na	200	na	na	100	na
Jakarta	1985	na	65	na	na	35	
Serang	1983	10	na	3	112	89	29*
Tasikmalaya	1983	16	na	17	159	101	106*
Cirebon	1983	10	na	4	275	35	18*
Surabaya	1976	200	42	144	2,300	na	na
Yogyakarta	1975	44	6	34	400	na	na
Bangladesh	1982	1,500	633	250	na	na	na
South Korea	1982	6,000	na	na	39,000	154	na
Thailand	1982	2,500	15	400	49,000	51	53
Thailand	1988	na	na	6,300	na	na	116
Malaysia	1982	2,500	na	900	14,000	179	64
Japan	1988	1,500	na	250	na	na	na
Netherlands	1985	11,000	na	4,900	14,000	786	350
United States	1988	103,000	na	139,000	245,000	420	567

* includes motorcycles and cars only. Otherwise includes all motor vehicles.

TABLE 2 Percentage of Person Trips by Various Travel Modes (*14;24*,p.4;*25*,p.2;*26*,p.2)

City	Year	Walk	Bicycle &NMV	Bus & rail	Motor-cycle	Auto-mobile	Other	Total
Kanpur, India	1977	72	24	0	3	1	0	100
Tianjin, China	1987	50	41	9	0	0	0	100
Shenyang, China	1984	10	65	25	0	0	0	100
Shanghai, China	1986	38	33	26	..	3	..	100
Kathmandu, Nepal	1987	56	8	16	14		6	100
Ahmedabad, India	1981	43	20	29	6	1	1	100
Bangalore, India	1984	44	12	36	6	2	0	100
Bandung, Indonesia	1976	40	16	46				100
Surabaya, Indonesia	1984	20	25	13	26	9	7	100
Delhi, India	1981	29	18	40	13			100
Tokyo, Japan	1988	45		28	**	27	0	100
Okayama, Japan	1982	23	30	7	**	39	1	100
Matsuyama, Japan	1982	27	23	12	**	34	4	100
Jakarta, Indonesia	1984	23	17	25	13	8	14	100
Bombay, India	1981	15	11	58	1	8	7	100
Melbourne, Australia	1979	19	2	13	..	64	2	100

Notes: ** small amount included with bike/NMV category; .. data not available or included in other categories.

income, metropolitan structure, level of motorization, climate, and transportation policies. Table 2 shows the variation in mode shares for selected cities in Asia. In Indian cities bicycles typically account for 10 to 30 percent of all person trips (including walking) and for 30 to 50 percent of the traffic on primary urban roads. Walking and cycling account for 60 percent of total trips and 40 percent of work-related trips in Karachi, Pakistan. Bicycles have largely replaced buses as the principal means of urban vehicular transportation in Tianjin, an experience repeated in other cities.

Cycle-rickshaws account for 10 to 20 percent of urban freight movement in many Asian cities. Of all land transportation in Bangladesh, nonmotorized vehicles produced 60 percent of all passenger miles and 36 percent of freight ton miles in 1985 (*5*,p.46). Annually, each urban cycle-rickshaw accounted for 32,810 passenger-mi and carried 94 ton-mi of goods (*4*).

A large portion of cycle-rickshaw trips are of a nature not readily replaced by overcrowded buses. Surveys on several main roads in Dhaka, Bangladesh, found that 22 percent of cycle-rickshaws were carrying goods and nearly as many were carrying passengers with small children. Nearly one-third of all cycle-rickshaws carried female passengers, and nearly one-fifth carried females alone. Many of the remaining trips were made by males traveling as passengers without goods, often for short-distance trips on irregular routes (*3*).

In many Indonesian cities, becaks (cycle-rickshaws or pedicabs) play an even greater role in urban mobility than the bicycle. In Bandung, cycle-rickshaws accounted for 12 percent of all work trips and an even higher share of nonwork trips in 1985, whereas bicycles accounted for about 6 percent of trips (*6*). In Jakarta, where the government is forcefully suppressing becaks through banning and confiscation, these vehicles accounted for 4.6 percent of all trips in 1985; bicycles held only a 2.4 percent mode share.

RELATIONSHIP OF INCOME TO BICYCLE USE

Income plays a significant role in influencing the choice of transportation that people have. People with low incomes face extremely limited choices. Where there is extensive poverty, it is vital to ensure that the modes used by the poor continue to remain available as travel options. Despite rising incomes in many cities across Asia, the distribution of wealth and income remains skewed in much of the region. Rapid urbanization and economic growth throughout much of Asia has left behind hundreds of millions of people who continue to live in desperate poverty. Indeed, two-thirds of the poorest of the world's poor live in India, Bangladesh, Pakistan, and China.

Many low-income people in Asian cities cannot afford even subsidized public transportation fares and have no choice but to walk or cycle, even for 10 to 20 km. For most poor households, walking accounts for the majority of all trips. When incomes are low, the value of time relative to cost for travelers is low as well. Although walking costs nothing, it takes much time for all but short trips. Cycling can be four or five times faster than public transportation, and it is cheaper once a bicycle is in hand. When a bicycle that will last years costs the equivalent of 6 or 8 months of bus fare, a poor person profits in having and using one. Thus, for the poor in Asia, increases in personal mobility are most commonly expressed in expanded use of bicycles. Increased mobility for goods movement and the transportation of children and families is often expressed in greater use of cycle-rickshaws, where they are available, or public transportation, where it is available.

Low-income households must spend a higher share of their income on transportation than higher-income households. The poor often must live far from their jobs to find cheap housing, they often hold several part-time jobs, and, because their income is so small, a single bus fare represents a larger share of their earnings than it does to others. The poor in general make fewer trips than higher-income people and engage in little discretionary travel. Irrespective of city size, the poor will continue for now to be dependent on nonmotorized transportation modes for mobility in Asian cities.

However, it is not only the poor who use bicycles. The travel time and convenience offered by the bicycle attracts people of all income levels to bicycles in many cities, particularly those in which measures have been taken to facilitate cycling. As traffic congestion in Asian cities increases, the reliability of public transportation schedules and the average travel speeds both decrease, making bicycles competitive at longer trip lengths because of their flexibility, convenience, and greater reliability.

EMPLOYMENT GENERATION BY NONMOTORIZED VEHICLES

The manufacturing, servicing, and repairing of nonmotorized vehicles generates substantial employment in Asia. Nonmotorized vehicles also form the foundation for a large informal sector providing goods or services on the street or transporting people and goods on a for-hire basis. In Dhaka, Bangladesh, for example, about 380,000 people are directly employed as cycle-rickshaw pullers, and another 80,000 are employed in ancillary services related to cycle-rickshaws. In all of Bangladesh, cycle-rickshaws in 1988 were estimated to provide employment for more than 1 million people and ancillary employment to another 250,000, representing about 3.5 percent of the nation's labor force (*7*).

An investment of 100,000 rupees ($8,000 in 1984 U.S. dollars, $5,000 in 1991 U.S. dollars) in a conventional bus system in Patna, India, was estimated to produce two new direct jobs. If that sum was invested in the motorized auto-rickshaw system, it was estimated to create six direct jobs; if invested in cycle-rickshaw transportation, it was estimated to create 75 jobs (*7*).

Promoting the nonmotorized transportation sector can stimulate employment growth and microenterprise development, especially in low-income cities, particularly benefiting the poor. Where cycle-rickshaws are suppressed by regulation, taxes, licensing requirements, bans, and even confiscation, many low-income people lose their livelihoods.

Most developing countries depend heavily on imported oil. More than half of low- and lower-middle-income countries import more than 90 percent of their commercial energy, with most of these imports in the form of petroleum (*8*). Low-income developing countries (excluding China) spent an average of 33 percent of their merchandise export earnings in 1985 on energy imports; many spent more than half (*9,10*).

In non-oil-exporting Asian cities, consumer expenditures on motorized private and public transportation usually require more foreign exchange and less local labor than expenditures for alternative nonmotorized modes. Thus, a shift from nonmotorized to motorized modes may have significant impacts on regional economies and foreign exchange requirements.

NONMOTORIZED VEHICLE FACILITIES

In many low-income Asian cities in which nonmotorized vehicles predominate, there has been little need to create a separate cycle network because large numbers of nonmotorized vehicles define their own legitimacy to right-of-way. However, as motorization increases, or as traffic congestion worsens, it becomes more important to develop modal separation in corridors of high traffic flow. This is particularly vital in mixed-traffic cities in which nonmotorized vehicle use is declining because of competition from growing motorized traffic. Motorized modes are heavier, faster, and often higher in social status than nonmotorized vehicles. When street space is scarce, nonmotorized vehicles are vulnerable to displacement from mixed-traffic streets unless they are present in sufficient numbers to assert an almost continuous claim to their share of road space. A key function of bicycle or nonmotorized vehicle facilities is to protect the legitimacy and safety of nonmotorized vehicles in the transportation system where they would otherwise be threatened by motorized traffic. Isolated bikeways and fragmented segments of bicycle paths cannot be expected to overcome the problems that urban cyclists face. Comprehensive networks of bicycle-safe roads and paths are needed to attract less-skilled cyclists to use the bicycle for a significant share of their short daily trips in motor vehicle–dependent cities and to avoid the diversion of cyclists to motorized modes in mixed-traffic and nonmotorized transportation–dependent cities.

Important factors to be considered in nonmotorized vehicle facility planning include continuity, facility standard and function, degree of separation of modes, anticipated traffic flows by mode, and available rights-of-way. The concept of network functional hierarchy used in classifying highways and evaluating their spacing is equally useful in planning and designing cycle networks. Conditions for cyclists and other slow traffic can be optimized if nonmotorized vehicles have available a fine-grained network of collector facilities (often shared with pedestrians and slow motorized traffic); a coarser network of primarily slow traffic facilities, some shared with pedestrians and slow motorized traffic and many reserved for exclusive nonmotorized vehicle use; and a coarse network of exclusive regional facilities designated for nonmotorized vehicles (*11*).

Although the spacing of networks must be adjusted for city patterns and densities, this network concept has been used successfully in a number of highly motorized cities, mostly in Europe, to arrest and often reverse the decline of nonmotorized vehicle use during times of rapid motorization. Many cities in the Netherlands, Denmark, and Germany have developed effective cycle networks: Delft, the Netherlands; Copenhagen, Denmark; Malmö, Sweden; and Hannover, Germany, clearly stand out as successful examples (*12*). Several cities in developing countries are noteworthy for their cycle networks, including Curitiba, Brazil, and Tianjin, China. Pune, India, has been working to develop an extensive cycle network for a number of years.

In many nonmotorized vehicle–dependent cities, bicycle networks can best be preserved by keeping cars and motorcycles out of many existing streets in neighborhoods. Creation of environmental districts—areas in which motor vehicles are restricted and traffic is calmed—can be a most effective strategy for supporting the use of nonmotorized vehicles, walking, and public transportation. Such districts are increasingly common in many affluent cities in Europe and Japan. In some cities extensive alley systems offer opportunities for creating nonmotorized vehicle networks while improving traffic management, as in a World Bank project in Shanghai, China.

Officially dedicated nonmotorized vehicle facilities are common in Chinese and Japanese cities but not found widely elsewhere in Asia. Instead, where nonmotorized vehicles make up a major portion of traffic flows, they frequently define nonmotorized vehicle "lanes" through their physical presence in large numbers. However, especially where nonmotorized vehicle lanes are not well defined by physical separation, the extensive mixing of nonmotorized and motorized traffic often fosters poor traffic discipline among all modes, which exacerbates traffic congestion and safety problems.

