TRANSPORTATION RESEARCH RECORD

No. 1396

Operations and Safety;
Planning and Administration

Nonmotorized Transportation Research and Issues

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1993

Transportation Research Record 1396
ISSN 0361-1981
ISBN 0-309-05469-9
$24.00

Subscriber Categories
IA planning and administration
IV operations and safety

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Foreword

Three years ago a Special Interest Group on Global Nonmotorized Transportation (NMT) under the leadership of V. Setty Pendakur assembled the first Record on international NMT. The special interest group became a TRB task force and issued a second Record on the same subject. This Record is compiled from the papers presented at the TRB Annual Meeting in January 1993.

NMT in China is one focus of discussion. The bicycle is a major transportation mode in China, and the five papers on NMT in China reflect this. Each discusses a different aspect of bicycle transportation in that country.

Following these papers, a variety of NMT topics are discussed from the vantage point of many countries around the world. Pedestrian and bicycle programs in Kuwait City and Nigeria are presented. Bicycle planning in states of the United States in response to new federal legislation is discussed. Transportation problems in developing countries and possible solutions are presented. The next paper presents a new approach to planning and policy making for NMT in Third World cities. The development and use of an NMT choice model is described. In this paper the effect of lower bus fares is simulated, and the short-run sensitivity of such exogenous measures on different income groups is demonstrated. Economic incentives as a determinant of mode choice are summarized in the next paper. Research recommendations are proposed that would lead to better understanding of these incentives and to development of economically efficient user fees encouraging use of NMT. Pedestrian speed-flow relationships in developing country central business districts are measured and compared with those of the *Highway Capacity Manual*. The data do not support using the *Highway Capacity Manual* capacity values in developing countries, and an alternative figure is recommended. The final paper of this Record addresses the worldwide experience in integrating bicycles as a mode of access to public transit. The experience is particularly relevant to the United States in making transit available through several modes, not just the automobile.

Overview of Bicycle Transportation in China

XIAOMING LIU, L. DAVID SHEN, AND FUTIAN REN

As the most populous country in the world, China has relied heavily on bicycles for passenger transportation. The economic reform policy adopted in the late 1970s has brought dramatic economic growth during the last decade. Subsequently, bicycle ownership in urban areas increased from one bicycle for every three persons in 1980 to one bicycle for every two persons in 1990. An overview of bicycle transportation in China is presented. The advantages and disadvantages of bicycle transportation and its usage in China are discussed. It was found that the average bicycle travel distance is less than 4 km (2.5 mi). Bicycling is the transportation mode of choice for up to 70 percent of the urban passenger trips in China. However, because of its slowness, serious traffic problems occur when bicycle traffic mixes with motorized vehicle traffic. The mixing of faster and slower traffic modes causes a lower capacity and results in higher accident rates. In the average Chinese city, about 30 percent of the traffic fatalities are bicyclists. Traffic separation, better intersection control, and improved bicycle management are recommended to improve bicycle transportation in China.

The use of bicycle as a mode of transportation in China has a history of nearly 100 years. However, its usage began to take off in the late 1970s after the economic reform brought more disposable income to the Chinese people. Bicycle ownership in China more than quadrupled during the 1980s.

Chinese have relied heavily on bicycles for both urban and rural passenger transportation. Of all the registered bicycles, 40 percent were in urban areas as of 1982 with an average of one bicycle for every three persons. As a result of rapid economic growth during the 1980s, bicycle ownership increased to one bicycle for every two persons in 1990. Bicycles are playing a very important role in the transportation system of China. The purpose of this paper is to present an overview of bicycle transportation in China.

ADVANTAGES

Flexibility, economy, efficiency, and affordability are four major advantages contributing to the bicycle's popularity in China. The continuous development of China's bicycle traffic has clearly proved that it is the transportation mode of choice for many Chinese.

Flexibility

The bicycle is more convenient than public transportation because of its private nature. When the travel distance is about 6 km or the travel time is less than 30 min, the bicycle is the more popular choice. Table 1 gives the average travel distance for bicycle traffic in 10 major Chinese cities.

Economy

Under ideal traffic flow, the average bicyclist will need 9 m^2 of road to operate, whereas an automobile needs 46 m^2. In addition, the average bicycle parking space is only 1.6 m^2, compared with 22 m^2 required for the automobile. A bicycle can easily operate in narrower lanes and requires relatively lower pavement strength.

Many Chinese cities have old districts, which are generally located in the central business districts. In many of these areas, 30 to 50 percent of the roads are narrow, ranging from 3.5 to 6 m in width. Public transit cannot operate in these narrow streets and back alleys. This kind of city structure gives a strong incentive to the development of bicycle traffic. For a nation of more than 1 billion people, the use of bicycles clearly reduces the pressure for more roads and parking lots.

Efficiency

Compared with other modes of transportation, such as the subway, bus, automobile, and so forth, bicycles consume the least amount of power and are pollution free and environmentally sound. If the travel distance is not more than 8 km, the average energy consumption of the bicycle is as little as one-ninth the power consumed by the motor vehicle, including power consumed in vehicle manufacture, trade, transport, maintenance, and operation as well as road construction. Bicycle traffic is free of both noise pollution and emissions. Developing bicycle traffic in urban areas is helpful in preserving the environment as well as saving energy.

Affordability

China, as a developing country, still has a long way to go in terms of developing its economy. With per capita income of U.S. $500 per year, few people can afford to own an automobile. Consequently, bicycle is the logical choice for most

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TABLE 1 Average Bicycle Travel Distances for 10 Major Chinese Cities

City	ATD(km)	City	ATD(km)	City	ATD(km)
Beijing	5.20	Wuhan	3.85	Zhengzhou	2.54
Shanghai	3.99	Guangzhou	3.84	Hangzhou	3.36
Tianjin	3.70	Chengdu	3.45		
Shengyang	3.40	Fushun	4.65		

Chinese. It is affordable; a bicycle costs the average citizen about 2 months' pay.

DISADVANTAGES

As most people know, bicycle transportation is not perfect due to its inability to accommodate longer travel distances, significant terrain changes, and varied weather conditions. The bicycle cannot be expected to travel long distances or operate in mountainous terrain. For example, in Chongching, a city with steep terrain, the bicycle is used for only a small part of passenger transportation. In addition, it is difficult to operate in bad weather conditions.

As bicycle traffic increases, conflicts between bicycle and motor vehicle traffic also increase, and this results in a significant increase in traffic accidents. The bicycle is vulnerable to motor vehicles in this respect, so both the frequency and the death rate of bicycle accidents are at a high level. According to the statistics of 20 cities in 1981, there were 15,966 bicycle accidents, 32.1 percent of all accidents, with 798 people dead, 24.9 percent of all traffic accident fatalities. In Shanghai, 367 cyclists died in 1989; this is up to 56.3 percent of the traffic accident fatalities. From 1987 to 1990, 174 bicyclist died in Hangzhou, and the statistics of Xian showed that 41.8 percent of the traffic accident fatalities were bicyclists. In the average Chinese city, about 30 percent of the traffic fatalities are bicyclists.

IMPACT ON PUBLIC TRANSIT

With an improved economy and more disposable personal income, more and more Chinese commuters in urban areas are traveling by bicycle. As a result, public transit is gradually losing its ridership. In Beijing, 70 percent of the people traveled by bicycle in 1990 compared with 50 percent in 1986, and the percentage of people using public transit decreased from 50 percent to 30 percent.

This dramatic modal change in a short 4-year period is unheard of in the public transportation history of China. The recent urban origin-destination surveys show that in most cities, more people travel by bicycle than by public transit (see Table 2). With the increasing numbers of registered bicycles, this trend will continue.

In China, the urban transportation strategy is to give priority to the development of public transportation and to take full advantage of the bicycle as a short-distance trip vehicle and for walking substitution. Existing policies that pertain to bicycles are as follows:

- The bicycle is partially tax free.
- There are monthly traffic subsidies of 2 to 10 yuan for bicycle users.
- Bicycle manufacturing is increasing capacity to keep bicycle prices down.
- Bicycle parking is subsidized in most agencies.

TABLE 2 Percentages for Various Traffic Modes in 20 Chinese Cities

City	Year	Transit	Bicycle	Pedestrian	Private	Others
Beijing	1986	24.3	54.03	13.76	4.38	3.83
Shanghai	1986	36.11	24.23	36.26	2.34	1.06
Tianjin	1990	8.32	74.63	10.58	3.98	2.49
Nanjing	1986	19.2	44.10	33.10	2.50	1.10
Shijazang	1986	5.0	58.65	33.35	NA	3.00
Guangzhou	1984	11.74	37.24	45.58	NA	1.11
Guiyang	1987	11.57	12.96	69.74	6.50	5.73
Zhengzhou	1987	3.23	63.05	32.95	NA	1.77
Dalian	1990	36.4	17.90	36.20	NA	3.00
Lanzhou	1984	22.57	29.30	45.01	NA	3.12
Shenyang	1985	10.10	58.65	29.00	NA	2.25
Fushun	1987	22.10	24.56	40.42	NA	13.01
Chengdu	1985	18.83	36.32	45.65	NA	3.20
Wuhan	1987	20.12	35.23	37.39	NA	7.26
Harebin	1985	17.70	28.48	39.41	NA	14.41
Changchun	1984	16.35	37.03	41.66	NA	4.96
Anshan	1987	9.31	54.04	33.74	NA	2.91
Hangzhou	1986	12.96	56.29	27.65	NA	3.10
Changsha	1983	25.19	31.39	39.21	NA	4.21
Zibe	1989	43.5	75.48	19.03	NA	0.60

It is clear that the existing policies in most Chinese cities encourage the development of bicycle transportation. In the foreseeable future, bicycles will continue to play a dominant role in the passenger transportation system of China. The Chinese have put a special touch on the bicycle and adapted it perfectly to their urban environment/highway design. Therefore, it is critical to coordinate the development of a bicycle–public transit transportation system to improve its overall efficiency.

MANAGEMENT OF BICYCLE TRAFFIC

In major Chinese cities, bicycle parking is well organized in the off-street parking lots around major bus or subway stations to facilitate traffic flow and minimize bicycle disturbance to motor vehicles. This was done to attract more bicycle users to transfer to public transit, and the results are encouraging.

Although public transportation has been improved significantly in the past decade, the poor accessibility, long waiting time, frequent delays, and crowded conditions make it impossible to meet the travel demands of daily commuters. This in turn pushes more people to bicycles. Therefore, it is clear that unless the mass transit system in China can improve its level of service, bicycles are going to remain a tough competitor in the future.

Chinese commuters would like to choose public transit for long trips, but a poorly planned transportation network forced them to consume too much time and energy. Some survey results show that people might prefer bicycling instead of walking to the public transit facility if the distance is more than 400 m. According to a survey of subway passengers in Beijing in 1990, about 30 percent travel to and from the subway station by bicycle.

When the bicycle and public transit work together, the result is a "pleasant" decrease in travel times for commuters, as indicated in Table 3. A recent study done in Beijing has shown that when the travel distance is within 4 km, the bicycle has obvious advantages. However, because of its slowness, serious traffic problems occur when bicycle traffic mixes with motorized vehicle traffic. The mixing of faster and slower traffic modes causes a lower capacity for both bicycles and motor vehicles and results in higher accident rates. To solve this problem, the following measures have been taken:

Separation

Bicycle traffic is segregated from motor vehicle traffic by raised pavement markers, guard rails, Jersey barriers, and separating strips. In some cities, the road network is constructed so that the bicycle is channeled by separating strips, which allows the bicycle to have absolute right-of-way.

Bicycle lanes also appeared in some cities. In Tianjin, for example, exclusive bicycle lanes have been adopted on streets that have high bicycle traffic volumes, and they prohibit cargo tricycles from operating during rush hours. In addition, at some bus stops, a separated midblock bus turnout is used to reduce the conflicts of bicycles with buses and pedestrians.

Intersection Control

The following traffic control measures are applied at intersections:

- Give priority to the bicycle at traffic circles.
- Create vehicle-prohibit zones.
- Set up a bicycle path/road.
- Limit left turns of arterial bicycles.
- Provide two- or three-level interchanges for bicycles and cars.
- Use channelization if the left-turn bicycle traffic is more than 15 percent.

Management

Since the bicycle is likely to continue its dominance in Chinese cities in the coming decade, a plan to manage bicycle traffic to improve its efficiency is critical for China. Bicycle management includes education of people, vehicle administration, and bicycle lane/road maintenance. It is recommended that a bicycle trust fund be set up by charging a nominal user fee/tax for bicycle manufacturing and registration. The money collected from this trust fund will be used exclusively to improve bicycle facilities in Chinese cities.