CAPACITY OF NONMOTORIZED VEHICLE FACILITIES

The rapid growth of bicycle traffic in Chinese cities in the 1980s has led to serious traffic congestion problems in many cities. Peak-hour flows at many main intersections in Beijing and Tianjin exceed 15,000, with 29,000 per peak hour observed at one main junction in Beijing. As a result, interest in assessing the capacity of bicycle facilities has been a serious matter for Chinese planners. In China, the practical saturation capacity of separated bike tracks has been estimated at 0.5 bicycle per second per meter width, or 1,800 bicycles per hour per meter width. Cycle-rickshaws typically require 1.5 to 3.0 times the capacity of a single bicycle, depending on size and weight (*13*). Mixed-traffic streets typical of Beijing, China, show a saturation capacity of about 0.37 bicycle per second per meter width, or 1,330 bicycles per hour per meter width (*13*).

ALLOCATION OF ROAD SPACE BETWEEN MOTORIZED AND NONMOTORIZED VEHICLES

The capacity of different types of rights-of-way to move people at different speeds in different modal mixes is an important consideration in analyzing travel management strategies. Proper analysis of transportation modal efficiency must differentiate on the basis of trip length, cost, and function.

For a given amount of road or corridor space, the most efficient modes of transportation are generally rail or bus operating on their own dedicated rights-of-way. The least efficient use of road space is low-occupancy automobiles. Bicycles fall in between this range, with road space use approaching that of buses in mixed traffic (*14*). Motorcycles, scooters, and other two-wheeled motorized vehicles fall between automobiles and bicycles in their road space utilization (*15*). All of these estimates are subject to a great deal of

variation in the real world, depending on vehicle occupancy, level of traffic congestion and traffic mix, topography, frequency of public transportation stops and other details of public transportation operations, quality of track or road surface, and other factors.

The function of modes and distribution of trip lengths that must be accommodated within travel corridors is an important consideration in evaluating the ways in which scarce road space should be most efficiently allocated. If a large share of traffic is of short to moderate trip length, rail modes are not likely to be cost-effective or practical for these trips. If a large share of traffic is of long trip length, bicycles and walking are not likely to be the most efficient or practical modes. If resources are unavailable to provide bus transportation sufficient to meet demand, bicycles may be more efficient than an overburdened public transportation system, even for longer trips. In most travel corridors, demand is in fact composed of a spectrum of trip lengths, meaning that a complementary combination of modes should be accommodated to meet the needs of diverse travel markets, recognizing limitations on road space, affordability of transportation modes in the community, and the required speed and distance of trips made in the corridor. Where road space is most scarce, traffic management should be the first step in dealing with traffic congestion problems. This can include restricting turns at intersections, introducing one-way street systems, improving traffic signalization, and managing encroachments on transportation rights-of-way. These steps can all affect the relative efficiency of different modes in using road space.

The segregation of different modes of transportation can result in far greater system efficiency. If street space is insufficient to accommodate demand even with separation, it is often useful to dedicate different streets to different modes and to impose or expand restrictions or costs for private automobiles, the most inefficient mode. Even in cities in which streets are generally congested, it is often possible to find underused street space, such as the use of alleys in Shanghai to provide right-of-way for a dedicated bicycle network. Similar opportunities exist in other cities, such as Bangkok. If space cannot be found, nonmotorized vehicles and public transportation should be favored in allocating street space.

The design of transportation facilities can greatly affect traffic safety. Segregating slow from fast traffic and designing intersections to maintain good sight distances, to reduce turning conflicts, and to channelize traffic to enhance predictability of flows can all reduce safety problems while improving operational performance. Poorly designed and improperly maintained separate cycle facilities can increase safety problems, particularly if many intersections or driveways cross the cycle paths and sight distances are poor. In some countries, design standards from highly motorized countries have been used with insufficient tailoring to local traffic conditions and economic realities. This has often led to unsafe designs that threaten nonmotorized travel.

INTEGRATION OF BICYCLES WITH PUBLIC TRANSPORTATION

Bicycles used in combination with public transportation offer a strong potential competitor to private motorized transportation for many types of trips. To reduce long-distance bicycle commuting and free congested road space, the Chinese have been establishing bicycle-subway and bicycle-bus exchange hubs in Beijing and other cities. Bicycle access to railways is also important in India, where many hundreds of bicycles can be seen parked at some stations.

Bicycle access expands the market area of high-speed public transportation services at low cost. This is one of the most valuable potential functions of nonmotorized vehicles in megacities, where average trip lengths are long. Integration of bicycles with public transportation is also an important strategy for sustaining nonmotorized and public transportation mode shares in rapidly motorizing cities with mixed-traffic systems, for reintegrating nonmotorized vehicles into motor vehicle–dependent cities, and for dealing with network capacity saturation in nonmotorized vehicle–dependent cities.

In Western Europe and Japan today, the fastest-growing and predominant access mode to suburban railways is the bicycle; it accounts for one-fourth to one-half of access trips to stations (*16*). Between 1975 and 1981 the number of bicycles parked at Japanese rail stations quadrupled to 1.25 million. By the end of the 1980s nearly 3 million bicycles were used daily to access suburban railway stations in Japan. Use is heaviest in the lower-density suburban fringe areas of large cities, in which 15 to 45 percent of rail station access is by bicycle. Japanese and European transportation policy and investment has encouraged bike-and-ride system development with secure parking at station entrances and safe access routes. In Japan more than 2 million bicycle parking spaces have been built at rail stations since the mid-1970s, including automated multistory structures (*17,18*).

Bike-and-ride strategies offer opportunities for increased public transportation system efficiency when factored into public transportation network and operations design. With expanded station catchment areas, interstation spacing can be greater, creating higher line-haul public transportation speeds and efficiency in equipment use, with a level of service comparable to that obtained with denser station spacing relying on pedestrian access. In the long-run, increased interstation and interline spacing may permit public transportation networks to concentrate more frequent service on fewer lines for the same size vehicle fleet, reducing average waiting time for public transportation services and increasing efficiency in use of rights-of-way. This is particularly important in megacities, in which average trip lengths are long and resources for express public transportation service provision are insufficient to meet demand. By reducing average point-to-point travel time throughout metropolitan areas, bike-and-ride systems can improve the competitiveness of public transportation with private motorized transportation. In cities in which public transportation services are inadequate to meet demand, it may be productive to shift some less-efficient short-distance public transportation trips to nonmotorized vehicles, allowing the concentration of public transportation resources on longer trips, with bike-and-ride access systems expanding market catchment areas.

REGULATIONS AND POLICIES INFLUENCING NONMOTORIZED VEHICLE USE

Regulations and policies, including taxes and import duties, fuel taxes, vehicle registration and licensing fees, and credit

financing systems for vehicle purchase, have a major influence on the cost and availability of various transportation modes. Frequently, regulations and policies have been used to discourage or suppress the use of nonmotorized vehicles, especially cycle-rickshaws, while fostering motorization.

Import duties frequently favor motorized transportation. Bangladesh, for example, has discouraged the import of bicycles and their parts to protect local bicycle manufacturers while offering concessions to affluent buyers of private motor vehicles. In 1989 Bangladesh taxed imported bicycles and most bicycle parts at 150 to 170 percent, whereas motor vehicles faced tariffs of only 5 to 50 percent. Although such taxes are intended to protect domestic bicycle producers, two-thirds of the bicycle parts needed in Bangladesh must be imported, which significantly raises the costs of owning and operating bicycles and cycle-rickshaws (*3*). Such stiff protectionist policies aimed at aiding domestic nonmotorized vehicle producers impose a high cost on cyclists and cycle-rickshaw users while often failing to create viable industries. When combined with low taxes on motor vehicle imports, such policies foster economically inefficient choices.

Vehicle licensing is commonly used to raise revenue, ensure vehicle safety, and regulate vehicle use. In many cities, however, it has been used to suppress cycle-rickshaws and other informal sector public transportation services, such as jeepnies, jitneys, motorized auto-rickshaws, and pirate taxis. In Karachi cycle-rickshaws were banned in 1960 and replaced by auto-rickshaws, which in turn were subjected to restrictions on new registrations from 1986 onward. In Manila, Philippines, the motorized tricycles that replaced cycle-rickshaws in the 1950s were later banned from main roads and now operate mostly on smaller roads as feeder services (*3*). Only in Singapore have restrictions been placed on private motor vehicle registrations, beginning in 1990, although such vehicles are the least efficient users of road space in Asian cities. In several cities in India, Indonesia, and Bangladesh, restrictions have been placed on the number of cycle-rickshaw registrations that will be permitted, often freezing registrations at a fixed level for many years. Restricting licenses creates a lucrative black market in duplicate or falsified licenses. It also makes cycle-rickshaw drivers and owners vulnerable to extortion and abuse from local police, who can threaten to seize their vehicles and cause the loss of, at a minimum, a full day's pay or, at worst, their livelihood. Indeed, Jakarta authorities have seized some 100,000 cycle-rickshaws in the past 5 years, dumping at least 35,000 into Jakarta Bay, as they seek to eliminate these vehicles from the city. Thousands more cycle-rickshaws were seized and destroyed in Delhi in the late 1980s.

Many cities have imposed constraints on nonmotorized modes of travel, particularly cycle-rickshaws, claiming that they cause congestion or unfairly exploit human labor, or that they represent backwardness. But these officials overlook far more degraded labor conditions that are hidden behind factory gates and in garbage dumps. The suppression of cycle-rickshaws is comparable to the removal of slums and squatter settlements: just as slum clearances destroy real housing resources for the poor, cycle-rickshaw bans eliminate real transportation resources for the poor, hurting hundreds of thousands of people who frequently lack the political power to defend their mobility systems and jobs.

CONDITIONS UNDER WHICH NONMOTORIZED VEHICLES SHOULD BE ENCOURAGED

Nonmotorized modes are the most efficient means of mobility over short distances in cities, and motorized modes offer greater efficiency for longer trips. The distance at which motorized modes become more efficient than nonmotorized modes for consumers depends on income levels, the value of time, and the price and speed of various transportation modes. For societies as a whole, it depends as well on how environmental costs, social costs, and other externalities related to transportation are assessed. Determining the most efficient modal mix for a city also requires consideration of constraints on street space, patterns of land use, existing investments in transportation vehicles and infrastructure, and funds available for new investment and transportation operations. It should also take into account current and anticipated problems in the overall transportation and land use system, such as traffic congestion, air pollution, economic impacts of growing petroleum use, access of housing to employment, motorization trends, and goals for poverty alleviation. Given the wide variation in these factors, urban nonmotorized transportation strategies must be tailored for different types of cities. The integration of urban development and transportation planning and policy is vital to expanding opportunities for nonmotorized transportation.

Bicycles should be encouraged as the most efficient transportation mode for short trips in cities of all types and income levels, particularly for trips too long for walking and too short for express public transportation services, particularly where travel demand density or economics do not permit high-frequency public transportation services. Bicycles are most important for personal transportation, but they also accommodate light goods hauling, being capable of carrying loads of 100 to 180 kg. Bicycles should be considered an integral part of urban transportation planning and management for cities across the world, just like public transportation, private motorized transportation, and walking. In smaller cities, bicycles should have a primary role on their own for work, shopping, and other travel. In larger cities, where trips are longer, bicycles should be seen as most important in providing access to efficient public transportation services for work trips and in serving some short-distance shopping and other trips. The integration of bicycles with public transportation can facilitate efficient polycentric metropolitan development patterns. By linking multiple urban centers by public transportation on its own right-of-way and expanding the service areas of public transportation stations with bicycle access, such strategies can favor the evolution of megacities into more manageable constellations of small cities.

The primary market for efficient bicycle use is generally from 600 to 800 m to distances of 5 to 7 km. The utility of bicycles is reduced, but not entirely eliminated, in cities with many hills or steep topography, where they may still serve a role, especially following waterways. Bicycles should be encouraged as a key element in access and egress to and from public transportation, particularly for intrametropolitan express services in large cities of all types. The catchment area for convenient and efficient access to rail or bus stops and stations can be enlarged by a factor of 20 to 40 by encouraging bicycle-based access systems. Bike-and-ride strategies offer an

important means for improving public transportation system efficiency, performance, and use. In large, low-income cities in which public transportation services are insufficient to meet demand, and in low-income areas of more affluent cities, bicycle use should be encouraged as the most efficient mode for trips of up to 10 km, at least until public transportation service provision can catch up with demand. The diversion of some public transportation travelers making trips shorter than several kilometers from buses to bicycles can permit a larger portion of public transportation vehicles to be concentrated on longer distance, limited stop, express services, where they can operate at higher efficiency. In nonmotorized vehicle–dependent cities in which public transportation is insufficient to meet demand, street space is saturated, and a large number of cyclists ride distances of more than 10 or 15 km, such as in some Chinese cities, express limited-stop public transportation services should be upgraded and long-distance cyclists should be encouraged to use bike-and-ride. The diversion of such cyclists to public transportation should be achieved not by suppressing bicycle use or constricting street space for nonmotorized vehicles, but by improving public transportation to provide more competitive travel time. When scarce street space in cities is allocated to different modes, less-efficient private automobiles should be restricted rather than bicycle traffic in setting aside added space for high-efficiency public transportation and pedestrians.

In cities of all types, sizes, and income levels, bicycles should be encouraged as a means of reducing air and noise pollution, petroleum use, global warming, and traffic congestion, and as an important means of increasing the mobility of low-income people. By meeting a larger share of urban mobility needs using low-cost bicycle transportation, cities can reduce total transportation system costs or free resources for other unmet needs.

Cycle-rickshaws are not as efficient as bicycles for personal transportation, but they should be encouraged to complement motorized goods transportation and to serve as a passenger paratransit mode, particularly in countries in which wages are low and there is substantial surplus labor. These vehicles are a major source of jobs; in some Asian cities they account for more than 10 percent of total employment. They provide many useful services to urban residents that cannot always be readily replaced by motorized modes, acting as a nonmotorized taxi, school bus, ambulance, delivery service, and small freight hauler in some cities. Cycle-rickshaws are quiet, do not pollute, use no petroleum, and can traverse very narrow streets. Improvements should be encouraged in vehicle design and patterns of vehicle ownership and operation, however, to improve safety, vehicle performance, the quality of working conditions for cycle-rickshaw drivers. Where they are in use, they should be accepted as a useful part of the transportation system that fills market-expressed needs, not as a nuisance or a barrier to modernization. They are a thoroughly 20th century, efficient, and sustainable mode of transportation, used even today in aerospace factories in North America. Even in high-income, motor vehicle–dependent cities, there are opportunities to use cycle-rickshaws for moving people and goods for short distances and as the basis for microenterprises providing goods and services at dispersed locations. There, they will find greatest utility where slow modes are allocated right-of-way separate from motorized traffic, in dense pedestrian-oriented neighborhoods or central areas with slow traffic speeds, in large factories and shopping districts, and in areas where private motor vehicles are restricted.

Cycle-rickshaws should be separated from motorized traffic when possible, except in areas in which traffic speeds or motor vehicle volumes will remain low. On higher-speed roads, the speed differential and combined vehicle width of motor vehicles and cycle-rickshaws can produce unsafe conditions. Where traffic congestion is most serious in cities and there are large volumes of cycle-rickshaws, it may make sense to enhance bicycle or bus modes to gain greater efficiency in the use of street space. However, the wholesale banning of cycle-rickshaws from large areas of cities where they fill market needs is inadvisable on economic, environmental, and social grounds.

KEY BARRIERS TO NONMOTORIZED VEHICLES

The key barriers to nonmotorized vehicle use include the affordability of vehicles, street environments hostile to nonmotorized vehicles, vehicle theft, negative social and government attitudes toward nonmotorized vehicles, and excessive and inappropriate regulation of nonmotorized vehicles. Overcoming these barriers may require changes in transportation investment patterns, infrastructure design standards, street space allocation, credit and financing systems, regulatory policy, public education, and marketing, depending on local circumstances. Such changes should be part of much larger efforts to manage the modal mix of cities to favor greater efficiency of resource utilization in the transportation sector while enhancing accessibility. However, few institutional structures focus on nonmotorized transportation and few data are collected on its attributes or problems. Many national and local transportation planning organizations are indifferent or hostile to nonmotorized transportation and focus solely on motorized transportation issues. Training and institutional reform is needed to address these problems. Many of these factors can be changed only over several years, and some are difficult to control. However, actions by multi- and bilateral development finance organizations, governments at various levels, and nongovernmental organizations can influence the direction and nature of change in many of these factors. Such actions should be accomplished through development and implementation of a nonmotorized transportation strategy by such organizations and by individual countries and cities in Asia and elsewhere.

FORMULATION OF NONMOTORIZED TRANSPORTATION STRATEGY

A nonmotorized transportation strategy, whether for a city, county, a region, or an international development agency working in various contexts, should be developed to establish and support the appropriate use of nonmotorized vehicles to maximize transportation system efficiency, equity, and environmental quality. Some elements described in the following are undertaken in transportation sector and project ap-

praisal studies today, but many aspects related to nonmotorized vehicles are often neglected.

Such a strategy should identify the extent, pattern, and current trends related to nonmotorized transportation availability and use, including variations based on income, cost, trip length, and other factors. It should assess the overall pattern of travel demand for different modes of transportation for low-, moderate-, and high-income groups to identify particular trip lengths where modal options are limited to inefficient transportation choices. A key focus should be on road safety problems, particularly those facing pedestrians and bicyclists. Road safety improvements offer the potential for widespread social and economic benefits in terms popular with all classes of society.

An urban nonmotorized transportation strategy should identify key traffic congestion locations and gather data on the composition and attributes of traffic flows, their trip length distributions and patterns, and the extent of encroachment on the transportation rights-of-way by nontransportation activities and uses. This information should be used to identify opportunities for improved traffic management in congested locations, including separating or channelizing different modes within the right-of-way or on parallel routes to separate slow and fast traffic; improving intersection design and operation to reduce turning movement conflicts and delays; and using turn prohibitions, one-way systems, grade separations, traffic signalization, and grade-separated under- and overpasses where appropriate. It should consider restricting private motor vehicle traffic in congested areas by limiting peak-hour entry or by creating automobile-restricted areas, streets, or traffic cells that discourage short trips by private motor vehicles. It should consider pricing changes for public and private transportation to influence travel demand. Where poor traffic discipline or encroachments are problems, stepping up enforcement, public education, and advertising campaigns and providing low-cost off-street market areas should be considered.

An urban nonmotorized transportation strategy should also identify and evaluate opportunities for shifting longer-distance trips made by private motorized and nonmotorized vehicles to bike-and-ride systems, with express public transportation operating on reserved rights-of-way. It should identify strategies for reducing average trip length in the long run through changes in land use patterns and the distribution of housing, markets and shops, and employment both in relationship to each other and to the public transportation system. It should identify appropriate networks for nonmotorized vehicle use to strengthen their utility for short to moderate-length trips within cities and evaluate the appropriateness of shifting long walking trips and short public transportation trips to nonmotorized vehicles.

Barriers to the nonmotorized vehicle manufacture and ownership and strategies for overcoming these should be identified as part of strategy work. These may include nonmotorized vehicle–related trade barriers, local nonmotorized vehicle industry structure and performance, affordability of nonmotorized vehicles to the population, credit systems for nonmotorized vehicle purchase, and licensing and registration requirements. Regulatory policies inhibiting nonmotorized vehicle use should be identified along with strategies for influencing them, including changes in traffic regulations, parking policies, and licensing requirements.

CONCLUSIONS

The transportation systems of many Asian cities are at a crossroads. If they continue on their current path of rapid and uncontrolled motorization, they may face very high long-term economic and environmental costs with diminishing benefits. If they instead follow the models of China, Japan, and the Netherlands, they may be able to stabilize or increase the appropriate use of nonmotorized vehicles with large positive long-term economic and environmental consequences.

Nonmotorized vehicles offer no panacea to growing problems of traffic congestion, air pollution, energy use, global warming, and regional economic development, but they should be seen as a potentially important element in addressing these problems. As we enter the 21st century, nonmotorized vehicles, instead of decline, may play a growing role in urban transportation systems worldwide.

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Nonmotorized Urban Transportation for Emerging Cities in India

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Urban transportation is a serious problem faced by the cities of developing countries such as India. Large metropolitan cities with more than 1 million in population are recording a rapid increase in population, urban area, and automobile ownership. The phenomenal growth has created intense congestion, because costs prohibit the provision of adequate transportation facilities. The costs of providing roads and other transportation infrastructure increase greatly with the increase in city size. In a recent census, the rate of rural urban migration to cities with populations between 300,000 and 1 million and emerging cities with populations between 100,000 and 300,000 has been observed to be higher than the rate of rural urban migration to major metropolitan cities. At present, these emerging cities have few transportation problems, and with proper land use transportation planning, a sustainable urban form can be provided. A nonmotorized transportation system for the sustainable urban form for emerging cities is described. It compares the savings in fuel, air pollution, and modal splits for different city sizes in India with cities in the United States. Specific infrastructure improvements are suggested to support nonmotorized transportation. Finally, a framework for sustainable urban form is introduced, and the planning requirements are described.

Urban transportation is one of the biggest problems faced by the cities of developing countries such as India. Large cities in developing countries with more than 1 million in population are recording a rapid increase in population, urban area, and automobile ownership. This phenomenal growth has created intense congestion, because costs prohibit the provision of adequate transportation facilities. Gupta showed that the costs of providing roads and other transportation infrastructure increase greatly with the increase in city size (*1*).

India has an inadequate internal energy supply and depends on imported oil for its mobility. But India has few resources available to pay the bill for the oil. Environmental control regulations are practically nonexistent, so large cities face more environmental problems than cities of the developed world. Hanson found that for developing countries, the motor vehicle–dominated city is a nonsustainable urban form (*2*). He clearly demonstrated that emerging land use patterns in large cities of the developing countries have locked these cities into nonsustainable urban forms.

URBANIZATION IN INDIA

Before the 1961 census, there was no accepted definition for urban area. The 1961 census for the first time standardized the definition of an urban area (*3*). According to this definition, any urban area is a municipal corporation, a municipal area, a town/notified Area Committee, or a cantonment board. As per the definition, cities have been categorized in six groups on the basis of population, as shown in the following table:

Class	*Population*
1	More than 100,000
2	50,000 to 100,000
3	20,000 to 50,000
4	10,000 to 20,000
5	5,000 to 10,000
6	Less than 5,000

TABLE 1 Number of Class 1 Cities by Population (*4*)

City Class	City Size	Number 1971	Number 1981	Percent Increase over 1971
Emerging Cities	100,000 - 300,000	104	147	40
Medium Cities	300,000 - 1,000,000	35	57	63
Major Metropolitan Cities	> 1,000,000	9	12	33
TOTAL		148	216	46

The number of Class 1 cities in various population ranges as reported in the 1971 and 1981 censuses are given in Table 1 (*4*). Table 1 also shows the classification of Class 1 cities into three categories. Cities with populations between 100,000 and 300,000 are classified as emerging cities; cities with population between 300,000 and 1,000,000 are classified as medium cities; and cities with more than 1 million population are classified as major metropolitan cities. The percentage of increase in the number of cities from 1971 to 1981 indicates that medium and emerging cities registered a greater percentage increase than the major metropolitan cities with more than 1 million population. This indicates an accentuated shift in the rural-urban migration trend.