CONCLUSION

Bicycle has a unique role in China's passenger transportation system. It is the mode of choice for up to 70 percent of the urban passenger trips. In the foreseeable future, the bicycle will continue its dominance in most Chinese cities because of its flexibility, economy, efficiency, and affordability. There-

TABLE 3 Travel Times for Various Traffic Modes in Beijing, China

	Trip Length (in kilometers)				
	2 km	4 km	6 km	8 km	10 km
Traffic Modes			Travel Time in Minutes		
Bicycle	11.0	21.0	31.0	41.0	51.0
Bus (no transfer)	16.5	24.0 (21)	32.5 (34)	40.0 (34)	48.0 (40)
Bus (one transfer)	20.0	27.5 (24)	36.0 (32)	43.5 (37)	51.5 (44)
Subway(no transfer)	31.0 (22)	34.0 (25)	37.0 (28)	40.0 (31)	43.0 (34)
Subway(one transfer)		39.0 (30)	42.0 (33)	40.0 (36)	48.0 (39)

Note: The statistics in ( ) are the times transfer procedure takes when using bicycle instead of walking.

fore, additional research to improve bicycle traffic flow in the urban environment is going to be one of the most important tasks for traffic engineers in China for the coming decade.

It is clear that the task of solving bicycle traffic problems in China cannot be undertaken by one agency alone. The cooperation and coordination of all transportation agencies are required if China is going to have the most efficient and safe bicycle transportation system. It is essential that the city planning agencies, highway agencies, traffic management agencies, educational institutions, and bicycle manufacturers work together to keep bicycle transportation in China among the best in the world.

Bicycle: A Vital Transportation Means in Tianjin, China

NONG REN AND HIROTAKA KOIKE

Nonmotorized transport (NMT), especially bicycle transport, plays an essential role in the traffic systems of Tianjin City, the third-largest city in China. The growth of the bicycle transport mode and how bicycle transport has been working in the city's traffic are described. The problems that NMT faces and the possibility of integrating the bicycle transport mode with the public one (bike-and-ride) are discussed.

In every country in the world, serving the needs of people who do not have cars is crucial for creating a sustainable transport system. Nonmotorized transport (NMT), especially bicycle transport, is the most common form of individual transport. It is extensively used by the residents of Tianjin City, China. It offers low-cost private transportation, emits no pollution, and emphasizes the use of renewable labor energy rather than capital for mobility. It is well suited for short trips for most people in Tianjin City regardless of income. It offers an alternative to motorized transportation for many short trips. The city's structure and transport systems have changed under the influence of the bicycle transport mode.

Tianjin City is one of three special cities directly under the jurisdiction of the central government of China and is one of the most important economic and industrial bases in China. As the city's economy has developed, traffic problems have become more serious. Economic growth has been hampered by inefficient transport systems. NMT, especially bicycles, has been emerging to meet transport demands. Commuting by bicycle is common in Tianjin.

Bicycles have become the predominant type of private vehicle in Tianjin City. A large number of bicycles are used daily for essential travel. According to the city authority's survey in March 1990, bicycle ownership in Tianjin was more than 3 million and was increasing rapidly. Almost everyone at the cycle age is using a bicycle for daily trips, mainly for commuting to work.

TIANJIN CITY'S TRAFFIC SYSTEMS

Conflicts with Old Streets

In 1860, Tianjin City was invaded by British and French armies, and in the latter part of the 19th century Tianjin was conquered by the combined armies of nine countries. The city was divided into many small blocks and areas. Many streets were built noninterchangeably for the purpose of the colonies' concessions' self-defense. Yingkou Avenue, the old boundary between the English and French concessions in the first half of the 20th century, was a typical example (see Figure 1) (*1*). Streets crossing Yingkou Avenue were staggered, curved, and T-typed. It was difficult to enter the old British concession from the French side because of the artificially imposed obstacles.

Another example is the Horse Field Road (see Figure 2) (*1*). The road was made by Britain's colonists for their horse racing and games. It extended into the central areas among the English, American, and German concessions. The road was planned so that travel would not be easy. It was crooked in several places, with few right intersections. To change its course or reconstruct it was impossible because of the many buildings and important facilities along the road. The road is still there in Tianjin City as it was half a century ago. It often slows traffic to a standstill.

There were several similar cases in the old colonized Tianjin City. It was not easy to reconstruct the unreasonable streets and structures built in colonial times, because the structures on the avenues and the streets were beautifully and solidly built. In addition, finances were not readily available for reformation. These old street networks have made the city's automobile traffic awkward and caused the city center to be congested and inefficient. In these streets, NMT is often faster than automobile traffic.

Population and Land Use

The population of urban Tianjin was about 1.8 million in 1949 when the People's Republic of China was established. It increased to about 3.5 million in 1988 (see Table 1) (*2*,p.15) distributed over Tianjin's six regions—Hebei, Hexi, Heping, Hedong, Nankai, and Hongqiao. The area was 154 km^2, for a density of 22,695 residents per square kilometer.

Most of the industrial areas were in the suburban towns. But the residential regions and newly developed housing areas were not attractive enough to accommodate people who were working in the suburban industrial areas while still living in the central urban part of the city. It was clear that this pattern implies a large increase in the number of commuters and the average length of commuting travel. It helped to bring about the city's high proportion of work trips, which are mainly composed of bicycle trips.

BICYCLE TRANSPORTATION AND WORK MODAL SPLIT

To produce correct predictions and an applicable master plan, Tianjin City authorities implemented a large-scale traffic modal

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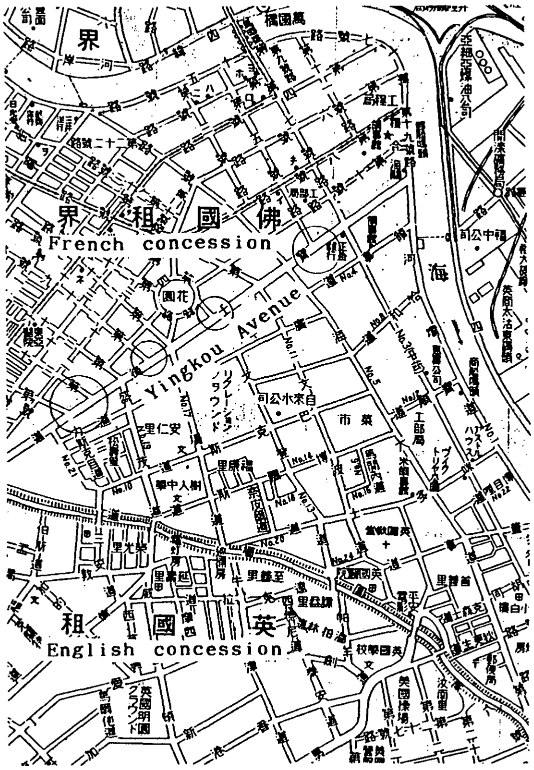

FIGURE 1 Yingkou Avenue.

split survey in March 1990. A total of 35,743 residents from 10,227 families in different regions and streets responded to survey questionnaires. This was approximately 1 percent of the urban Tianjin population and was supposedly representative of urban Tianjin residents. The results of the survey indicated that the bicycle transport mode played a major role in residents' transportation, especially in commuting to and from work.

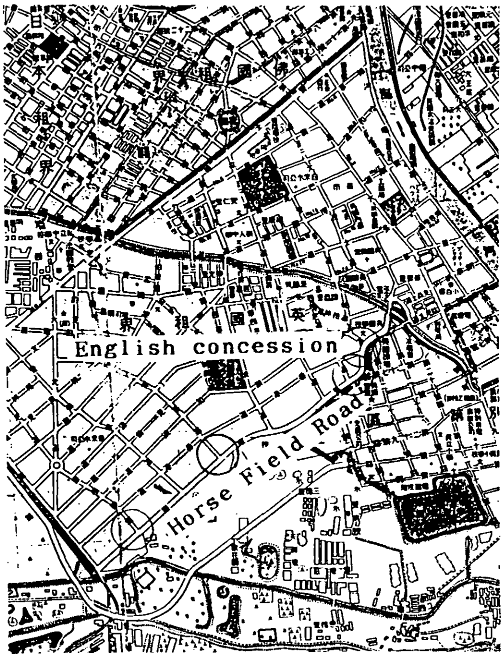

FIGURE 2 Horse Field Road.

TABLE 1 Urban Population Change in Tianjin

Year	Population(,000)	Background
1840	200	Opium War
1860	300	Invasion of Britain and France
1903	750	Invasion of Multi-National Army
1920	850	After World War I
1937	1,080	Invasion of Japanese Army
1949	1,790	P.R. of China Established
1959	2,820	National Census
1966	2,950	"Cultural Revolution" Began
1988	3,495	

About 68 percent of total daily trips in 1981 were work trips, and 56 percent of them were made by bicycle. In 1990 the proportion of bicycle work trips had increased to 74.6 percent (see Figure 3) (*3*,p.6). Bicycle work trips increased by 18.4 percent compared with 1981.

First, why did work trips have such a large increase? According to the investigation in 1981, work trips took 68 percent of total daily trips (which were estimated to be about 7.5 million per day). Major traffic problems occurred mostly during peak times for work trips, so we have to understand why work trips took such a high percentage of total daily trips in the city.

1. It is customary for husband and wife to have their own occupations, which doubled the work trips.
2. In the daytime, not many housewives go out for a day trip. They go shopping on their way back home after work.
3. There are fewer social activities.
4. In the evening the couple must do housework because they both work in the daytime and have a limited number of holidays to do housework.

These reasons indicate that the majority of resident trips were for work. Second, they indicate the important role that the large number of bicycles plays in work trips. The survey results showed that approximately 74.6 percent of work trips were made by cycling in 1990. This was the main transportation mode that ordinary Tianjin residents used and was a main component of city traffic.

Production of Bicycles

The largest bicycle producer in China, Tianjin Bicycle Manufacturing Group, produced 6,123,000 units in 1989. Bicycles were readily available, and the bicycle market has become a buyer's market.

The average price of an ordinary bicycle is about RMBY 300 or about $45. The price of a higher-quality bicycle would be twice that of an ordinary one. Compared with bicycle prices in developed countries, $45 seems inexpensive. However, for an ordinary Chinese person, this represents an average monthly

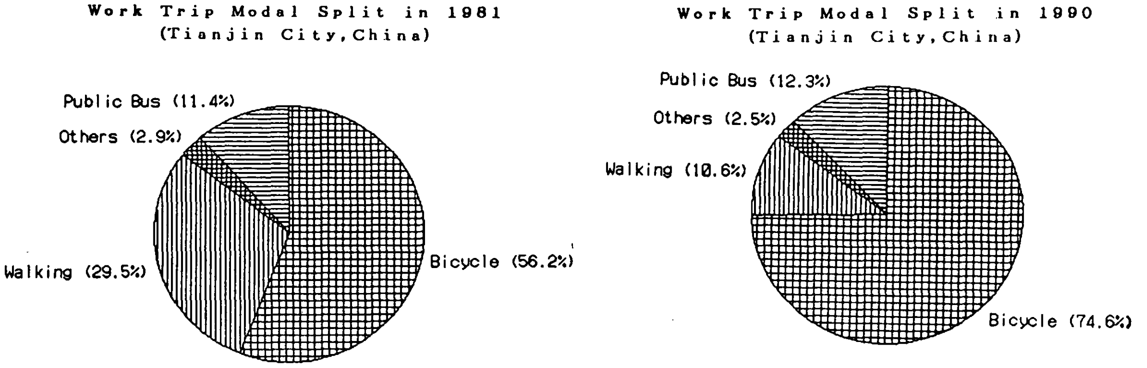

FIGURE 3 Work trip modal splits.

salary. Nevertheless, they are buying new bicycles without hesitation, because bicycles have become the only vehicle they can afford. Bicycles are a convenient, money-saving, and gas-saving mode of transportation, and people like them. In addition, because their social system is different, people do not have to worry about problems concerning land, housing, and food. A bicycle may be their only possession, which could contribute to its popularity.

Status of Bicycle Utilization

Bicycle ownership in the urban area was 3.05 million at the end of 1988. The population of the area at the same time was 3.5 million, which means that 87 percent of the residents possessed bicycles (see Table 2) (*4*,p.14).

When investment in public transportation could not keep up with population growth (there were about 2,400 residents per bus in 1985), bicycles were useful in meeting transportation needs, although they were seen as a symbol of backwardness and were considered an obstruction of high-speed traffic by some government planners and some residents. Bicycles became extremely useful not only for daily travel but also for transporting a family or goods. A bicycle would be used for transporting materials, towing a trailer or baby buggy, or carrying a friend or relative to a destination. This is observed especially in the suburban areas.