PLANNING EFFORTS

Over the past decades major efforts of planners for planning transportation activities in India were for such large metropolitan cities as Bombay, Calcutta, Delhi, Madras, and Bangalore. The other medium-sized and emerging cities have not received any input in terms of a systematic effort for planning the land use transportation system. During recent years, because of the serious problems in large cities, importance has been attached to these smaller urban areas to save them from chaos and environmental degradation. These cities are ideal

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for planning nonmotorized transportation, because a very high percentage of person trips and goods trips are performed through nonmotorized transportation.

Currently, the land use patterns and street configurations of the emerging cities are suitable for nonmotorized transportation. To promote nonmotorized transportation and to preserve the environment, these cities need strong transportation policies from the federal and state governments. Proper land use planning and land banking efforts may achieve nonmotorized transportation in these emerging cities. The term "land use planning" is used to focus on achieving the built environment in keeping with the nonmotorized transportation policies. To control the unplanned urban form, the planning agencies should create land banking and allow urban development only according to the land use plan. A good example of land banking was developed by the Delhi administration in formulating its land use policies for the greater metropolitan city of Delhi (*5*).

EMERGING CITIES

Chapin and Kaiser showed the area required in the United States per 100,000 people is as follows: inside city limits, approximately 6,107 acres (24.71 km^2); the total planning area is 45,171.31 acres (182.80 km^2) (*6*). Much less land area is required to support 100,000 people in India. Table 2 shows the land area requirement for various city sizes in India. Comparing the developing land area inside city limits for U.S. cities with the developed land area inside cities of India shows that approximately 60 percent less land area is needed to support 100,000 people in the emerging cities in India. It is obvious that cities in India have a large number of dwelling units per acre. Also, land devoted to streets and highways is only 12 percent as compared to 24.2 percent of developed areas for U.S. cities.

TIME AND DISTANCE

Mode of travel depends on many variables: cost and comfort, which are usually based on socioeconomic and life-cycle factors; the value that a worker places on time; and the degree to which a worker is willing to make a specified journey to work by a particular mode. Khisty showed a general transportation concept in terms of time, distance, and speed (*7*). He indicated that when the time of travel is doubled, distance covered increases tenfold as mode of travel changes, and speed of travel increases fivefold. This is because every mode is competent and efficient over a certain distance. In developing countries, affordability is a key factor in selecting a mode of travel. Thus city size, urban land area, and affordability dictate the predominant mode of travel.

Critical review of Table 2 suggests that the major percentage of trips can be performed through nonmotorized transportation up to 2.5 km. Bouladon has demonstrated that the spectrum of transportation modes can be divided into roughly five areas (*8*). When demand for transportation (vertical axis) is plotted against the speed, time, or distance measure (horizontal axis), the transportation range is well covered by the modes: walk, bike, bus, car, and aircraft.

Table 3 shows the application of the Bouladon concept to five city sizes in India. Trip length and trip time dictate the

TABLE 2 Developed Land Area and Transportation Elements for Various City Sizes in India (*9,10*)

City Size (population)	Developed Land Area (sq. kms.)	Area Under Street (sq. kms.)	Area Under Main Road (sq. kms.)	Main Road Length (kms.)	Mean trip Length (kms.)
48,000	3.84	0.46	0.23	1.15	1.0
132,000	10.56	1.27	0.63	3.15	1.5
212,000	16.96	2.04	1.02	5.10	2.5
323,000	25.84	3.10	1.55	7.15	3.5
1,070,000	85.60	10.27	5.13	20.52	5.0

TABLE 3 Theoretical Travel Mode, Speed, and Travel Time by City Size (*8*)

City Size	Mean Trip Length (kms)	Mode of Travel	Speed (km/h)	Time (min)
48,000	1.0	walk/bike	5/11.0	12/5.5
132,000	1.5	walk/bike	5/11.0	18/8.2
212,000	2.5	walk/bike	5/11.0	30/13.8
323,000	3.5	bike/bus	11.0/17.5	19/12
1,070,000	5.0	bike/bus	11.0/17.5	29.3/17.2

TABLE 4 Nonmotorized and Motorized Modal Split by City Size in India (*12*)

City-Size	NON-MOTORIZED		MOTORIZED		
	Walk	Bike	Public	Private	Hired
48,000	75	25	-	negligible	-
132,000	59	40	-	1	-
212,000	45	50	3	2	-
323,000	40	45	8	4	3
1,070,000	20	36	20	14	10

mode of travel. One can draw a line between the nonmotorized and motorized travel to a trip length of 2.5 km and travel time of 30 min walking or 13.8 min biking. Any trip in excess of 2.5 km will require some sort of motorized transportation. Thus, a suitable urban form for emerging cities around a nonmotorized transportation system for a mean trip length of 2.5 km can easily be developed.

Table 4 shows that the best estimates of a work trip modal splits in terms of nonmotorized and motorized percentage of trips for the five city sizes in India. It shows that the percentage of nonmotorized transportation trips decreases with the increased city size. In a city with a population of 48,000 or less, almost all intracity work trips are accomplished by walking or bicycling; an insignificant percentage of trips are taken by motorized transportation. For emerging cities, 85 percent of intracity trips are made by walking or bicycling, and only 15 percent are made by motorized transportation.

ENERGY AND ENVIRONMENT

Energy and the environment are critical issues in urban centers of developing countries. A series of models is developed to calculate the fuel consumption and air pollutants. FHWA provides a procedure to estimate fuel consumption and air pollution (*11*). The rates of air pollution given in the procedures are for the prevailing transportation system in the United States. In the absence of the rates for Indian conditions, these rates have been used in this study to show the amount of pollutants by city size. The models developed are

$$MWT = MTPL * LF \quad (1)$$

$$(MPT)_i = MWT * P_i * OC_i \quad (2)$$

$$G_{Ly} = 250 \sum_i (MPT)_i * (PK_L)_i \quad (3)$$

$$CO = 250 \sum_i (MPT)_i * (R_{CO})_i \quad (4)$$

$$HC = 250 \sum_i (MPT)_i * (R_{HC})_i \quad (5)$$

$$NO_x = 250 \sum (MPT)_i * (R_{NO_x})_i \quad (6)$$

where

MWT = length of motorized work trips,
MTPL = mean trip length,
LF = labor force,
$(MPT)_i$ = motorized trips by mode i (km),
P_i = percentage of trips by mode i,
OC_i = vehicle occupancy for mode i,
G_{Ly} = gasoline consumption (L/year),
$(PK_L)_i$ = kilometers per liter for mode i,
CO = carbon monoxide emission (kg/year),
HC = hydrocarbon emission (kg/year),
NO_x = nitrogen oxide emission (kg/year),
$(R_{CO})_i$ = rate of CO emission for mode i (kg/1,000 veh-km),
$(R_{HC})_i$ = rate of HC emission for mode i (kg/1,000 veh-km), and
$(R_{NOx})_i$ = rate of NO_x emission for mode i (kg/1,000 veh-km).

Because of the paucity of data, many assumptions were made for automobile occupancy and fuel consumption rates for various modes as shown in Table 5. Table 6 provides an estimation of fuel consumption, and emissions of carbon monoxide, hydrocarbons, and nitrogen oxides by city size. Thus, the figures shown in Table 6 are only for comparison among city sizes. It shows that the rate of fuel consumption and air pollutants per 1,000 population increases exponentially with city size. In an emerging city with a population of 212,000,

TABLE 5 Assumed Automobile Occupancy and Fuel Consumption Rates for Various Modes in India

MODE	AUTO OCCUPANCY (person/vehicle)	FUEL CONSUMPTION RATE (km/liter)
Passenger Car	2	10
Scooter	1.4	40
Auto Rickshaw (scooter base)	2	25
Tempo (motorcycle base)	8	10
Bus	45	4

TABLE 6 Yearly Fuel Consumption and Emissions of Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides by City Size in India

CITY SIZE	FUEL CONSUMPTION		CARBON MONOXIDE		HYDROCARBONS		NITROGEN OXIDES	
	Liters	L/1,000 population	k g	kg/1,000 population	k g	kg/1,000 population	k g	kg/1,000 population
48,000	negligible		-		-	-		
132,000	6,000	45.5	780	5.9	80	0.61	65	0.49
212,000	76,500	360.9	15,900	75.0	1,350	6.37	700	3.30
323,000	359,000	1111.5	87,660	271.4	7,550	23.37	3,410	10.56
1,070,000	5,485,000	5,126.2	1,722,447	1609.8	149,685	139.89	43,985	41.11

TABLE 7 Daily and Yearly Fuel Consumption Rates for Work Trips in Comparable Sizes of City in United States

City Size	Fuel Consumption (liters)	
	L/1,000 Population	L/1,000 Population
48,000	31,267	162,857
132,000	139,840	264,848
212,000	263,394	310,608
323,000	467,772	362,055
1,070,000	2,255,274	526,933

the yearly fuel consumption rate for work trips is 361 L/1,000 population. This rate is increased by three times, to 1,112 L/1,000 population, when the city size increased to 323,000 and by 14 times when the population increased to more than 1 million. The same is true for the various air pollutants. The data clearly demonstrate that the developing countries should develop a policy to control the city size to 300,000 population in order to limit the rate of fuel consumption and pollutant emissions.

The daily fuel consumption and yearly fuel consumption rates for work trips in a city of comparable size in the United States are shown in Table 7. This table is developed by considering mean trip length of work trips for various city size and the combined average fuel efficiency rates for automobiles of 6.5 km/L. A comparison between Tables 6 and 7 shows that in the United States the fuel consumption for work trips is 100 to 4,000 times higher than in cities in India. This clearly demonstrates that developing countries such as India cannot economically sustain large fuel consumption.

NONMOTORIZED TRANSPORTATION FACILITIES

Pedestrian Facilities

Even in cities with populations over 1 million, walking or walking-bicycling trips may constitute as much as 40 percent of daily work trips and 60 to 70 percent of all daily person trips (*11,13*). Improvements in pedestrian movement conserve fuel and reduce pollutants in the environment. Facilities for pedestrian movement can be achieved at a minimal capital cost as compared to facilities for vehicular traffic.

Emerging cities are ideal for the development of pedestrian facilities. These cities are growing from rural to urban form, and with the institution of comprehensive land use planning it is possible to arrange land use to keep many trip lengths short enough for walking and safe pedestrian movement. However, legal and institutional changes are needed in India to keep these facilities free from encroachments, construction debris, animals, and such.

The benefits of walking relative to other modes are numerous:

- The capital cost of vehicles is zero.
- No foreign exchange requirements are necessary.
- Infrastructure facilities requirement is minimal—only lightly surfaced paths.
- Air pollution is eliminated.

Bicycle Facilities

The bicycle is one of the most convenient and energy-efficient forms of individual transportation. Like walking, bicycling is an ideal mode of transportation in emerging cities. It helps conserve energy and preserve the environment. It provides excellent individual transportation at capital costs that are low for the user and for the government. Operating costs are also lower than they are for other modes.

A lightly surfaced path can be used as a bicycle facility and can be built at a low cost. The facility can be built exclusively for bicycles or it can include pedestrian use. In India private and government agencies provide low-interest loans to their employees for the purchase of bicycles. Governmental efforts should be expanded to enable the rest of the population to use such loans for buying bicycles.

TRANSPORTATION PLANNING IN EMERGING CITIES

Transportation planning projects undertaken in emerging cities should achieve the majority of trips by walking or walking

and bicycling. This can be done in cities that are developing. By keeping the human scale in planning, a low-cost, pollution-free transportation system is achievable. Only this form of urban development is sustainable in the developing countries where most energy for mobility is imported, the foreign exchange is meager, and the balance of payment is outstanding.