TABLE 2 Urban Tianjin Bicycle Growth

Year	Population (thousand)	Bicycle (thousand)	Possession Rate
1981	3,026	1,629	53.8%
1982	3,072	1,952	63.5%
1983	3,172	1,969	63.0%
1984	3,186	2,078	65.2%
1985	3,247	2,310	71.1%
1986	3,339	2,530	75.7%
1987	3,396	2,750	81.0%
1988	3,500	3,052	87.2%

Bicycle transport mode has been extensively accepted by urban Tianjin residents. It has directly or indirectly provided greater mobility and has benefited the city's difficult traffic circumstances as well as providing advantages to commuters. It is irrefutable that bicycles have become the most significant part of Tianjin's transportation system and are indispensable.

There are several reasons why bicycle utilization expanded so rapidly in Tianjin City:

1. The scope for bicycle riding is reasonable. The urban city area is about 173.3 km^2. The average radius of the urban city area is $R = (S/3.14)^{1/2} = 7.43$ km. The average distance from the residential areas in the six administration regions to the central area is about 4.8 km. The average distance from industrial areas to the central area is 6.5 km. The area with all of the city's political, economic, and cultural activities is inside the Middle Ring Road—the center of the city, about 71 km^2. The average velocity of bicycles in other large cities of China is 11 km/hr. In Tianjin, where many new bicycle lanes are made to prevent bicycles from being mixed with automobile traffic, bicyclists can travel more easily than in other cities. The average velocity is higher than that of other cities and is estimated to be 13 km/hr. According to the travel time estimate by Gibson for daily trips such as trips to work, shop, and play (see Table 3) (*5*,p.172), if the acceptable bicycle trip time is 25 min, a reasonable radius for bicycle travel will be as follows: $13 \text{ km/hr} * (25/60) \text{ hr} = 5.4$ km.
2. The central city has been undergoing a great change from a residential-commercial-industrial to a business-commercial-residential area. People have been moving away from the noisy narrow streets of the central city. From 1980 to 1988, about 170,000 residents moved from inside the Inner Ring Road. About 207,000 moved out of the area between the Inner Ring and the Middle Ring. These people, who used to commute on foot, have shifted to bicycles. The completion of the Ring roads, especially the Middle Ring Road, also encouraged people to use bicycles because the Ring roads have broad paths exclusively for bicycle transport mode.
3. Public transportation service is poor. Many people who are supposed to take the bus or train for work trips use bicycles. Shortages of financing have kept public transportation to low availability. The quality of service of the public transportation system falls far short of meeting the normal demand.

TABLE 3 Estimated Travel Times (min)

Travel Time	Minimum (Ideal)	Average (Don't Care)	Maximum (Barely Tolerable)
To work	10	25	45
To shop	10	20	35
To play	10	30	85

Usually there is no timetable at a bus stop in Tianjin. Buses come irregularly. Sometimes two or three buses come together and sometimes they will not appear again for a long time. Because of this, people prefer bicycle riding. The ratio of buses to residents is only 1:2,400. Buses are operating under oversaturated conditions. Looking at the bicycles traveling faster than the bus, passengers who are squeezed inside the bus decide not to ride the bus and then make a different and inevitable choice. This has accelerated bicycle usage in Tianjin.

The inaccessibility of convenient connections of public transportation is another reason for choosing to bicycle. People do not want to use two travel modes in one trip. They believe that it is better, even for a long time or a great distance not easily endured, to ride a bicycle. This way they can go all the way to their destination rather than going by bicycle to a bus station and then getting off the bus to take another bicycle on to their destination.

There are almost no work trips made by private cars in Tianjin, so for most residents, to give up bus transportation means using a bicycle. That is the only transportation choice they have.

4. As living standards rise, the ordinary resident's purchasing power has had a great boost. Considering the bicycle as the only private transportation means for their daily trips, they take it for granted that everyone has a bicycle. People who go to work by bicycle have been subsidized by the government and their companies. They will get money (about 6 RMBY per month) for bicycle maintenance if they declare that they use a bicycle to commute. This amounts to about 2 percent of their salary. People who commute by public bus have to pay a part of the traffic fare themselves. This policy also has become a major factor in encouraging people to use bicycles as much as possible.

Organization of Bicycle Traffic

Traffic conditions in the city have become serious because of the increasing numbers of bicycles. The most severe problems occurred at some intersections where more than 20,000 bicycles passed per hour. At some intersections more than 30,000 bicycles passed per hour. Since bicycles are regarded as a type of vehicle, they must take turns with automobiles and follow the same traffic signals at intersections. Left-turning bicycles and automobiles were the foremost cause of traffic problems. Though roads and streets were improved greatly in the 1980s by separating fast from slow traffic modes with fences or green belts, the two would join at intersections. Reasonable bicycle traffic organization is needed to create new routes and to guide bicycle traffic flow on the newly developed routes.

The cyclists often do not like to change their established routes once they have chosen them. Yet, cyclists may not necessarily prefer the direct route if it follows heavy motorized traffic. There might be many controlled intersections and frequent stops, or it may pass through an area considered undesirable from the personal safety standpoint.

Figure 4 shows an example of how to divert the flow of bicycles from Route A to Route B (*4*,p.30). Wujiayao Road is the city's trunk road, with many intersections and signals. It connects several residential areas with business areas. One large intersection is at Qixiangtai Street. In the 1989 survey, the intersection had about 18,500 bicycles passing through between 7:00 and 8:00 a.m. Most of the bicycle commuters going to Quanyechang business area live in the residential areas along Wujiayao Road. Route A was thought to be the

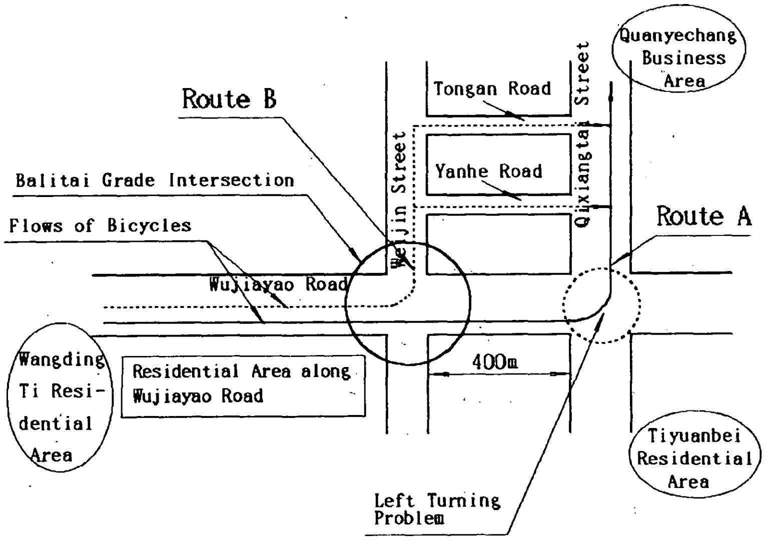

FIGURE 4 Bicycle route arrangement.

simplest route for the cyclists to travel. However, on the Route A turning point of the intersection, bicycles turning together with automobiles caused massive traffic congestion.

To solve this problem, experts suggested, a bypass route had to be developed to move a portion of the bicycle flow in a separate direction. Route B was proposed for cyclists, who could turn left at Balitai Grade Intersection, turn right to Yanhe Road or Tongan Road, and proceed to Qixiangtai Street.

There are dozens of similar examples in Tianjin City. Changes and adjustments of the routes, especially at intersections, should be made to improve traffic flow.

BICYCLE SAFETY

According to the report of the Tianjin police station, there were 4,316 traffic accidents in 1990 in Tianjin City, with 3,098 injuries and 422 fatalities. About 40 percent of the accidents were related to bicycles.

The most severe problems occurred at intersections where more than 20,000 bicycles passed per hour. Regarded as a kind of vehicle, bicycles take turns with automobiles observing the signals at the intersections. Motorcycles and other motorized two-wheelers offer greater speed, mobility, and status than bicycles. Left-turning bicycles and automobiles were the foremost causes of accidents.

The lack of traffic facilities is also an important reason for Tianjin's increase in accident rates. There were only 122 signals in the city's traffic network in 1990. Only a few roads and streets had painted lines for dividing lanes. Even at intersections where traffic signals have been installed, they have to be reinforced by the physical presence of a police officer to be effective.

It is inherently dangerous for nonmotorized vehicles to operate in heavy motorized traffic flows if the motorized traffic is dominant in the street system or there has not been provision for the separation of slow and fast traffic modes.

In Tianjin City, almost no department stores, recreation areas, theaters, or hotels have enough parking places for cars. Most have none at all. Customers and clients were expected to walk or ride bicycles. Later they were expected to travel on public buses. When the social economy developed, the number of automobiles increased rapidly. People began to use automobiles for various activities, which caused more and more road parking problems. Illegal road parking has been causing problems everywhere in urban Tianjin, and its adverse effect is much more serious than in developed countries.

INTEGRATION OF BICYCLES WITH PUBLIC TRANSPORTATION

As more Tianjin residents move from the city center to the outskirts, the average trip length tends to increase. Different transportation modes can be used in one trip by the most convenient way, intermodal coordination—bike-and-ride. Bicycles would be seen as the most important feature in providing access to efficient public transport services. Because of its good accessibility and flexibility, bicycle transport mode can make existing transport systems more efficient. It offers an integration of trips and is an ideal way to travel for long-distance commuters.

To encourage bicycles to access express transit services for longer-distance trips, it is necessary to link them with motorized public transportation. Convenient bicycle parking places are important projects to be subsidized by the government.

As in other cities, as mentioned earlier, the competition for space between automobiles and bicycles has become the main problem. Coexistence between massive bicycle transport and motorized vehicle transport is very important to prevent unexpected conflicts between the two sides when bicycle transport is encouraged and at the same time the motorized public transportation is expanding.

CONCLUSION

The purpose of this paper has been to analyze utilization of NMT, especially bicycles, in Tianjin City, China. Through analysis and discussion, it is concluded that bicycle transport mode is reasonable and acceptable for the development of Tianjin City's traffic systems. The advantages of bicycle transport use in Tianjin City are summarized as follows:

1. Productivity superiority; centralized mass production: The annual output of Tianjin Bicycle Manufacturing Group in 1989 was 6,123,000 units.
2. Market superiority; individual purchasing power: People use bicycles as a kind of convenient, money-saving, and energy-efficient transport vehicle. Bicycles are their most important possession. There is a large potential market for bicycles.
3. Improved road network superiority: Every street is a potential bicycle route, and bicycles are recognized as vehicles. This concept endorses bicycles as part of the legitimate existing transport system.
4. Inferiority of city's public transportation: The service level is very low, and public transportation is more expensive than the bicycle.
5. City land use formation: The average distance of a bicycle trip is less than 6 km. This distance is too long for walking and too short for express public transport services, particularly where travel demand density or economics do not permit high-frequency public transport services. Bicycles are most important for personal transport and also accommodate light goods hauling.

However, the future of bicycle transportation in Tianjin City is threatened by growing motorization, loss of street space for safe bicycle use, and changes in urban form prompted by motorization. The following are barriers to bicycle transportation:

1. Negative attitudes to bicycle transport from society and authorities;
2. Hostile street environments for bicycles as the city develops—poor road conditions in some areas, which have too little room for the bicycle transport mode to be used;

3. Unreasonable and inappropriate regulation of bicycle transportation; and
4. The desire of the city's residents to own automobiles as a status symbol.

For long-distance bicycle trips, the bike-and-ride transport system needs to be gradually adopted to make motorized public transportation supplementary to commutes that are too difficult to bicycle. At the same time, it is important to give priority to the development of NMT such as bicycles. A large-scale motorized public transport system is needed to carry passengers into or out of the city's urban center. Individual traffic can be fed into the perimeter of the urban center area. Bicycle-bus exchange hubs and bicycle parking garages need to be built there. It is important for NMT and motorized transport to work together to promote the growth and development of both of these necessary transportation systems.

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Traffic Segregation on Spatial and Temporal Bases: The Experience of Bicycle Traffic Operations in China

Jun Wang and Heng Wei

For many years, appropriate techniques for establishing suitable traffic regulations under mixed-traffic conditions in Chinese cities have been explored. Generally, it is considered that the segregation of motorized and nonmotorized traffic by temporal and spatial means is a basic principle for managing and operating mixed traffic on most urban streets. Many Chinese cities, especially large cities, have used this principle in their urban traffic operations and management for a long time. A study of the implementation of this principle on the basis of the experiences of several large cities in China is presented. Traffic operation and management under mixed-traffic conditions from the standpoint of roadway planning, traffic engineering, operation, and various treatment measures to separate mixed traffic, particularly at intersections, are discussed. Detailed examples of intersection traffic operation and unique patterns of interchange are presented with regard to the traffic segregation principle. It is indicated that the mixed-traffic congestion or chaos due to massive use of nonmotorized vehicles could be resolved to a great extent by sound engineering and traffic operation solutions.