A detailed study of a land use transportation system for emerging cities needs to be undertaken to demonstrate the socioeconomic development of these cities. It is also important not to overlook the necessary infrastructure requirement for the industrial development for these cities because an efficient motorized transportation system is essential for viable industrial development.

Land use transportation planning for the city of Chandigarh provides a good example for nonmotorized transportation facilities. In Chandigarh separate dedicated bike paths were planned and provided throughout the city. The intracity bike paths have minimum conflicts with automobile traffic. Conflicts are avoided or reduced through a traffic signal. The usual problems of encroachment, debris, and animals are avoided because the bike paths are designed to pass through the center of the sector in the greenbelt. The nonmotorized transportation planning efforts were possible in the very early stage of development of the capital city of Chandigarh. The emerging cities in India currently have an urban form that lends itself to conflict-free nonmotorized transportation facilities.

The federal, state, and local governments need to develop strong land use transportation policies. Land banking and zoning regulations along with strong orderly land development policies will create nonmotorized transportation in emerging cities. With the present legal and institutional constituents in India, land use planning becomes the key tool in pursuing government policies.

CONCLUSIONS AND RECOMMENDATIONS

A nonmotorized urban transportation system for emerging cities appears to be an achievable solution to many transportation problems faced by India. It has been demonstrated that as the city size increases, the rate of consumption of gasoline fuel for work trips increased exponentially. The same is true for various air pollutants. This paper clearly demonstrates that India should develop a policy to control city size to 300,000 population and develop an urban form based on human scale as the most sustainable form. The cost of providing nonmotorized transportation facilities is minimal when compared with large savings in fuel consumption and pollutants reduction.

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Low-Cost Opportunities for Making Cities Bicycle-Friendly Based on a Case Study Analysis of Cyclist Behavior and Accidents

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Cycling as a means of transportation has increased substantially in cities throughout the developed world. This increase in bicycle use has taken place largely on urban transportation systems that were not specifically planned or designed to accommodate cyclists, particularly in North America. As a result, these cities are witnessing increases in bicycle accidents and growing problems in coping with bicycle traffic. Furthermore, the proportion of adult cyclists involved in accidents has increased, reflecting the bicycle's increased role in urban transportation. Field observations of cyclist behavior were carried out at key sites in the cities of Winnipeg and Vancouver, Canada, whose road networks were not specifically planned with the bicycle in mind. These observations reveal that only half of cyclists ride correctly. Practices such as riding on the sidewalk, going straight from right-turn-only lanes and bus bays, and overtaking between traffic and the curb were common. In addition, two-thirds of left turns were done incorrectly and cyclists tended to "switch roles" between pedestrian and vehicle operator. These behavior patterns are compared with Winnipeg's bicycle accident experience, on the basis of detailed consideration of some 2,300 police-reported, bicycle–motor vehicle collisions over 13 years. The comparison indicates that many of the observed patterns contribute to accidents. To counter the increase in bicycle accidents and to make current transportation systems bicycle-friendly, low-cost opportunities in the areas of roadway modifications, cyclist training, and public awareness are proposed.

The bicycle is increasingly used as a means of transportation in cities throughout the developed world. This increase in bicycle use has taken place on urban transportation systems that typically were not planned or designed to accommodate cyclists, particularly in North America. As a consequence, these cities are experiencing growing problems with bicycle accidents and coping with bicycle traffic. Furthermore, the proportion of adult cyclists involved in accidents has increased, reflecting the bicycle's growing role in servicing short-distance urban trips. Given the increased concern for the environment, cycling as a means of transportation is likely to continue to increase.

If bicycles are to play a greater role in urban transportation, it would be helpful to identify and implement low-cost methods to retrofit transportation systems in order to increase cyclist safety and to make urban areas more bicycle-friendly. To assist in this effort, it is useful to examine cyclist behavior in the current transportation setting and to identify cyclist actions that contribute to accidents. Currently, little research has been done to examine the influence of roadway and traffic characteristics on cyclist behavior and to link cyclist behavior to accidents.

The cities of Winnipeg and Vancouver, Canada, are used as case study situations. These are good examples of medium-sized North American cities (populations of 600,000 and 1,500,000, respectively) whose road networks were not planned or designed with the bicycle in mind.

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PURPOSE AND SCOPE

The purpose of this research is to explore possible links between cyclist behavior and accidents with a view to developing countermeasures. Specifically, this paper

1. Examines the influence of urban roadway traffic characteristics on cyclist behavior through field observation at seven key locations in the cities of Winnipeg and Vancouver;
2. Correlates the behavioral characteristics observed in item 1 to the bicycle accident experience in Winnipeg, on the basis of some 2,300 police-reported bicycle–motor vehicle collisions over a 13-year period;
3. Suggests low-cost methods and countermeasures to make the transportation system more accommodating to cyclists and to improve overall safety, specifically in the areas of roadway modifications, cyclist training, and public awareness.

OBSERVATIONS OF CYCLIST BEHAVIOR

Why Observe Behavior?

It is hypothesized that cyclist behavior patterns are influenced by different roadway and traffic characteristics. It is also hypothesized that certain cyclist behavior patterns influence accidents. In order to link cyclist behavior to accidents, it is necessary to observe how cyclists ride under varying roadway and traffic characteristics in different urban settings.

Summer 1991 Field Study

Field observations were carried out at seven key locations to examine cyclist behavior under varying roadway and traffic characteristics in Winnipeg and Vancouver. Observations were done on 900 cyclists in June and July 1991. A total of 14 hr of data were collected, or 2 hr of data for each site. All observations were conducted on weekdays between 9:00 a.m. and 9:00 p.m. to include a variety of traffic and cyclist characteristics.

Observation Methodology

Data for individual sites were collected by a single observer. The observer was to select a vantage point with a clear view of the site while being as inconspicuous as possible to motorists and cyclists. Observations were made on all cyclists passing through the site during the 2 hr. Information was collected on the following parameters for each cyclist.

Cyclist Maneuver

One of three possible cyclist maneuvers was indicated: going straight, turning left, and turning right.

Correct Riding Style

A cyclist was considered to be riding correctly if the cyclist obeyed stop signs and red lights, yielded the necessary right-of-way to traffic and pedestrians, rode with traffic, positioned self correctly in the intersection for the maneuver, shoulder checked and signaled before changing lanes, and did not weave or overtake traffic on the right. If a cyclist maneuver was considered to be incorrect, the reason was indicated according to the parameters that follow (with the exception of "riding on shoulder" and "in bus bay," the parameters were considered to be actions that contributed to accidents, on the basis of the Winnipeg study):

- *Disobeyed stop sign or red light.* The cyclist failed to stop at a stop sign or red light or proceeded into an intersection on a red light.
- *Fail to yield right-of-way.* The cyclist failed to yield the necessary right of way to pedestrians or traffic during a maneuver.
- *On sidewalk or in crosswalk.* The cyclist was riding on a sidewalk or in a crosswalk for all or part of a maneuver.
- *Improper position for left turn.* The cyclist was in the incorrect position at an intersection when making a left turn. Examples of incorrect positions include turning left from the right curb, turning left from a sidewalk or crosswalk, turning left from the wrong side of the roadway, or turning left from the right side of a dual left/through lane.
- *Proceeding from exclusive right-turn lane.* A straight-through cyclist was proceeding from a right-turn-only lane.
- *Too close to parked cars.* The cyclist was riding less than a car door's width to the left of parked cars.
- *Overtaking between traffic and curb.* A cyclist was overtaking slower-moving or stopped traffic between the traffic and the curb.
- *Weaving.* The cyclist was weaving in traffic or in gaps between parked cars.
- *In bus bay.* The cyclist proceeded from a bus bay.
- *Wrong way.* The cyclist was riding on the roadway or road shoulder against traffic. This parameter did not include cyclists who were riding against traffic on the sidewalk or in a crosswalk.
- *Riding on shoulder.* The cyclist was riding on a shoulder.

In the event that the observer was unable to collect the required information for a particular cyclist (for example, if his or her view was blocked by a passing transit vehicle), all information on the cyclist was discarded.

Description of Observation Sites

The intent of the observations was to examine cyclist behavior on arterial roads in the vicinity of intersections, where more than half the bicycle–motor vehicle collisions occurred (*1*). Bicycle volumes for each of the sites had to be high enough to obtain an adequate number of observations within a short time frame. Therefore, cyclist behavior on resident streets, back lanes, parking lots, and driveways, where some 30 percent of the accidents took place, was not observed. The sites were selected in an attempt to incorporate a variety of roadway, cyclist, and traffic characteristics and to reflect the accident situation along arterial roads rather than represent all accidents.

Figure 1 represents the layout of the seven sites. The speed limit (in kilometers per hour) and approximate average daily traffic volumes are indicated for each site. All traffic lanes are 3.7 m (12 ft) wide, with the exception of one roadway at Site 6, which has curb lanes 4.9 m (16 ft) wide.

Site 1

Site 1 is situated just outside the downtown area. Observations were carried out during the afternoon rush hour. Traffic was generally heavy and slow-moving. Most of the cyclists observed were adults, many of whom appeared to be regular bicycle users, and many were traveling as fast as the traffic. Of special interest was the incidence of cyclists going straight from the right-turn-only lane and the bus bays.

Site 2

Site 2 is on a suburban university campus. Observations were performed during the morning rush hour. Traffic was operating under free-flow conditions. Most cyclists observed were regular adult commuters and were traveling at about half the speed of traffic. Close attention was paid to cyclists turning left from the right side of the dual destination lane.

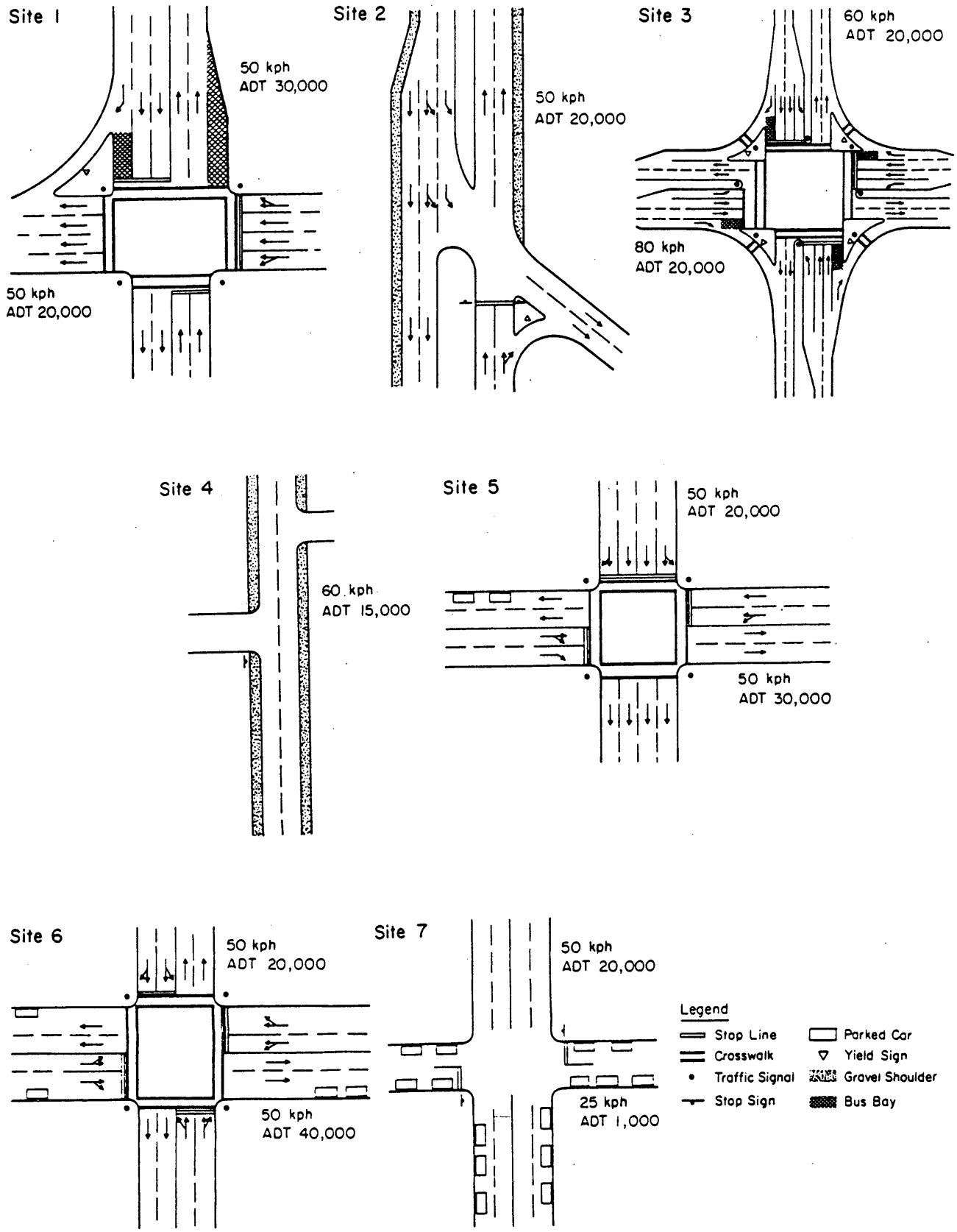


FIGURE 1 Site layouts.