The bicycle plays a vital role in urban passenger transportation in virtually all of the cities of China. It offers low-cost private transportation, provides a great deal of flexibility and convenience for short trips in most cities, emits no pollution, and uses renewable energy. It has been recognized that bicycle transportation predominates in urban transportation in China and that bicycles will continue as a major type of private vehicle in most Chinese cities for decades. Recent statistics showed that, in major Chinese cities, bicycle ownership has increased more than 10 percent annually, and the ownership rates are one bicycle per household or more (*1*). Between 1980 and 1988, the number of bicycles in Beijing grew more than 12 percent per year to 7.3 million (*2*).

It is obvious that this massive usage of the bicycle as a passenger transportation mode in urban China has adversely affected the entire urban traffic operation. In Beijing, for example, peak-hour bicycle flow exceeded 20,000 at 14 intersections in 1986 at inner-city areas. By 1989 the number of such intersections increased to more than 20 (*3*). Currently, there are three major problems in urban traffic operations in Chinese cities caused by heavy bicycle traffic:

- On narrow roads or roads where saturated bicycle flow exists, bicycles and motor vehicles compete to occupy the limited road spaces.
- In at-grade intersections, the mingling of bicycles and motor vehicles because of a lack of separation measures causes traffic chaos and a great reduction in traffic capacity.
- There are large numbers of alleys intersecting with roads or streets in inner-city areas. Many bicycles often maneuver suddenly and wantonly turn left on the street to enter or exit the alleys. This situation seriously affects the traffic operation of motor vehicles on the street and greatly reduces the speed of the vehicles.

It is well known that the mixed traffic of bicycles and motor vehicles is a major characteristic of urban transportation in China, and it has led to serious traffic congestion and recurrent accidents in many cities. For many years, traffic operation and management in Chinese cities have been devoted to exploring appropriate operation methods and to establishing suitable traffic regulations under the mixed-traffic conditions.

Generally, the segregation of motorized and nonmotorized traffic by temporal and spatial means is a basic principle for managing and operating mixed traffic on most urban streets. Many Chinese cities, especially the large cities, have used this principle in their urban traffic operations and management for a long time. This paper presents the results of a study of the implementation of this principle on the basis of the experiences of several large cities in China. It discusses traffic operation and management under mixed-traffic conditions from the standpoint of roadway planning, traffic operation, and various treatment measures to separate mixed traffic, particularly at intersections. The paper explains traffic segregation by means of various engineering and management treatments for different categories of traffic (vehicle types, speeds, etc.) and turning movements of the traffic. These treatment measures outline the basic methods of traffic segregation either by spatial separation at the same time or by temporal separation in the same space.

ALLOCATION OF BICYCLE ROADS

There are two major categories of bicycle roads in Chinese cities. One is the separated bicycle road, in which the bicycle traffic is divided from motorized vehicular traffic by an open space, barrier, or even pavement markings, either within the roadway right-of-way (the most common type in China) or within an independent right-of-way. The other is the mixed bicycle road, in which bicycles share the roadway with mo-

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torized vehicular traffic or pedestrian traffic without any physical or nonphysical separations. The separated bicycle road can be further classified according to the extent of the separation between motor traffic and bicycle traffic:

- Exclusive bike paths, mostly positioned on one or both sides of motor vehicle–traveled ways with designed outer separations (these are called "three-slab roads" by Chinese, a vivid description of this type of roadway);
- Independent bike lanes, positioned on one or both sides of motor vehicle lanes with barrier separations; and
- Nonindependent bike lanes, positioned on one or both sides of motor vehicle lanes without physical separation but separated by pavement markings.

The mixed bicycle roads can be further classified according to their mixture compositions. One type is bicycle-pedestrian mixed paths, and the other is bicycle-motor mixed roads.

In a few Chinese cities, so-called special bicycle roads, which are independent of the vehicular road network and dedicated to bicycle use only, are being developed. In some cities, the extensive alley systems provide opportunities for creating bicycle networks while improving traffic operations, as shown in a World Bank project in Shanghai.

The concept of network functional classification used in classifying highways is also applied to planning and designing cycle networks in most Chinese cities. There are two classes of bicycle roads. The first is the city-level bicycle road, which carries citywide or interdistrict bicycle traffic and provides for faster speeds, less interference, and higher capacity. The second is the district-level bicycle road, which mainly serves as a secondary or collector road, functions as a major road for intradistrict and some interdistrict bicycle traffic. Table 1 gives the general relationship between the classifications and the facility types.

According to the concept of traffic segregation, the Chinese experts developed a special evaluation index, separation ratio (SR), for evaluating and determining the levels of service (LOSs) of the bicycle roadway system (*4*). The separation ratio is defined as

$$\mathrm{SR} = L_s/R \qquad \text{(percent)}$$

where L_s is the length of primary and secondary roads that provide a physical separation between motorized and nonmotorized traffic within a certain area and R is the total length of primary and secondary roads in the area. Table 2 indicates the classifications of the SR.

BICYCLE TRAFFIC OPERATIONS AT INTERSECTIONS

Bicycle traffic operations at Chinese urban intersections are discussed under the typical four-leg crossing intersection conditions. In industrial countries, traffic conflicts between motor vehicles at intersections are the main consideration in traffic analyses and operations. However, the big difference between traffic characteristics in Chinese cities and those of motorized cities is the large amount of bicycle and pedestrian traffic. All traffic conflicts can be classified on the basis of safety concerns as follows (*5*):

- Type A includes crossing conflicts between motor vehicles, motor vehicle and bicycle, and motor vehicle and pedestrian.
- Type B includes merging and diverging conflicts between motor vehicles.
- Type C includes all conflicts between bicycles and between bicycle and pedestrian.

The relationship among these three types of traffic conflicts on the basis of accident severity can be indicated as

$$A > B > C$$

Figure 1 shows all traffic conflict points at a typical signalized crossing at-grade intersection. The related data are given in Table 3.

The bicycle is a flexible but slow and unstable transportation mode. In movement, particularly at intersections, the bicycle is unlike the motor vehicle, which appears in a linear queue and keeps a constant lateral distance, whereas the bicycle shows a "group" movement in which a number of bicycles move close together in a cluster pattern. This unique travel pattern brings traffic conflicts everywhere within the moving area. It virtually increases conflict points to a conflict area at the intersection (Figure 1).

In fact, the bicycle starts moving faster than the motor vehicle. A study done by Chinese experts indicates that a

TABLE 1 Classifications and Facility Types of Bicycle Roads[a]

Classifications		Facility Types			
		Separated Roads			Mixed Roads
		Exclusive	Independent	Non-Independent	
City Level	Large, Medium City	O[b]	O	x[d]	x
District	Large, Medium City	O	O	x	x
Level	Small City	O	O	Δ[c]	Δ

[a] Q.S. Xiao and W.Z. Xu, *Urban Transportation Planning* (in Chinese). People's Transportation Press, Beijing, China, 1990.

[b] O indicates the facility should be built.

[c] Δ indicates the facility may be built depending on the situation.

[d] x indicates unsuitable for building the facility.

TABLE 2 Separation Ratios for Evaluating LOS of Bicycle Roadway Systems (*4*)

Levels	A	B	C	D
SR	> 80	70 - 79	50 - 69	< 50

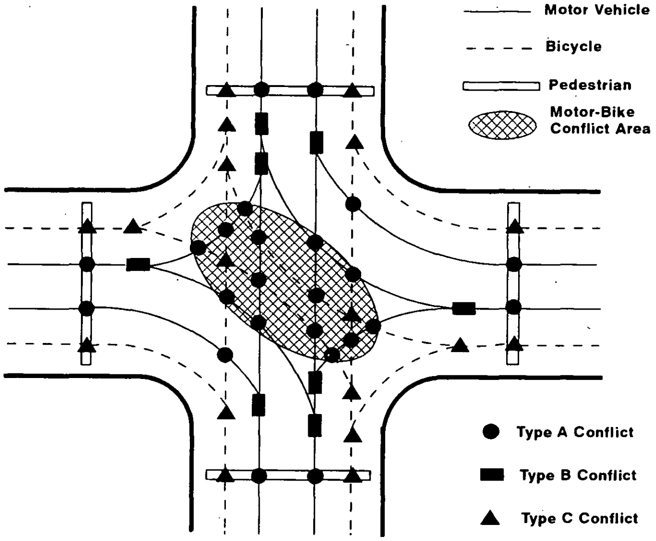

FIGURE 1 Intersection conflicts.

bicycle starts to move more than 1 sec faster than a motor vehicle; however, the motor vehicle has a greater speed afterwards (*6*). Therefore, bicycles start moving promptly when a green signal turns on; when left-turning bicycles reach the middle of the intersection, they encounter through vehicular flow from both the same and opposing directions, which significantly interferes with their movements.

In general, the presence of bicycle traffic at intersections dramatically increases the number of conflict points and the breadth of the conflicting areas at the intersection. Consequently, the pivotal concept is to separate vehicular and bicycle traffic on either a spatial or a temporal basis to reduce the chance of traffic conflicts. On the basis of this concept and the unique characteristic of mixed traffic, several measures have been adopted by Chinese engineers and administrators to alleviate traffic congestion at urban intersections. These measures can be generally categorized as (*a*) pavement marking channelization, (*b*) engineering treatment, and (*c*) regulatory management.

Pavement Marking Channelization

Bicycle Banned Area

As Figure 1 indicates, bicycles appear in a "cluster" move pattern producing a conflict area at the center of the intersection. On the basis of this feature, a square or rectangular space marked at the center of the intersection is enforced as a bicycle banned area (Figure 2). All bicycles are required to travel outside the banned area while motor vehicles maintain their original route. If the gap of through vehicles does not allow left-turning bicycles to pass through the vehicle stream, the bicycles need to wait outside the banned area at Location A until an appropriate gap acceptance exists. As a safety measure, a bike protection pathway may be created at the periphery of the banned area (Figure 2), and cyclists will be given priority if they follow the prescribed pathway.

This method has been implemented in Beijing with very positive results. To evaluate the effectiveness of the method, a before-after study was conducted by the Institute of Beijing Traffic Engineering in 1989 (*3*). It was found that after the bicycle banned area was implemented, the percentage reduction of average travel time at the intersection was 0.1 percent per vehicle for through motor vehicles, 8.3 percent per vehicle for left-turning vehicles, and 15.5 percent per bicycle for left-

TABLE 3 Number of Conflicts for Different Types of Intersection/Interchange[a]

Type of Intersection/ Interchange	Number of Conflicts							Peak Hour Traffic[e]
	Type A				Type B	Type C		
	M-M[b]	M-B[c]	M-P[d]	SUM	B	C	Total	
Signal Intersection	2	14	8	24	8	18	50	4202
2-Level Roundabout	4	8	8	20	12	28	60	3885
3-Level Roundabout	0	0	8	8	12	20	40	6201
2-Level Cloverleaf	0	16	8	24	16	20	60	6253
3-Level Cloverleaf	0	0	8	8	16	20	44	7030

[a] Reference 5.
[b] M-M represents conflicts between motor vehicles.
[c] M-B represents conflicts between motor vehicle and bicycle.
[d] M-P represents conflicts between motor vehicle and pedestrian.
[e] Peak hour traffic represents monitoring result on September 9, 1987.

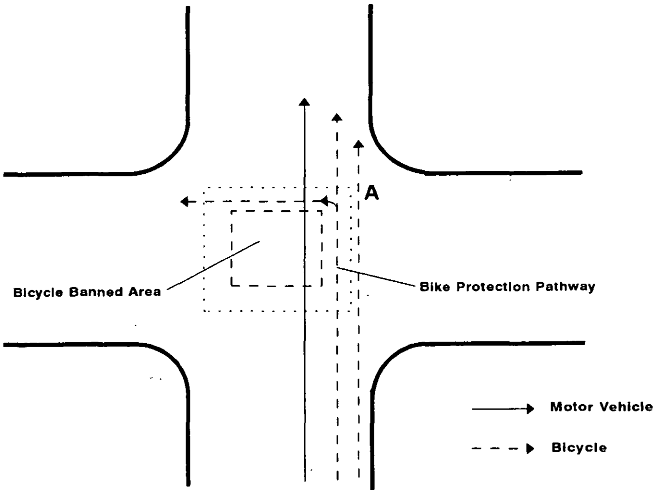

FIGURE 2 Bicycle banned area.

turning bikes. The traffic capacity at the intersection increased about 16.1 percent (passenger car equivalent). The study result also indicated the following:

- The establishment of a bicycle banned area channelizes bicycle traffic at the intersection.
- The bicycle banned area method is more suitable for large intersections.
- Cyclists are willing to accept the bike protection pathway because of the legal endorsement of the priority of bicycles on the pathway.
- The bike protection pathway appears to be more effective at three-slab T-intersections (Figure 3).

The study also found that the major problem in implementing the method is violation of traffic rules by cyclists, so the effectiveness of the measure has not been fully demonstrated.

Second Stop Line at the Intersection

As mentioned earlier, although the bicycle starts moving faster than the motor vehicle, its speed is much lower than that of the motor vehicle afterwards. At wide intersections, when left-turning bicycles move to the place where they start to turn left, the through vehicular flow from the same direction also arrives at the same place and, thus, blocks the left-turning bicycles. Therefore, two stops exist when left-turning bicycles traverse an intersection. The first is at the stop line during a red signal period, and the second occurs while waiting for an acceptable gap in the through vehicular flow during a green signal period. On the basis of this trait, a left-turning bicycle waiting line, the second stop line, can be established to maintain priority for the vehicular traffic in the conflict area, reducing motorized vehicle-bike conflicts and restricting arbitrary movements by cyclists (Figure 4) (7).

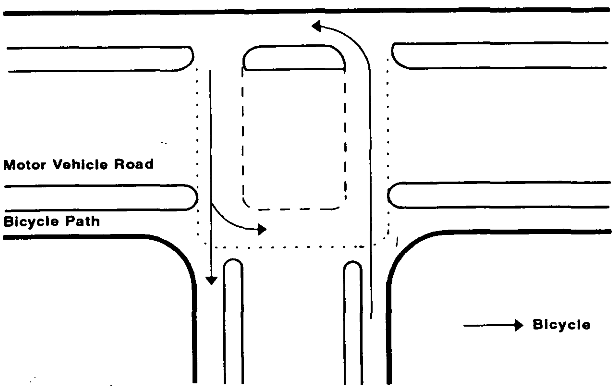

FIGURE 3 Bicycle banned area at T-intersection.

Special Waiting Area for Left-Turning Bicycles

At some narrow intersections, because of the bicycle trait of prompt starting speed, a special bike waiting area can be created beyond the approach stop line at the intersection (Figure 5). Bicycles, especially left-turning bicycles, wait in this area during a red signal period. Once a green signal turns on, the bicycles waiting in the area can quickly pass the intersection while the motor vehicles are just starting to move. In this way, bicycles and motor vehicles can be separated on a temporal basis, which will avoid conflicts between them. If the pedestrian crosswalk is not close to the intersection, the bicycle stop line (or the bicycle waiting area) can be positioned close to the center of the intersection (Figure 5, east approach). Therefore, the prompt start trait of bicycles can be used to make left-turning bicycles quickly pass the intersection and avoid conflict with through motor vehicles.

Engineering Treatment

At some intersections, a common engineering measure can be used to expand the width of intersection approaches. In many cases, separate left-turn, through, and right-turn bike lanes can be created. If necessary, a physical barrier can also

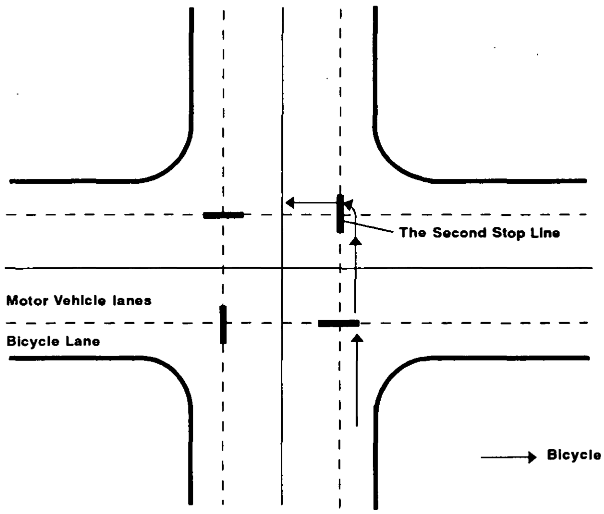

FIGURE 4 Second bicycle stop lines.

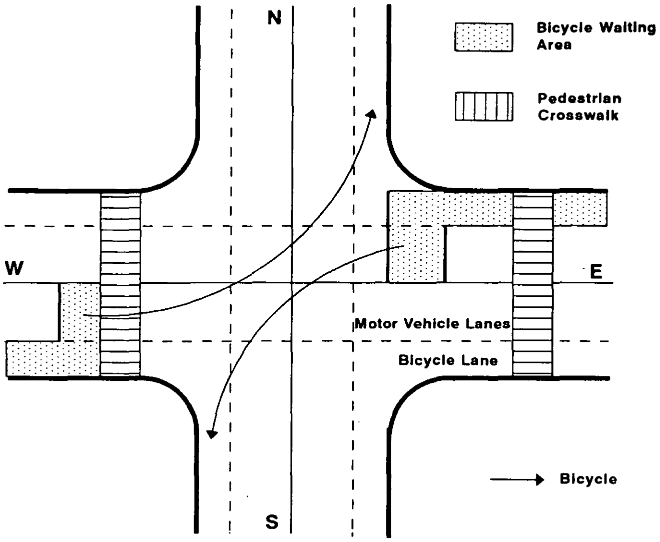

FIGURE 5 Special waiting area for left-turning bicycles.

be built to separate right-turning bicycles to prevent right-turn jam. It is believed that this treatment can effectively eliminate conflicts among bike turning movements at an intersection and increase the capacity of the intersection to deal with mixed traffic.

Regulatory Management

One-Way Bicycle Roads

As a part of roadway network planning, a one-way bicycle network can be established on the basis of existing traffic conditions and future traffic demand analyses. At the same time, the public transit routes and stops in the network area may need to be adjusted to best coordinate the one-way bike traffic. A study concluded that, for a particular route, if the bicycles whose O-D points are not located on the linking roads of the route exceed 70 percent and the distance of this route to a parallel route that is able to facilitate bicycle traffic is less than 200 to 300 m, the route can be considered for implementation of one-way bicycle traffic (*8*).

Left-Turn Prohibitions

At intersections where serious congestion exists, prohibiting bicycle left turns is a means of reducing bike-motor conflicts and relieving such congestion. Because the bicycle is propelled by human power, it is not appropriate to force cyclists to make a long detour. In many cases, the alleys near the intersection can be used to make left-turning bikes change to a right-turn travel path (Figure 6). This measure has been tried in Beijing but proved to be unpopular with cyclists.

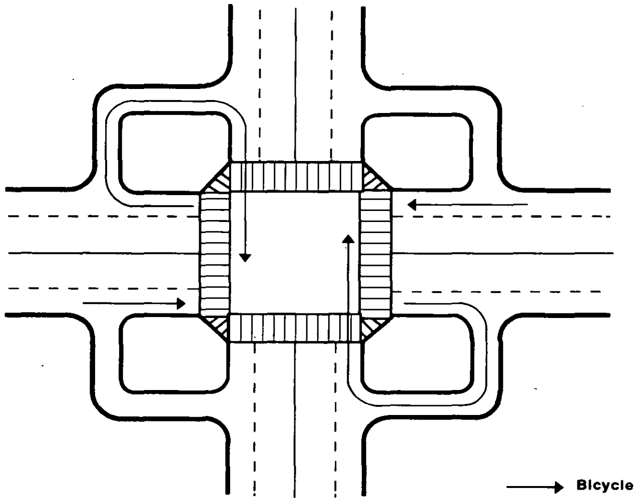

FIGURE 6 Intersection for prohibiting bicycle left turns.

Changeable Traffic Lanes

In most Chinese cities, urban arterial routes can experience much greater peak-hour bicycle traffic than motor vehicle traffic. In contrast, the off-peak motor traffic is greater than bicycle traffic. With the changeable lane system, one or more lanes are designated for moving bicycles during peak periods and motor vehicles during off-peak periods. The same concept could be applied to bicycle left-turn bans at intersections. It is not necessary to prohibit bicycle left turns at all times to alleviate congestion or accident problems resulting from conflicts produced by turning bicycles. Left-turning movements should be prohibited only during periods when the study data indicate that a congestion or accident problem exists and when a suitable alternative route is available. When part-time changeable lanes or turning restrictions are used, the signs used to notify cyclists and motorists of the action must be carefully designed and placed so that the time of the action is clearly visible.

BICYCLE TRAFFIC OPERATIONS AT INTERCHANGES

The greatest efficiency, safety, and capacity of crossing intersection traffic are attained when intersecting through traffic flows are grade separated by using interchanges. Two types of nonmotor vehicle pathway treatments at interchanges have been built in Chinese cities. One is the mixed-traffic interchange, in which nonmotor and motor traffic flows are at same levels. This type retains conflicts between turning motor vehicles and through and left-turning bicycles. The other type is the divided-traffic interchange, in which nonmotor traffic flows are separated into an independent level of the interchange. Generally, the mixed-traffic interchange is designed with two levels, and the divided-traffic interchange is designed with three levels. Therefore, the latter type of interchange involves more construction work and financial investment than the former. Statistics gathered from interchange constructions in the Beijing area indicate that the cost of a divided-traffic interchange is 30 percent more than that of a mixed-traffic interchange. However, traffic conditions of the divided-traffic interchange are much better than those of the mixed-traffic interchange because the divided-traffic interchange eliminates interference between motorized and nonmotorized traffic. Therefore, the choice between these two types of interchanges must be based on overall cost-effectiveness and long-term development analysis and evaluation.

Two popular patterns of divided-traffic interchanges have been built in Chinese cities, especially in the Beijing metropolitan area: the cloverleaf pattern and the roundabout pattern. Figures 7 and 8 show these two types and indicate their conflict points.

Data concerning the types of conflicts for signalized intersections, cloverleaf interchanges, and roundabout interchanges have been collected and synthesized in Table 3. As indicated, the three-level divided-traffic interchange has the best traffic conditions in terms of traffic separation, because it eliminates crossing conflicts between motor and nonmotor vehicles and only retains merging and diverging conflicts, which have a much lower accident severity. On the basis of many years of experience with interchange operation in the Beijing area, the roundabout interchange produces lower capacity and poorer safety than does the cloverleaf interchange.

In general, divided-traffic interchanges provide the most effective way to separate motorized and nonmotorized traffic regardless of cost. This type of interchange is the most efficient method of applying the concept of spatial separation of traffic and represents a unique contribution for interchange design by Chinese engineers.

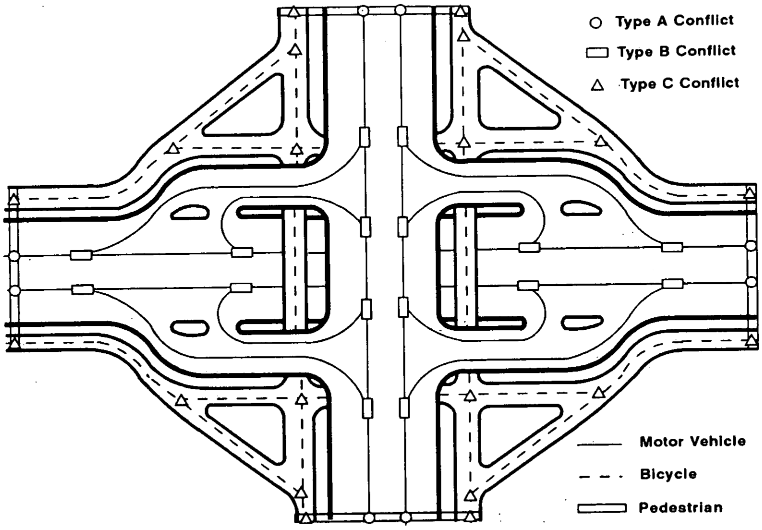

FIGURE 7 Cloverleaf interchange.

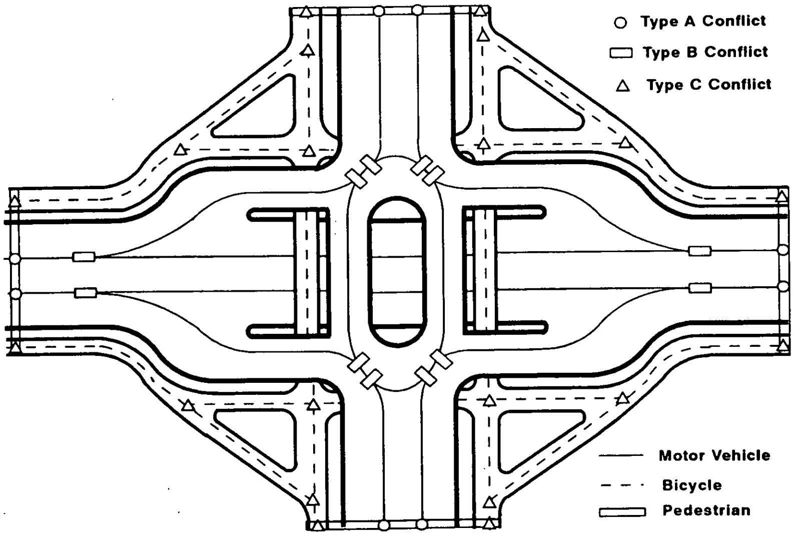

FIGURE 8 Roundabout interchange.