Site 3

Observations at Site 3, a suburban intersection, were made on a weekday evening under light, free-flow traffic conditions. The cyclists observed were a mixture of children and adults riding for recreation. There was a greater tendency here for cyclists to travel in groups than at the other sites. Of interest were cyclists riding on sidewalks or in crosswalks and cyclists riding in the bus bays. Most of the bicycle traffic was concentrated on the 60-km/hr roadway and was traveling slower than traffic.

Site 4

As with Site 3, observations on Site 4, a suburban arterial, were made on a weekday evening under light traffic conditions. Cyclists were primarily children and adult recreational riders, a number of whom were traveling in groups and were slower than traffic. Of interest were cyclists riding on the gravel shoulders and sidewalks because of the perceived danger of riding on the roadway.

Site 5

Observations at Site 5, a downtown intersection, were made during the afternoon rush hour with heavy, slow-moving traffic. Most cyclists were adult commuters or adult recreational riders who were traveling near the speed of traffic. Special notice was given to cyclists going straight through from the right-turn-only lane and cyclists riding the wrong way on the one-way street.

Site 6

Site 6 is in a well-developed urban setting outside of downtown. Observations were made during the mid-afternoon and early rush hour under moderate to heavy traffic flow with cyclists traveling near the same speed. Cyclists varied from school children to adult recreational riders to adult commuters.

Site 7

Site 7 is one block from Site 6. Observations were carried out during the afternoon rush hour with generally heavy, slow-moving traffic; recreational adult riders and community cyclists were most frequent. Of interest were cyclists that might disobey stop signs or fail to yield to traffic when crossing the arterial from the residential street. It was anticipated that a number of cyclists would use the residential street as an alternative to the arterial road at Site 6.

Observation Results and Comments

In total 900 cyclists were observed and recorded during the study. The results of the individual site observations are summarized in Table 1. The following comments can be made:

- *Incorrect riding style is very common.* One-half of cyclists were doing something wrong during a maneuver, as will be described in detail.
- *Sidewalk and crosswalk cycling is common.* Nearly one of four cyclists observed was riding on the sidewalk or in a crosswalk for all or part of a maneuver. This reflects cyclists' perceived danger of riding on the roadway in traffic and negotiating busy multilaned intersections. At Site 4, a two-lane, two-way arterial with gravel shoulders, sidewalk usage by cyclists was particularly high (about one-half of the cyclists observed). This may be motivated by fear of overtaking traffic on a narrow roadway.
- *Left turns are performed incorrectly.* Of the 160 cyclist left turns observed, less than one-third were done correctly. Many cyclists either lack the skills to safely get in the correct position for a left turn or perceive that changing lanes in traffic is extremely dangerous. Cyclists thus opt to ride through the crosswalk for all or part of the maneuver or turn left from the curb. At Site 2, 60 percent of the left turns were made from the wrong side of the dual left turn–through lane.
- *Right turns are more likely to be done correctly than other maneuvers.* Only 40 percent of the 114 right turns observed were considered to be done incorrectly, compared with more than 65 percent of left turns and 47 percent of straight-through maneuvers.
- *Cyclists proceed from exclusive right-turn lanes.* Approximately two-thirds of the cyclists going straight ahead at an intersection equipped with right-turn-only lanes (Sites 1 and 5) did so without changing to the adjacent through lane. Many cyclists either find changing lanes difficult or choose to ignore signage and pavement markings.
- *In heavy traffic, cyclists weave and overtake between traffic and the curb.* During periods of heavy traffic, there was a greater tendency for cyclists to overtake between traffic and the curb and to weave between lanes of slow-moving or stopped traffic when approaching an intersection. This phenomenon was evident at Sites 1 and 5. In free-flow traffic conditions, no cyclists were observed to be weaving in traffic. Cyclists were, however, more likely to disobey red lights and stop signs when traffic was light.
- *Cyclists travel in bus bays.* Approximately 80 percent of straight-through cyclists observed at sites with bus bays (Sites 1 and 3) were riding in the bus bays. It is probable that many cyclists do this believing that bikes belong near the curb.
- *Wrong-way riding on the roadway is uncommon.* The vast majority of cyclists riding on the roadway were observed to be riding with traffic. Wrong-way riding was more common at sites with one-way streets (Sites 1, 3, and 5). As many as half of the cyclists riding on the sidewalk or in crosswalks were riding against traffic.

Commentary

From the field observations, it is apparent that many cyclists do not ride according to the established rules and principles of traffic flow: only half of the cyclists were observed to be riding correctly. There is the tendency for cyclists to "switch roles" between being a vehicle operator and a pedestrian whenever they think it is safer or more convenient to do so. A significant number of cyclists lack an understanding of how

TABLE 1 Summary of Cyclist Observations in Winnipeg and Vancouver, June–July 1991

Observations	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Total (%)
Observations	265	113	75	47	150	150	100	900
Cyclist Maneuver:								
Straight	203	31	51	38	120	105	78	626 (69.6)
Turning Left	17	73	11	5	17	26	11	160 (17.8)
Turning Right	45	9	13	4	13	19	11	114 (12.7)
Cyclist Action:								
Disobeyed stop sign/red light	1	3	9	0	2	1	6	22 (2.4)
Fail to Yield Right of Way	0	0	0	0	1	0	1	2 (0.2)
On sidewalk/in crosswalk	75	10	27	24	16	46	16	214 (23.8)
Improper position for left turn	10	43	2	4	6	9	4	78 (8.9)
Proceeding from right turn only lane	43	n/a	n/a	n/a	30	n/a	n/a	73 (8.1)
Too close to parked cars	0	0	0	0	0	0	5	5 (0.6)
Overtaking between traffic and curb	13	0	0	0	13	2	1	29 (3.2)
Weaving	4	3	3	0	3	1	1	15 (1.7)
In bus bay	71	n/a	20	n/a	n/a	n/a	n/a	91 (10.1)
Riding wrong way	6	6	0	2	4	2	2	22 (2.4)
On shoulder	n/a	0	3	1	n/a	n/a	n/a	4 (0.4)
Correct riding style	96	56	24	19	95	96	71	457 (50.8)

n/a - not applicable

traffic operates, perceive cycling in traffic to be very dangerous, or believe that the rules of the road do not apply to them.

The high incidence of sidewalk riding may be motivated by the perceived dangers of overtaking traffic. In heavy traffic conditions, cyclists were observed trying to "get ahead" by overtaking between traffic and the curb, weaving, and taking to the sidewalk.

Left turns pose difficulties for many cyclists; only one-third of these were done correctly. Cyclists elect to use crosswalks or turn left from the curb in many cases. The use of exclusive right-turn lanes and bus bays by straight-through cyclists could be motivated in part by traffic laws requiring cyclists to ride next to the right curb.

WINNIPEG'S BICYCLE ACCIDENT EXPERIENCE

Data Base

This section presents the results of an analysis of nearly 2,300 police-reported bicycle–motor vehicle collisions in Winnipeg between 1976 and 1989. The purpose of the analysis was to determine the nature and extent of car-bike collisions with a view to identifying trends. The results of the analysis provide the basis for examining the bicycle accident problem as it relates to cyclist behavior.

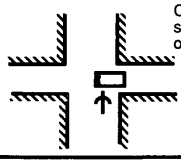
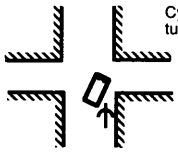
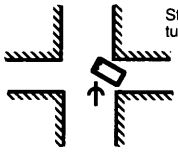
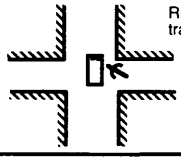
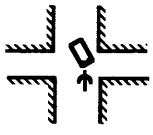
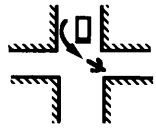
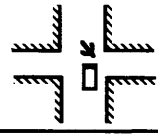
The analysis did not include accidents involving (a) a person walking a bicycle at the time of the collision, (b) unattended bicycles, and (c) falls or cyclist collisions with fixed objects, pedestrians, animals, or other cyclists.

Methodology

To develop an understanding of the nature of the accidents, it was necessary to reconstruct each collision on the basis of the data and witness narratives in the police reports. Currently, all accidents resulting in injury or a minimum of $500 property damage are required to be reported to the police. A total of 2,293 accidents were analyzed.

For each accident, cyclist, roadway, and weather characteristics were determined. Contributing factors were identi-

TABLE 2 Number of Bicycle–Motor Vehicle Accidents by Configuration: Winnipeg, 1976–1989

	Configuration		Description		Principal Contributing Factors	
A. Mid-block Collisions 528 (23.0%)	1. Rear End 156 (6.8%)		Cyclist strikes rear of stopped or parked motor vehicle.	[83]	• Cyclist inattentiveness • Cyclist loss of control	[78]
			Rear of cyclist struck by front of overtaking motor vehicle.	[73]	• Motorist improper overtaking • Cyclist swerves unexpectedly • Cyclist lack of reflector / taillight	[22] [35] [16]
	2. Opening Car Door 113 (4.9%)		Cyclist stricks driver side door.	[107]	• Motorist opening door into traffic • Cyclist too closed to parked car	[107] [107]
			Cyclist strikes passenger door	[6]	• Cyclist improper overtaking	[6]
	3. Sideswipe same Direction 222 (9.7%)		Cyclist sideswiped by overtaking motor vehicle	[162]	• Cyclist swerves unexpectedly • Motorist improper overtaking • Cyclist lack of reflector / taillight	[67] [82] [6]
			Motorist changes lane to right	[29]	• Motorist improper lane change	[26]
			Motorist entering/exiting parking spot	[31]	• Cyclist improper over taking • Motorist fails to yield right of way	[6] [25]
	4. Sideswipe - Opposite Direction 20 (0.9%)		Cyclist sideswiped by motor vehicle travelling in opposite direction	[20]	• Cyclist or Motorist travelling wrong way • Cyclist or Motorist loss of control	[10] [10]
	5. Head on 17 (0.7%)		Front of cyclist struck by front of motor vechicle travelling in opposite direction	[17]	• Cyclist or motorist travelling wrong way • Cyclist or motorist loss of controll	[15] [2]
B. Intersection Collision 1765 (77.0%)	6. Right Angle 983 (42.9%)		Cyclist proceeding straight intersection struck by straight through motor vehicle on perpendicular road way	[983]	• Cyclist or motorist disobeys traffic control device • Cyclist or motorist fails to yield right of way • Cyclist on sidewalk and / or wrong way • Cyclist lack of head light	[276] [486] [95] [23]
	7. Right turn 306 (13.3%)		Cyclist going straight struck by motorist turning right	[181]	• Motorist improper turning • Cyclist improper over taking • Cyclist riding on sidewalk and / or wrong way • Cyclist lack of reflectors / taillight	[105] [54] [9] [8]
			Straight through cyclist struck by motorist turning right from perpendicular road way	[113]	• Motorist fails to yield right of way • Cyclist riding on sidewalk and / or wrong way • Cyclist lack of head light	[28] [79] [2]
			Right turning cyclist struck by motorist travelling straight on perpendicular roadway	[12]	• Cyclist fails to yield right of way	[12]
	8. Left Turn 476 (20.8%)		Straight through cyclist struck by motorist turning left across his path	[312]	• Motorist fails to yield right of way • Cyclist riding on sidewalk and / or wrong way • Cyclist lack of head light	[212] [45] [49]
			Left turning cyclist struck by overtaking motorist	[117]	• Cyclist turning left from curb • Cyclist failure to shoulder check • Cyclist lack of reflector / taillight	[117] [117] [8]
			Cyclist turns left across motorist's path	[47]	• Cyclist fails to yield right of way	[47]

[ ] indicates number of occurrences

fied for both the motorist and the cyclist. For cyclists, typical accident causation factors included failing to yield right-of-way, disobeying stop signs and red lights, riding on the sidewalk, riding the wrong way, and lacking nighttime equipment. For motorists, common factors included failing to yield right-of-way and turning right improperly. An accident classification system was devised incorporating 16 configurations as illustrated in Table 2. The methodology and study results are reported in detail in Thom and Clayton (*1,2*).

Results

The following bicycle–motor vehicle accident characteristics were observed:

- Bicycle–motor vehicle collisions on Winnipeg's roadways increased by 50 percent between 1976 and 1989. In comparison, total accidents remained steady during the period.
- Cyclists are currently involved in 10 percent of all injury-producing accidents in the city during the peak cycling months (i.e., May to October).
- Not surprisingly, 9 of 10 accidents resulted in injury to the cyclist, 15 percent of which were serious enough to require medical attention.
- The proportion of adult cyclists involved in accidents increased from 20 percent in 1976 to greater than 49 percent in the late 1980s, reflecting the bicycle's increased role as an urban transportation mode.
- Nearly two-thirds of the accidents involved a major (arterial) roadway. This reflects cyclists' preference for these roadways because of their directness and fewer delays. In many situations, there are no alternative "quiet" roads paralleling arterial roads.

The distribution of accidents by configuration and contributing factor is shown in Table 2. From this table,

- Nearly one-quarter (528) of accidents occurred at midblock locations, with rear-end, sideswipe, and cyclist striking opening car door being the most frequent configurations
- More than three-quarters (1,765) of the accidents were intersection-related, with right-angle collisions being the most common (983, or 43 percent) (Configuration 6).
- The rear-end collision (Configuration 1*b*) was very uncommon: only 1 percent of the accidents were the result of cyclists' being rear-ended by improperly overtaking motorists in daylight conditions. In fact, more than half of the overtaking collisions were the result of the cyclist's swerving unexpectedly into the motorist's path.
- One of 10 (230) accidents occurred in darkness. In nearly all of these, the cyclist lacked a headlight and adequate rear reflectors or taillight. One-quarter of the nighttime accidents involved a motorist turning left across the path of a straight-through cyclist (Configuration 8*a*).

The distribution of accidents by contributing factor for cyclists and motorists is shown in Table 3. From this table,

TABLE 3 Number of Bicycle Accidents by Principal Contributing Factor: Winnipeg, 1976–1989 (*2*)

(a) Cyclist	Number of Accidents	% Accidents
Fail to yield right of way	347	15
Sidewalk/wrong way riding	328	14
Disobey traffic control device	255	11
Improper left turn	117	5
Swerves unexpectedly	102	4
Lack of night-time equipment	230	10
Loss of control	84	4
Too close to parked car	107	5
Total cyclists	1570	69
(b) Motorist	**Number of Accidents**	**% Accidents**
Fail to yield right of way	447	19
Disobey traffic control device	31	1
Improper overtaking	104	4
Improper lane change	29	1
Improper right turn	113	5
Wrong way	3	< 1
Loss of control	6	< 1
Opening door into traffic	107	5
Unsafe backing	5	< 1
Total motorists	845	35

- The most frequent contributing factor on the part of the cyclist was failure to yield right of way (in 347, or 15 percent, of accidents), followed by sidewalk and/or wrong-way riding (in 328, or 14 percent, of accidents). Over 250 (or 11 percent) of the accidents were the result of cyclists' disobeying stop signs or red lights.
- The most frequent contributing factor on the part of the motorist was also failure to yield right of way (in 447, or 19 percent, of accidents), followed by improper right turn (in 113, or 5 percent, of accidents).

Cyclists were at fault in nearly 70 percent (1,570) of the accidents analyzed. Motorists contributed to 35 percent (845) of the accidents, 5 percent of which the motorist and cyclist were judged to be equally at fault. More than a quarter of accidents were the result of cyclists' either failing to yield the right of way or disobeying a traffic control device. Even in those accidents in which the cyclist legally had the right of way, the cyclist was often doing something unusual, such as riding on the sidewalk or riding against traffic (and in many cases, both). Virtually all of the nighttime accidents were the result of the motorist's not being able to see the cyclist until it was too late to avoid a collision because of the cyclist's lack of either a headlight or rear reflectors and taillight. More than 5 percent of accidents were the result of cyclists' making improper left turns.

CYCLIST BEHAVIOR AND ACCIDENT EXPERIENCE

This section relates the findings of the behavioral observations with the bicycle accident experience. The observed cyclist actions described earlier are compared to cyclist contributing factors in bicycle–motor vehicle collisions just summarized. The comparison of cyclist behavior and accident causation is shown in Table 4 as percentages of observed cyclists and accidents, respectively. In making the comparison, it is to be realized that no direct cause-effect relationship was expected (i.e., because *X* percent of cyclists are seen to be riding the wrong way does not necessarily mean that *X* percent of the accidents should be caused by wrong-way riding). The relatively high or low incidences of certain cyclist behavior patterns may reflect the nature of the sites from which the observations were made. Nonetheless, the comparison is considered useful in helping to establish cyclist actions that may contribute to accidents, particularly on arterial roads. The following observations respecting cyclist behavior and the contribution of that behavior to accidents are drawn from this table.

Disobeying Stop Sign or Red Light

Less than 3 percent of the cyclists were observed to disobey stop signs or traffic signals. This action contributed to more than 11 percent of bicycle–motor vehicle collisions. This suggests that when a cyclist does disobey a traffic control device, the probability of a collision is high. As well, this action is probably more common in residential areas where traffic volumes are low and the perceived danger of a collision is also low. At the observation sites, most cyclists were forced to comply with stop signs and red lights because of high traffic volumes.

TABLE 4 Cyclist Behavior and Accident Contribution (*2*)

Cyclist Action	% of Observations	% of Accidents
Disobeyed stop sign/red light	2.4	11.1
Failed to yield right of way	0.2	15.1
On sidewalk/in crosswalk	23.8	14.3
Improper left turn	8.9	5.1
Proceeding from right turn only lane	8.1	0.3
Too close to parked cars	0.6*	4.7
Overtaking between traffic and curb	3.2	2.9
Weaving	1.7	4.4
In bus bay	10.1	0.0
Riding wrong way	2.4	7.6**
Lack of night-time equipment	no night-time observations made	10.0
Sample size	900	2293

* Only a limited number of observations were made of cyclists passing parked cars. Five cyclists were considered to be riding too close to parked cars out of a sample of 10 cyclists.

** Includes accidents where cyclists were riding wrong way on a sidewalk or in a crosswalk

Fail To Yield Right-of-Way

More than 15 percent of bicycle–motor vehicle collisions were the result of cyclists' failing to yield the right-of-way. In the field study, only 2 of the 900 cyclists did not yield to traffic when they were required to do so. As with disobeying stop signs or red lights, failing to yield incurs a great risk of collision. The low incidence of failing to yield the right-of-way is a reflection of the observations sites selected. In most cases, cyclists were forced to yield because of the traffic characteristics.

Riding on Sidewalk or in Crosswalk

Nearly a quarter of the cyclists were observed to be riding on the sidewalk or in a crosswalk for all or part of a maneuver. This action places cyclists in significant danger of collision at intersections, where 14 percent of the accidents were attributable to sidewalk or crosswalk riding. When motorists are crossing or turning at intersection, they are scanning for traffic on the roadway and simply do not expect to see cyclists coming off of the sidewalk. This action contributed significantly to the incidence of the right-angle, motorist-left-turn, and motorist-right-turn configurations (Configurations 6, 8*a*, 7*a*, and 7*b*, respectively, from Table 2).

Sidewalk riding also poses a danger to pedestrians. This danger, however, is difficult to quantify, since very few bicycle-pedestrian collisions are reported to the police.

Improper Position for Left Turn

Cyclists were incorrectly positioned for left turns in 9 percent of the observations, or in approximately half of the left turns observed. Many of these cyclists failed to shoulder check before moving left. Five percent of the accidents were due to cyclists making improper left turns.

Proceeding from Right-Turn-Only Lanes

In 8 percent of the observations, cyclists were going straight from exclusive right-turn lanes. Only six accidents were attributable to this action (Configuration 7*a*). This difference between observed behavior and accident experience reflects the fact that the vast majority of collisions involving right-turning motorists occurred at intersections that were not equipped with right-turn-only lanes. In addition, two of the seven sites selected for observation had these lanes, therefore the number of cyclists observed going through exclusive right-turn lanes could be expected to be high.

Cyclists who attempt to go straight from a right-turn-only lane are likely to conflict with right-turning traffic. In fact,

several near-collisions were observed at Sites 1 and 5 as a result of this action.

Too Close to Parked Cars

More than 100, or 5 percent, of the accidents were the result of cyclists' striking opening car doors (Configuration 2*a*). In all of these, the cyclist was riding too close to the parked car. In this study, the number of cyclists observed passing parked cars was too small to be able to conclude whether cyclists generally allow enough room between themselves and parked cars. Of 10 cyclists observed passing a row of parked cars, 5 were considered to be traveling too far to the right.

Overtaking Between Traffic and Curb

More than 3 percent of the cyclists were observed to be passing between stopped traffic and the curb. A similar percentage of the accidents were attributed to this, particularly collisions involving right-turning motorists (Configuration 7*a*). Motorists turning right onto a perpendicular roadway, or into a driveway parking lot, do not expect to be overtaken on the inside. In addition, cyclists overtaking on the right are often caught in the motorist's blind spot. This practice also frequently annoys motorists.

Weaving in Traffic

Less than 2 percent of the cyclists were observed to be weaving or "lane jumping" in traffic. This action was most frequent during periods of heavy traffic. Weaving or swerving contributed to more than 4 percent of the accidents, particularly those configurations involving overtaking motorists (Configurations 1*b* and 3*a*). In addition, this practice can be annoying to motorists stopped in traffic.