SUMMARY

The guiding principle of mixed-traffic operations is the segregation of motorized and nonmotorized traffic. For bicycle road allocation, an independent bicycle road network provides the most efficient and safe bicycle traffic environment. Traffic operation in at-grade intersections should use the temporal separation principle to reduce conflicts between the two types of vehicles to a minimum. The spatial separation principle can be successfully used in divided-traffic interchanges where motorized and nonmotorized traffic are separated into different physical levels, which eliminates the conflicts between through and left-turning traffic for both types of vehicles.

It is believed that more and more interchanges of all types will be built in many Chinese cities. There are a large number of intersections with congested mixed traffic that need to be improved. However, the current state of research for urban transport under mixed-traffic conditions is far behind the need. Therefore, it is necessary to stimulate more studies of the mixed-traffic transportation system. These studies should focus not only on policy and planning issues but also on detailed engineering and operation solutions.

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Operational Analysis of Bicycle Interchanges in Beijing, China

XIAOMING LIU, L. DAVID SHEN, AND FUTIAN REN

Beijing, a city with more than 10 million residents and nearly 8.4 million registered bicycles, has the highest bicycle ownership in China. In addition, Beijing has more than half a million motor vehicles, and that number is increasing at a rapid rate. To cope with this nonmotorized and motorized traffic, more than 50 interchanges with special facilities to accommodate bicycle traffic were built in Beijing during the last decade—more than half of all the interchanges in China are in Beijing. The operational experience of these bicycle interchanges is presented. The study indicates that a three-level cloverleaf interchange design with an exclusive bicycle facility can accommodate more than 28,000 bicycles per hour. A less sophisticated two-level rotary interchange can accommodate up to 21,500 bicycles per hour. Different adjustment factors were developed after an extensive study of existing bicycle operations in Beijing and other major Chinese cities. It is believed that the operational experience of these high-volume interchanges for nonmotorized transport will be useful to transportation engineers in other countries who are contemplating similar plans.

An interchange is a system of interconnecting roadways in conjunction with one or more grade separations that provides for the movement of traffic between two or more roadways or highways on different levels (*1*). In the United States, most if not all interchanges are designed to accommodate motorized vehicles such as cars or trucks. However, in China, where automobile ownership is not as high and bicycles are relied on heavily for passenger transportation, bicycle traffic is an important consideration in interchange design.

During the last decade, as a result of the economic reform policy in China, the Chinese economy grew rapidly at a two-digit annual rate—nearly twice the international average. The economic boom in China brought more disposable income to its people, and the standard of living increased significantly. In the United States, people buy more and better cars when they have more disposable income; in China, people buy more and better bicycles. For instance, Beijing, the capital, has more than 10 million residents, and nearly 8.4 million bicycles were registered in 1990. Across the urban areas in China, bicycle ownership increased from one bicycle for every three persons in 1982 to one bicycle for every two persons in 1990.

With the bicycle dominating as the single most important mode of transportation for most Chinese urban residents, the ability to accommodate high volumes of bicycle traffic safely and efficiently through intersections becomes a difficult task for Chinese traffic engineers. The greatest efficiency, safety, and capacity are attained when the intersecting through-traffic lanes are separated in grades. The creation of bicycle interchanges has become a reality during the last decade. Bicycle interchange, a unique Chinese traffic engineering design, is defined in this paper as an interchange designed with a special facility to accommodate heavy bicycle traffic. The purpose of this paper is to present this unique bicycle interchange operation in Beijing, China.

SYSTEMS

More than 60 percent of the residents of Beijing live in urban areas. The population density in the Beijing urban area is about 4,600 people per square kilometer, or 11,800 people per square mile. In addition to the 8.4 million bicycles, more than half a million motor vehicles were also registered in Beijing, as indicated in Table 1. The trend of bicycle ownership in Beijing is shown in Table 2 (*2*). In Beijing, the economic boom in the 1980s nearly tripled the number of registered bicycles in the city, from 2.88 million in 1980 to 8.3 million in 1990. On the basis of a study done in 1986, bicycles accounted for more than half of the passenger trips in Beijing (see Table 3).

To accommodate daily trips generated by nearly 9 million cars and bicycles, there were 51 interchanges in Beijing as of the end of 1991—approximately half of all the interchanges in China. Most of these interchanges are either cloverleaf, rotary, or trumpet-type. A two-level rotary interchange with separated bicycle lane design is shown in Figure 1. The dashed line indicates bicycle traffic, and the solid line represents motorized vehicular flow. A two-level cloverleaf interchange with separated bicycle lane design is shown in Figure 2. In these types of two-level interchange designs, the predominant flow of bicycle traffic is kept at ground level so climbing maneuvers can be eliminated completely. The design for underpasses is such that the minor bicycle flow can negotiate the smooth vertical grades without too much difficulty. *A Policy on Urban Street Design* specifies that the maximum vertical grade design for interchanges with mixed motorized and nonmotorized vehicles should not be more than 2.5 percent.

A three-level rotary interchange with separated bicycle lane design is shown in Figure 3. A three-level cloverleaf interchange with separated bicycle lane design is shown in Figure 4. As in the two-level interchange designs mentioned previously, the predominant flow of bicycle traffic is kept at ground level so climbing maneuvers can be eliminated completely. The design for underpasses is such that the minor bicycle flow can negotiate the smooth vertical grades without too much

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TABLE 1 Traffic-Related Statistics for Beijing

	TOTAL	Urban	Suburban
Population (Millions)	10.012	6.142	3.570
Area (sq. km)	16,808	1,333	15,475
Roadway Mileage (km)	11,787	3,400	8,387
Vehicle ownership	500,000 (include 140,000 motorcycles)		

difficulty. In the three-level cloverleaf interchange, the middle level is reserved exclusively for bicycles. Some directional interchanges also have an exclusive level for bicycles. Except for these two, all interchanges have potential turning conflict points between motorized and nonmotorized vehicles.

OPERATIONS

A traffic study of 178 intersections/interchanges in Beijing was conducted in 1986 to collect the relevant bicycle volume data. The study indicated that there were 14 interchanges with peak-hour volume of 20,000 bicycles or more and 42 interchanges/intersections with peak-hour volume between 15,000 and 20,000 bicycles per hour. In addition, 50 intersections were found to have peak-hour volume of 10,000 bicycles or more.

Capacity at Two-Level Cloverleaf Interchange

The equation for calculating nonmotorized vehicle capacity at a two-level cloverleaf interchange design is as follows:

$$N = \sum_{i=1}^{4} N_{iR} + K\sum_{i=1}^{4} (N_{iL} + N_{iT})$$

where

N = number of nonmotorized vehicles per hour;
i = number of approaches, typically four;
N_{iR} = ith approach nonmotorized vehicular right-turn capacity;
K = revision factor depending on motorized vehicular volume (the higher the motorized vehicular volume, the smaller the K value, and vice versa);
N_{iL} = ith approach nonmotorized vehicular left-turn capacity; and
N_{iT} = ith approach nonmotorized vehicular through capacity.

Capacity at Three-Level Cloverleaf Interchange

The equation for calculating nonmotorized vehicle capacity at a three-level cloverleaf interchange design is as follows:

$$N = \sum_{i=1}^{4} n_i * 2{,}000$$

where n_i is the number of bicycle lanes at midlevel (or exclusive bicycle level) for the ith approach and other terms are as defined previously.

Capacity at Two-Level Rotary Interchange

The equation for calculating nonmotorized vehicle capacity at a two-level rotary interchange design is as follows:

$$N = \sum_{i=1}^{4} \mathrm{N}_{iR} + K_1\sum_{j=1}^{2} \mathrm{N}_{jT} + \mathrm{N}_{R1}$$

where

K_1 = revision factor for thoroughfare (underpass street) motorized traffic, depending on the right-turn motorized and nonmotorized vehicular volume (the higher the right-turn traffic volume, the smaller the K value, and vice versa);
N_{jT} = jth approach (underpass thoroughfare) nonmotorized vehicular through capacity; and
N_{R1} = ground-level (rotary) nonmotorized vehicle capacity.

Other terms are as defined previously.

Capacity at Three-Level Rotary Interchange

The equation for calculating nonmotorized vehicle capacity at a three-level rotary interchange design is as follows:

$$N = \sum_{i=1}^{4} N_{iR} + K_1\sum_{j=1}^{2} N_{jT} + N_{R2}$$

where N_{R2} is the midlevel (exclusive level) nonmotorized vehicular capacity (typically, $N_{R2} > N_{R1}$) and other terms are as defined previously.

Observed bicycle volumes at 10 major interchanges in Beijing during the morning peak hour (7:00 to 8:00 a.m.) are given in Table 4. Jiankuomen Interchange is a three-level cloverleaf interchange design. Bicycle capacities for the three different types of interchange are given in Table 5.

TABLE 2 Trend of Bicycle Ownership in Beijing

Trend of Bicycles						
Year	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**
Bikes (Millions)	2.88	3.21	3.77	4.29	4.88	5.51
Year	**1986**	**1987**	**1988**	**1989**	**1990**	
Bikes (Millions)	6.21	6.41	7.32	7.89	8.38	

TABLE 3 Modal Splits for Beijing (1986)

Mass Transit	24.32%
Bicycles	54.03%
Walk	13.76%
Private car	4.35%
Rental car	0.30%
Other	3.25%

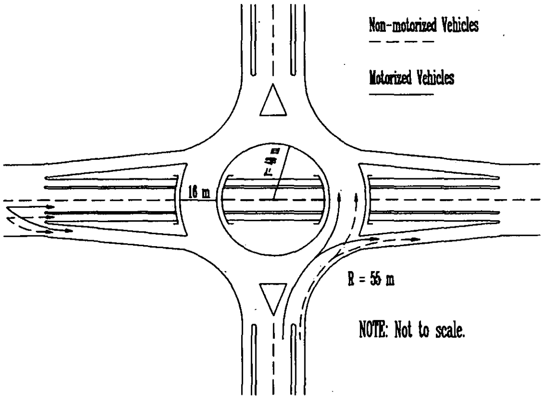

FIGURE 1 Two-level rotary interchange design.

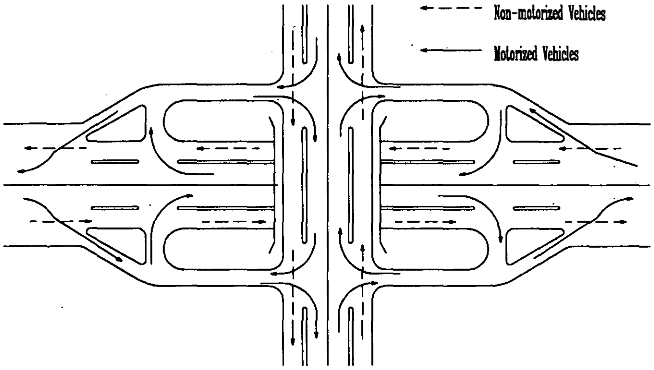

FIGURE 2 Two-level cloverleaf interchange design.

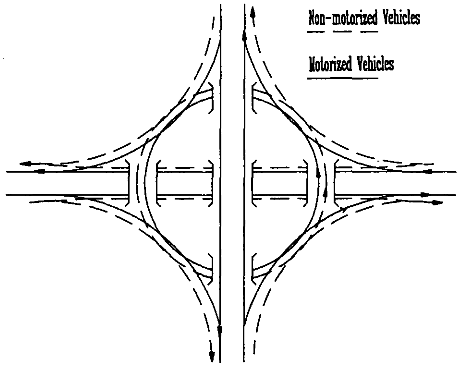

FIGURE 3 Three-level rotary interchange design.

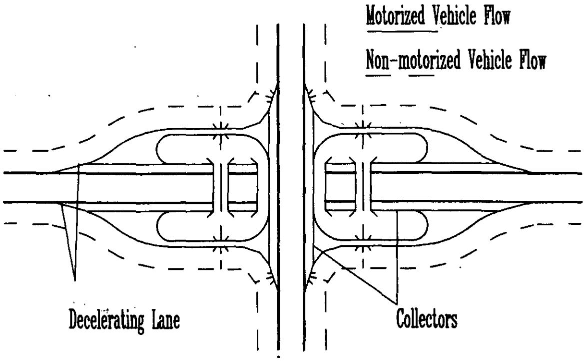

FIGURE 4 Three-level cloverleaf interchange design.

TABLE 4 Observed Bicycle Volumes During Morning Peak Hour (7:00 to 8:00 a.m.) at Major Interchanges in Beijing

Interchange	Volume (veh/peak hour)	Interchange	Volume (veh/peak hour)
Jiankuomen	28,391	Poochanmen	23,040
Chouyangmen	19,037	Tabeiyao	14,603
Tungchimen	22,724	Sanyuan	14,574
Andinmen	16,560	Anchen	11,728
Hsichimen	20,355	Marding	10,398

TABLE 5 Theoretical Bicycle Capacity at Three Interchanges in Beijing

Location of Interchange	Type of Interchange	Bicycle Capacity (vehicles/hour)
Fusingmen	2-level Cloverleaf	28,000
Jiankuomen	3-level Cloverleaf	28,300
Chouyangmen	2-level Rotary	21,500

Capacity Between Intersections

The observed vehicle headway for bicycle traffic at intersections/interchanges typically varies from 1.2 to 2.37 sec (i.e., the observed capacity per bicycle lane varies from 1,500 to 3,000 bicycles per hour). The average headway is about 1.8 sec (i.e., the average bicycle lane capacity is about 2,000 vehicles per hour per lane). On the basis of more than 130,000 observations in China, the headways in several major Chinese cities are given in Table 6. From the observed values in Table 6, bicycle lane capacity was converted to number of bicycles per hour per meter of roadway. Typical bicycle lane capacity in China is as follows: without raised island separating motorized and nonmotorized vehicles, $N = 0.51 * 3{,}600 = 1{,}836$ vehicles per hour per meter; with raised island separating motorized and nonmotorized vehicles, $N = 0.58 * 3{,}600 = 2{,}088$ vehicles per hour per meter.

If the delay at the signalized intersection is to be considered, the intersection adjustment factor based on the field obser-

TABLE 6 Observed Bicycle Volumes at Selected Major Chinese Cities

City	With R.I.	Width of Bike Lane (meters)	Observe Data	Speed km/hour	Volume/ 5 sec.	Volume/ sec./meter
Beijing	No	3.9	12,433	14.23	9.85	0.51
Beijing	Yes	5.5	8,678	16.28	17.91	0.61
Nanjing	Yes	3.3	1,551	14.28	9.39	0.57
Fuchou	Yes	6.5	3,096	13.44	14.5	0.45
Wusi	Yes	3.2	2,976	12.05	10.52	0.66
MEAN	**No**		**12,433**	**14.23**		**0.51**
MEAN	**Yes**		**16,300**	**14.01**		**0.58**

Notes: With R.I. = With Raised Island for separation of motorized and non-motorized traffic.
Speed km/hour = Observed bicycle speed in kilometers per hour.
Volume/5 sec. = Observed bicycle volume in five seconds.
Volume/sec./meter = Observed bicycle volume per second per meter of bicycle lane.

vations is 0.55 (i.e., the capacity has to be adjusted by multiplying by this factor). In addition, if the roadway characteristics are to be considered, the following roadway adjustment factors should be used: for major arterial streets, 0.8; for minor arterials and collectors, 0.9.

The effective bicycle lane capacity between signalized intersections can be calculated as follows:

	Capacity (vehicles per hour per meter)
Without raised island	
Major arterial streets	800
Minor arterials and collectors	900
With raised island	
Major arterial streets	900
Minor arterials and collectors	1,000

However, if interchanges are used, these capacities can easily be doubled. Therefore, along major streets where the intersecting traffic is heavy, the building of appropriate interchanges becomes cost-effective because the road-user costs due to delays at congested at-grade intersections are substantial. Travel time and accidents can be significantly reduced by the building of interchanges in urban areas. In general, interchanges require somewhat more total travel distance than direct crossings at grade. However, the added cost of the extra travel distance is less than the saving in cost brought about by the reduction in stopping and accident costs. In an effort to reduce delays at signalized intersections and improve traffic safety, nearly 50 interchanges in Beijing were built during the last decade. This significant investment has greatly improved traffic flow within the city.

SUMMARY

The bicycle plays a key role in Beijing since it accounts for more than 54 percent of passenger trips. Because of Beijing's ideal geographic and weather conditions, it is the transportation mode of choice for most Beijing residents. As the city with the highest bicycle ownership in China, the building of nearly 50 interchanges in Beijing during the last decade greatly improved the way traffic flows in Beijing. The three-level cloverleaf interchange with its exclusive bicycle level design has been a great success for bicyclists in Beijing. It is hoped that this unique Chinese experiment can benefit transportation engineers in other countries who are contemplating similar plans.

ACKNOWLEDGMENTS

The assistance of Jer-Wei Wu and Christopher Moore is acknowledged and appreciated.

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Characteristics of Bicycle Users in Shanghai, China

YORDPHOL TANABORIBOON AND GUAN YING

The characteristics of bicycle users in Shanghai, China, were examined through questionnaire surveys. A total of 2,613 completed questionnaire forms were returned from 72 survey locations. The results indicated that bicycles in Shanghai are used by commuters irrespective of sex or age. The majority of Shanghainese rode their bicycles at least 6 days per week as a form of private transport for various purposes, but mainly for work. Despite some dangers, the majority of users still used their bikes because of the convenience and reliability of this transport mode. Moreover, they indicated that they are not willing to shift to the bus system unless bus services are improved.

Although the expansion in urban transport demands mainly focused on the increase of automobiles in many industrialized countries, this phenomenon is not evident in many urban cities in China due to the high costs and restrictive national policies on the usage of such vehicles (*1*). As a result, the bicycle has become a predominant mode of transport in many cities in China, including Shanghai. According to a study of the distribution of trip purposes in Shanghai (*2*), among the various modes used for home-based work trips, bicycles dominated the total trips made (41.4 percent), compared with walking (28.2 percent), transit (27.6 percent), and others (2.8 percent). Furthermore, with the rapid increase of bicycle ownership in Shanghai from 1.77 million in 1980 to 6.55 million in 1989, it is necessary to study the characteristics of bicycle users. This paper presents research conducted at the Asian Institute of Technology on the characteristics of bicycle users in Shanghai.

DATA COLLECTION

Questionnaire surveys were conducted to collect data. A total of 3,100 questionnaires were distributed randomly to bicycle users at 72 survey locations. Only 2,613 questionnaire forms were returned and used for the analyses. Included in the survey sites were various public parking places throughout the city. Several government as well as private offices were also included as survey sites. Details of various survey locations along with questionnaire response rates are summarized in Table 1. Information on bicycle ownership, trip frequency, trip purpose, average travel time, opinion of safety, age, sex, educational background, income level, and employment status was included.

BICYCLE USER CHARACTERISTICS

Though in Shanghai the number of males and females is nearly even, with the males slightly more numerous (50.6 percent versus 49.4 percent) (*3*), results of the surveys indicated more male than female users (60 and 40 percent, respectively). Regulations of the Chinese government forbid children younger than 12 years old from riding bicycles along the streets. Bicycling appeared to be intense among the age groups 21 to 35 and 36 to 45, which represented 37.3 and 36.8 percent of the total respondents, respectively. These dominant groups are typical of motorized transport users in other developing countries and Taiwan. Studies conducted at the Asian Institute of Technology on public transportation users in Bangkok, Karachi, and Taipei (*4–6*) all indicate that the dominant user age groups are between 20 and 40.

Further analysis of the age and sex of bicycle users indicates that female cyclists shy away from riding bicycles as they become older, compared with males (see Table 2).

Of all the bicycle users surveyed, 71.3 percent responded that their average earned income was rather low, ranging from 100 to 300 Yuan (U.S. $22 to $66). However, these respondents' incomes compare well with the average earned income of the Shanghainese. According to statistics published by the Shanghai Municipal Bureau (*3*), in 1988 the average annual earned income in Shaghai was 2,258 Yuan, or roughly 188 Yuan per month. Despite the low earned income, the number of bicycle owners is still relatively high. Whereas the average price of bicycles sold in China was between 200 and 400 Yuan (*7*), the 1990 annual growth rate of bicycle ownership in Shanghai was 14 percent (*8*). Furthermore, the questionnaire surveys indicate that nearly two-thirds of the households surveyed have at least two bicycles per family. These results support other studies indicating that Shanghai is a highly nonmotorized city, one of the dominant modes of transport being the bicycle.

In addition to the restrictive policy on car ownership, the low average earned income of Shanghainese is a deterrent to obtaining private cars. In China, car prices range between 80,000 and 200,000 Yuan (*7*), much more than average annual income. In fact, in Shanghai there were only 8,400 cars in 1985, and they were primarily used by high-ranking government and party officials (*1*). It is clear that bicycles will remain one of the dominant modes of transport in Shanghai.

Table 3 indicates that bicycle users are relatively well educated. Nearly one-third of the respondents have completed university education. However, for certain groups of users, income does not completely depend on educational background. Some well-educated users who obtained higher than

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TABLE 1 Survey Sites

Location of Survey		No.	No. of Distributed Forms	No. of Return	Rate of Return
Factory		21	700	620	88.6%
Government Office		25	930	769	82.7%
Company		10	300	263	87.7%
Department of Education	University	4	104	96	92.3%
	School	5	126	114	90.5%
Hotel		1	60	59	98.3%
Bank		1	50	41	82.0%
Hospital		1	30	19	63.3%
Bicycle Parking Places		4	800	632	79.0%
Total		72	3100	2613	(84.3%)

TABLE 2 Age and Sex Distribution

Sex	Age Group (Years)								Total
	12-15	16-20	21-25	26-35	36-45	46-55	56-65	>65	
M	17 68%	59 59%	132 53.2%	403 55.5%	561 58.4%	215 63.4%	166 86.9%	16 69.6%	1569 (60.0%)
F	8 32%	41 41%	116 46.8%	323 44.5%	400 41.6%	124 36.6%	25 13.1%	7 30.4%	1044 (40.0%)
Total	25 (0.9%)	100 (3.8%)	248 (9.5%)	726 (27.8%)	961 (36.8%)	339 (13.0%)	191 (7.3%)	23 (0.9%)	2613 (100.0%)

Note: M - Male; F - Female

TABLE 3 Monthly Income and Occupation

Education Levels	Monthly Income (Yuan)										Total
	< 100	100 to 200	201 to 300	301 to 400	401 to 500	501 to 600	601 to 750	751 to 900	> 900	No Income	
Primary School	1	26	15	10	2	7	0	5	0	2	68 (2.6%)
Middle School	14	218	243	101	17	11	7	7	1	38	657 (25.3%)
High Middle School	14	294	429	128	28	23	5	8	1	28	958 (36.9%)
Bachelor Degree	19	232	344	117	24	22	17	10	0	38	823 (31.7%)
Above Bachelor Degree	0	26	21	22	4	7	1	1	1	0	83 (3.2%)
Others	1	3	2	0	0	1	0	0	0	1	8 (0.3%)
Total	49 (1.9%)	799 (30.8%)	1054 (40.6%)	378 (14.6%)	75 (2.9%)	71 (2.7%)	31 (1.2%)	31 (1.2%)	3 (0.1%)	107 (4.0%)	2597 (100%)

Note: Number of Missing Observations = 6

a bachelor's degree still earned between 100 and 200 Yuan per month. Though some of these users earned a higher income, there were only a few of them, and they were even fewer than those who had only received a primary school education (see Table 3). The less-educated bicyclists who earned higher incomes could be private businessmen. Nevertheless, as indicated in Table 3, the majority of users classified as well educated earned within the expected average income level.

TRAVEL CHARACTERISTICS

Though obviously the dominant trip purpose is working trips, which constituted 85.3 percent of the total, other trip purposes such as shopping and recreation are evident, even with the rather small percentages. Responses from the questionnaire surveys indicated that an overwhelming majority of users interviewed (85.7 percent) used their bicycles at least 6 days per week. Whereas in China people work 6 days per week in both private and public offices, only 20 percent of the respondents stated that they used their bicycles every working day. Another 65.7 percent rode on their bicycles every day. This means that they were riding not only for working purposes but for other purposes as well. Thus, it can be said that generally those who own a bicycle would not easily refrain from riding unless the trip distances proved to be too far or the environmental conditions were not favorable.

To verify the previous statement about the duration of the trip affecting the usage of bicycles, the Shanghai bicyclists were asked about average riding time as well as maximum bearable riding time. Generally speaking, bicycles are more suitable for short trips, and these are commonly practiced in western countries. However, the results of this study indicated that bicycles in Shanghai are used not only for short trips but for long trips as well. Twenty percent of the respondents indicated an average riding time between 16 and 20 min. Other responses on average riding time were nearly uniformly distributed among 5-min intervals, including those who rode their bicycles longer than 45 min, as indicated in Table 4. The range of 1 to 5 min average riding time had the smallest group of users, only 1.4 percent (37 respondents). On the contrary, 347 bicyclists (13.5 percent) spent an average of longer than 45 min riding. The average riding time of all respondents was 25.3 min. If the average riding speed of bicyclists in Shanghai is 13 km/hr as mentioned in another study (*9*), they ride their bicycles for about 5.5 km per trip.