In Bus Bay

Ten percent of observed cyclists were proceeding from bus bays. In none of the accidents was it noted that a cyclist was in a bus bay before or at the time of the collision. However, this action is potentially dangerous in that (a) the cyclist is forced to reenter the traffic stream more often than is necessary, and (b) by being well to the right of the traffic stream, the cyclist is less visible to left-turning motorists (Configuration 8*a*) than by staying out of the bus bay. In addition, cyclists stopped in bus bays may interfere with transit operations.

Riding Wrong Way

Only 2 percent of cyclists were seen to be riding against traffic on the roadway. This practice was more common on one-way streets. In the Winnipeg accident study, approximately 70 percent of the cyclists who were riding against traffic at the time of the collision were doing so from a sidewalk. Cross and Fisher demonstrated that as many as 17 percent of car-bicycle collisions are attributable to wrong-way riding (*3*).

Lack of Nighttime Equipment

Although no observations were made at night, a casual survey indicates that the vast majority of bicycles operated at night lack a headlight and have the bare minimum in rear reflectors (including pedal reflectors). Many cyclists are also seen wearing dark-colored clothing. More than 90 percent of cyclists involved in nighttime collisions lacked the necessary equipment.

LOW-COST OPPORTUNITIES FOR MAKING ROADWAYS BICYCLE-FRIENDLY

On the basis of bicycle accident experience and observations of cyclist behavior, this section identifies low-cost countermeasures in the areas of roadway improvements, cyclist training, and public awareness to assist in making the current transportation system more accommodating to cyclists.

Roadway Improvements

From the findings in earlier sections, the following roadway modifications are suggested. Some of these suggestions may not be feasible on all roadways.

Wide Curb Lanes

On some roadways, it may be possible to widen curb lanes from the current width of 10 to 12 ft to 12 to 14 ft. This may be accomplished by restriping lanes or paving gravel shoulders. The provision of wider lanes may help to reduce the incident of sidewalk riding by increasing the level of comfort between cyclists and overtaking motorists, particularly at Site 4. This modification has the potential of reducing overtaking-type accidents (Configurations 1*b*, 3*a*) and opening-car-door collisions (Configuration 2*a*) by enabling cyclists to ride far enough to the left of parked cars without having to travel in the adjacent traffic lane.

More Clearly Defined Lane Destinations

On multilane roadways, the destination of each lane (i.e., left, straight through, or right) should be made clear through overhead signs or pavement markings such as at Site 2. This would help left-turning cyclists select the proper lane. In addition, dual-destination lanes, such as left and straight-through, should be avoided so that a cyclist only has to ride on the right side of the lane that serves his or her destination.

Modifications to Right-Turn-Only Lanes

Exclusive right-turn lanes can benefit cyclists because they can reduce the frequency of collisions between straight-through

cyclists and right-turning motorists (Configuration 7*a*). Straight-through cyclists might be more likely to stay out of right-turn-only lanes if these lanes were designed in such a way that it was not necessary to make a lane change in moving traffic to proceed straight (i.e., requiring right-turning traffic to lane change to the right), particularly at Sites 1 and 5. Right-turn-only lanes can also be created by restricting parking on the near side of an intersection and allowing parking on the far side of the same intersection. This modification may be applied to Sites 6 and 7. A cyclist could thus avoid conflicting with right-turning motorists by remaining on the extreme left side of the lane.

Other Measures

A number of other modifications that do not relate specifically to cyclist behavior and accident experience may be considered to make roadways more amenable to cycling and to improve overall cycling safety. These include the following.

Bicycle-Sensitive Traffic Signals Many traffic-actuated signals do not respond to bicycles, resulting in delays to cyclists during low traffic periods; occasionally cyclists proceed on a red light. Vehicle detectors should be set up so that they can detect a bicycle.

Extended Amber or All-Red Phases at Signalized Intersections Because cyclists generally move slower than most traffic, cyclists require additional time to clear an intersection when the light changes to amber. Consideration might be given to extending the amber phase by several seconds or following a standard-length amber phase with an all-red interval.

Left-Turn Phases at Signalized Intersections To reduce the frequency of collisions involving left-turn motorists (Configuration 8*a*), an exclusive left-turn phase could be incorporated in the signal sequence at most intersections on arterial roads.

Right-Turn-on-Red Restrictions Restricting right turns on red at signalized intersections has the potential of reducing the frequency of collisions involving motorists turning right from a perpendicular roadway (Configuration 7*b*) and, to a lesser extent, the frequency of cyclists being cut off by right-turning motorists (Configuration 7*a*).

Improved Roadway Maintenance and Hazard Removal In addition to roadway modifications, attention should be paid to maintaining road surfaces and removing road surface hazards. Debris such as sand, glass, and gravel must be swept on a regular basis. Programs must be in place to remove wheel-trapping catch basins and to replace them with a safer design. Hazards such as potholes and longitudinal cracks must be kept in check. When resurfacing takes place, attention must be paid to parallel-to-traffic pavement joints and making the pavement flush with manhole covers. Railway crossings and bridge expansion joints should also be designed to minimize the hazard to cyclists.

Cyclist Training

Increasing the level of traffic cycling skills can help to make cyclists more comfortable when riding in traffic, improve relations between cyclists and motorists, and facilitate the smooth and orderly flow of traffic.

The objectives of any cyclist training program are to improve traffic cycling skills, to increase knowledge and awareness of accidents, and to present methods to avoid accidents. To have a significant impact, such courses must be readily available, and the cycling population, particularly adults, must be convinced of their value. From these findings, cyclist training programs should include the following.

Knowledge of Accident Types

Cyclists need to realize that most collisions involving motor vehicles are intersection-related and that very few accidents are caused by improperly overtaking motorists.

Awareness of Cyclist Behavior That Contributes to Accidents

Cyclists must know how practices such as riding the wrong way, riding on the sidewalk, weaving in traffic, and overtaking between traffic and the curb result in accidents. Cyclists should be predictable and ride where motorists expect to see them.

Destination Positioning at Intersections

Cyclists need to know how to position themselves at intersections according to their destination, particularly for making left turns. To minimize conflicts, it is essential that a cyclist be in the lane that serves his or her destination rather than always riding next to the curb.

Skills in Shoulder Checking and Lane Changing

In order to make safe left turns in traffic, cyclists need to either develop skills in shoulder checking and lane changing or dismount and walk through the intersection.

Public Awareness

Awareness campaigns aimed at both motorists and cyclists are necessary to ensure a safe coexistence between the two

groups. For motorists, awareness campaigns should emphasize the following:

- Exercise care in overtaking cyclists;
- Expect to encounter cyclists anywhere on the road system at any time;
- Remain behind a cyclist when turning right;
- Always scan for cyclists when crossing or turning at intersections; and
- Expect cyclists to stay out of exclusive right-turn lanes, bus bays, and parking lanes.

Motorists should also expect cyclists to move to the left at intersections to make left turns. For cyclists, emphasis should be placed on the following:

- The safest place to ride is on the roadway with traffic, not on the sidewalk or against traffic;
- Obey stop signs and red lights, and yield to pedestrians and traffic when it is required by law;
- Ride in the lane that serves the destination; and
- When approaching intersections, be alert for crossing and turning motorists.

CONCLUDING REMARKS

The principal findings of this work follow:

- Only one in two cyclists rides correctly, on the basis of the field observations of cyclist behavior.
- Many cyclist behavior patterns—such as riding on the sidewalk, riding against traffic, and weaving in traffic—contribute to collisions with motor vehicles.
- Accidents involving cyclists and motorists have increased over the past decade. As many as 10 percent of all injury-producing road accidents in Winnipeg during the summer months involve a cyclist. Furthermore, these accidents are increasingly involving adult cyclists, reflecting the bicycle's increased popularity as an urban transportation mode.
- Low-cost countermeasures in the areas of roadway modifications, cyclist training, and public awareness are available to address the increase in cycling accidents and to make the transportation system more accommodating to cyclists.

Cycling as a means of transportation in North America and throughout the world is likely to continue to increase, given the growing concern for the environment. This will call for a greater effort in retrofitting transportation systems to make cities bicycle-friendly.

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DISCUSSION

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Thom and Clayton's paper provides a valuable insight into the realm of bicycle crash statistics and bicyclist behavior on the basis of observations and statistics from Winnipeg, Manitoba. The paper confirms the hypothesis that cyclist behavior patterns are influenced by different roadway and traffic characteristics.

The authors are clearly experienced cyclists who have developed and adhere to the principles of "effective cycling," or the vehicular style of cycling. This is reflected in the commentaries given on different patterns of behavior. For example, at the busiest observation sites a substantial number of bicyclists were observed riding on the sidewalk or shoulder, riding in bus bays, or proceeding straight ahead from a right-turn lane. The authors ascribe that "wrong" behavior to a fear of traffic and cyclists' belief that they belong as far to the right of the road as possible. It is also an indication that bicyclists enjoy the channelization offered by painted lines and car-free lanes.

In the suggested "low-cost opportunities for making roadways bicycle-friendly," the authors do not mention bike lanes, preferring to recommend wide-curb lanes. Wide-curb lanes are adequate for cyclists with confidence and experience, but for the type of cyclist observed riding on the sidewalk or in the bus bays, these widened curb lanes would do little to alter this behavior—and thus little to reduce the dangers caused by this behavior.

Other recommendations, such as more clearly defining lane destination markings, restricting right turns on red, and avoiding the use of dual-destination lanes, are helpful and practical suggestions that will benefit all road users.

The authors make the interesting observation that cyclists tend to switch roles between vehicle operator and pedestrian whenever they think it is safer or more convenient to do so. This is crucial, and very true. The existing roadway system simply does not work for many existing bicyclists, and it deters many more potential bicyclists from ever getting started.

AUTHORS' CLOSURE

Clarke's discussion provides several useful and valid comments. We take this opportunity to clarify and discuss several issues.

First, bike lanes can be effective in improving the cycling environment on roadways with few intersections, such as rural highways. However, in urban areas with a multitude of intersections, special lanes can promote dangerous behavior by both motorists and cyclists. The principal danger of bike lanes is that they attempt to separate traffic flow by vehicle type rather than by direction of travel. Bike lanes prevent motorists

from making right turns from the extreme right side of the roadway, as is required by law, and encourage cyclists to overtake right-turning motorists on their right side. Cyclists wishing to turn left tend to avail themselves to the bike lane until they arrive at the intersection, then proceed to turn left in front of overtaking traffic rather than merging left well in advance of the intersection. Bike lanes also prevent motorists from using the full width of the roadway in the absence of cyclists. This usually results in the accumulation of debris in the bike lane, unless vigorous maintenance programs are in place.

Second, the roadway modifications suggested in the paper are not all-inclusive. For example, to make roadways more bicycle-friendly, we could have suggested additional measures, such as reducing speed limits, synchronizing closely spaced traffic signals to match cyclist speeds, and adding special pavement markings to guide cyclists through multilane intersections. We limited ourselves to suggesting low-cost measures that related specifically to observed cyclist behavior and accident experience. Further suggestions are welcome.

Third, roadway modifications alone will do little to change cyclists' behavior. None of the suggested improvements are substitutes for traffic cycling skills. In this regard, cyclist training programs can play a substantial role by increasing cyclists' confidence and enabling cyclists to make the existing roadway system work for them. The principles of traffic cycling are within easy grasp of virtually anyone, particularly if these are first practiced on residential streets and then applied to progressively busier roadways and more difficult traffic situations.

Finally, although we don't have all the answers to the problems that face cyclists, it is clear that efforts to make cities more bicycle-friendly must be taken from several fronts. These include modifying the existing roadway system, improving the skill levels of cyclists, making motorists more bicycle-friendly, and creating bicycle-friendly traffic laws.

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