Results in Table 4 indicate that males can tolerate longer trips than females. Average riding time for males and females were 26.9 and 22.8 min, respectively. Average trip distances were 5.8 and 4.9 km for males and females, respectively.

The overwhelming majority of bicycle users (91.7 percent) stated that they can bear a maximum riding time longer than 20 min, as indicated in Table 5. Moreover, nearly half (45.4 percent) of the bicyclists surveyed claimed that they could ride a bicycle at least 1 hr. Many females as well as males indicated the same ability and willingness to ride their bicycles for such a long duration. Nevertheless, Chinese males can tolerate longer riding times than females, with the average maximum riding time found to be 46 and 38 min, respectively.

As indicated in Table 6, regular users, defined in this study as those who used their bicycles at least 6 days per week, can tolerate much longer riding times than nonregular users. In fact, nearly 52 percent of the daily users were able to ride at least 1 hr or even longer. Nevertheless, even among the nonregular users, a number could manage to ride for longer durations, though a majority of these users could tolerate only between 20 and 30 min riding time.

REASONS FOR RIDING BICYCLES

In a motorized urban society, even among the developing countries, one may never expect that bicyclists asked about their reasons for riding bicycles will put more emphasis on convenience and reliability rather than the low expenses of this transport mode. In Shanghai, however, more than 80 percent of all bicycle users surveyed used their bicycles because of convenience and reliablity. Other reasons, such as "saving money" and "safety aspect," were not the main concerns of Shanghainese bicyclists. Only 59 persons (2.3 percent) indicated that the reason they used bicycles was to save money, even though obviously it costs practically nothing to ride a bicycle. Moreover, only 106 users (4.1 percent) chose safety as a reason.

The convenience and reliability of the bicycle mode were selected as the dominant reasons by both regular and nonregular users. Even among those who seldom used their bicycles, these two reasons were dominant, as indicated in Table 7. These results could reflect the poor public transport services

TABLE 4 Average Riding Time

Average Riding Time	Sex		Total
	Male	Female	
1 - 5 minutes	16 (43.2%)	21 (56.8%)	37 (1.4%)
6 - 10 minutes	121 (55.8%)	96 (44.2%)	217 (8.3%)
11 - 15 minutes	198 (51.8%)	184 (48.2%)	382 (14.7%)
16 - 20 minutes	279 (53.2%)	240 (46.8%)	519 (20.0%)
21 - 25 minutes	208 (61.5%)	130 (38.5%)	338 (13.0%)
26 - 30 minutes	255 (60.4%)	167 (39.6%)	422 (16.2%)
31 - 45 minutes	229 (68.2%)	107 (31.8%)	336 (12.9%)
> 45 minutes	255 (73.5%)	92 (26.5%)	347 (13.5%)
Total	1561 (60%)	1037 (40%)	2598 (100%)

Note: Number of Missing Observations = 15

TABLE 5 Maximum Riding Time

Maximum Riding Time	Sex		Total
	Male	Female	
20 minutes	112 (53.6%)	97 (46.4%)	209 (8.3%)
30 minutes	295 (52.8%)	264 (47.2%)	559 (22.3%)
45 minutes	331 (68.2%)	268 (31.8%)	599 (24.0%)
60 minutes	239 (59.5%)	163 (40.5%)	402 (16.1%)
> 60 minutes	522 (71.3%)	210 (28.7%)	732 (29.3%)
Total	1499 (60%)	1002 (40%)	2501 (100%)

Note: Number of Missing Observations = 112

TABLE 6 Maximum Bearable Riding Time, by Frequency of Usage

Frequency	Maximum Bearable Riding Time					Total
	20 min.	30 min.	45 min.	60 min.	> 60 min.	
Everyday	122 7.4%	286 17.6%	379 23.3%	273 16.8%	568 34.9%	1628 (65.3%)
Working days	33 6.5%	128 25.2%	142 28.0%	90 17.7%	115 22.6%	508 (20.4%)
3 - 4 days	21 10.2%	88 42.7%	44 21.4%	22 10.7%	31 15.0%	206 (8.3%)
1 - 2 days	15 16.8%	33 37.1%	21 23.6%	11 12.4%	9 10.1%	89 (3.5%)
Seldom	18 29.0%	21 33.9%	12 19.3%	5 8.1%	6 9.7%	62 (2.5%)
Total	209 (8.4%)	556 (22.3%)	598 (24.0%)	401 (16.1%)	729 (29.2%)	2493 (100.0%)

Note: Number of Missing Observations = 120

TABLE 7 Reason for Riding, by Frequency of Usage

Frequency	Reason for Riding					Total
	Faster	Convenient	Safer	Save Money	Reliable	
Everyday	149 8.9%	946 56.2%	51 3.0%	30 1.8%	506 30.1%	1682 (66.1%)
Working days	54 10.7%	254 50.4%	26 5.2%	14 2.8%	156 30.9%	504 (19.8%)
3 - 4 days	17 8.2%	91 44.2%	15 7.3%	10 4.9%	73 35.4%	206 (8.1%)
1 - 2 days	6 6.5%	56 60.9%	7 7.6%	4 4.3%	19 20.7%	92 (3.6%)
Seldom	3 4.8%	38 61.3%	7 11.3%	1 1.6%	13 21.0%	62 (2.4%)
Total	229 (9.0%)	1385 (54.4%)	106 (4.2%)	59 (2.3%)	767 (30.1%)	2546 (100.0%)

Note: Number of Missing Observations = 67

being provided. Bicycles require no waiting time or transferring, unlike other public transport, particularly bus services. In many instances, they can offer door-to-door services, which probably cannot be offered by bus services. Thus, it can be concluded that bicycles will remain one of the dominant transport modes in Shanghai unless other public transport services are improved.

OPINIONS ON THE SAFETY ASPECT

Although 106 persons rode on bicycles because of the safety reason, as mentioned in the preceding section, this mode is not totally safe. When asked whether they have ever experienced any accident while riding a bicycle, though nearly 90 percent never experienced an accident, the other 295 (11.6 percent) indicated that they had experienced accidents. According to the *1990 Traffic Accident Yearbook in Shanghai* (10), among the 7,527 accidents that occurred in Shanghai in 1989, 2,393 (31.8 percent) involved bicycles. Furthermore, among the 652 fatalities by traffic accidents in 1989, 250 (38.3 percent) were bicycle victims. Thus, the safety aspect of the bicycle mode cannot be overlooked.

When asked their opinions on the safety aspect of the bicycle mode, 599 persons (23.3 percent) said that riding bicycles in Shanghai was "quite dangerous" (16.9 percent) or "very dangerous" (6.4 percent) (see Table 8). Nevertheless, a considerable number of Shanghainese bicyclists still have faith in the safety of this transport mode. Nearly two-thirds (64.1 percent) of the respondents claimed that riding bicycles was "not really safe but not dangerous either." Table 8 indicates that of the 434 users who expressed the "quite dangerous" opinion, 83.6 percent (363 persons) were regular users who rode the bicycles at least 6 days per week. In addition, 140 other regular users chose the "very dangerous" category, representing 84.9 percent of the 165 persons who chose that category. It would be understandable if nonregular users expressed fear of riding bicycles due to the safety aspect, but having the majority of daily users criticizing the safety of this mode deserves attention.

It is interesting to note that residents of Bangkok had more faith in patronizing their boat services (*11*) than did the Shanghainese in riding their bicycles. Though it may sound impractical to compare two different modes from two different countries, it is impossible to compare the attitude of other bicycle users in other places even among the Chinese cities. The same five choices regarding the safety of the boats in Bangkok were offered the boat users. One of the psychological factors that may affect the ridership of the water transport mode is the safety aspect of the system. Among the total 1,075 boat users interviewed, the following responses were gathered: "very safe," 38 persons (3.5 percent); "quite safe," 445 persons (41.4 percent); "not that safe but not dangerous either," 456 persons (42.5 percent); "quite dangerous," 99 persons (9.2 percent); and "very dangerous," 13 persons (1.2 percent). The remaining 24 persons did not give any comment. Thus, it can be clearly seen that Thai people expressed more positive feelings toward their boat services, whereas the Shanghainese expressed rather negative attitude toward their bicycle mode.

OPINIONS ON BUS SERVICES

As discussed earlier, one reason why Shanghainese prefer to ride their bicycles may be the poor bus services being provided. To verify this finding, users were asked whether they would use bus services under the present conditions. Nearly 90 percent of the users interviewed indicated that they would not use the bus services. Then, those who ignored the bus services were requested to state their reasons. Nearly two-thirds of these commuters expressed unwillingness to use the buses because of poor service. Whereas 890 persons (39.5 percent) were concerned about the unreliable services being provided, 545 people (24.2 percent) complained about the buses being too crowded. It is apparent that bus services in

TABLE 8 Opinion on Safety, by Frequency of Usage

Frequency	Opinion on Safety						Total
	Very Safe	Quite Safe	Not Safe but Not Dangerous Either	Quite Dangerous	Very Dangerous	No Comment	
Everyday	24	86	1143	279	109	47	1688 (65.6%)
Working Days	8	50	327	84	31	15	515 (20.0%)
3-4 days	5	32	105	36	20	14	212 (8.2%)
1-2 days	2	17	47	16	3	7	92 (3.6%)
Seldom	4	5	27	19	2	10	67 (2.6%)
Total	43 (1.7%)	190 (7.4%)	1649 (64.0%)	434 (16.9%)	165 (6.4%)	93 (3.6%)	2574 (100%)

Note: No. of Missing Observations = 39

Shanghai need to be improved and that there is a need to provide efficient and adequate services to ensure the trust of the local commuters.

If the bus services can be improved, they may be able to attract more users. Slightly over half of the total bicycle users interviewed (51.8 percent) indicated that they may shift to the bus system if the services improve (see Table 9). Furthermore, 1,057 regular cyclists may shift to bus services if they are improved. However, 434 regular users are still loyal to the bicycle mode, as indicated in Table 10. Undoubtedly, the majority of nonregular users will shift to bus services, as also indicated in Table 10.

Exclusive bike lanes, similar to the bus lanes being provided for bus transit in many urban areas, are also being provided at certain streets in Shanghai. This study also emphasized the significance of this bicycle facility through the opinion of actual users. The results indicated that 1,914 users (74 percent) strongly agree with the need for more "bike only lanes" in Shanghai. Only 8.6 percent did not appreciate this preferential treatment, whereas 17.4 percent did not express any comment. Thus, to provide an efficient flow of bicycle traffic and to avoid conflict with other vehicluar traffic, exclusive bike lanes are strongly recommended. This will not only ensure a smoother flow of traffic but also could help minimize bicycle accidents.

PROPOSED IMPROVEMENTS

When asked to state their preference for improving the bicycle system in Shanghai from the seven attributes given in Table 11, Shanghainese bicyclists expressed more concern about bicycle facilities than about the price of bicycles or other given transport attributes. The two outstanding attributes, as indicated in Table 11, were the provision of more exclusive bike lanes (31.0 percent of respondents) and an increase in parking spaces in the public area (30.3 percent of respondents).

The bicycle users' preference for more exclusive bike lanes along the streets of Shanghai may not be well accepted by a number of researchers, even among the Chinese researchers themselves. Setty pointed out (*9*) that some Chinese researchers expressed concern either to discourage the use of bicycles or to curb bicycle ownership. The provision of more exclusive bicycle lanes may attract more users, which would contradict these researchers' desires. Nevertheless, considering the alarming rate of bicycle accidents in Shanghai, would it not be worthwhile to consider exclusive bike lanes? This would not only help ensure the safety aspect of bicycles but would also help minimize conflicts with other vehicular traffic, which may lead to the smoother flow of all traffic in Shanghai.

The second preference, an increase in parking spaces, reflected the inadequate bicycle parking spaces in Shanghai.

TABLE 9 Attitude Toward Bus System

	Willingness to Use Bus System Now?*			Willingness to Use Bus System in Future?**			
	Yes	No	Total	Yes	No	Not so sure	Total
Frequency	310	2,294	2,604*	1,320	485	742	2547**
Percentage	11.9%	88.1%	100%	51.8%	19.0%	29.2%	100%

Note: * Number of Missing Observations = 9
** Number of Missing Volume = 66

TABLE 10 Willingness To Use Bus System in the Future, by Frequency of Usage

Frequency	Opinion			Total
	Yes	No	Not so sure	
Everyday	800 48.3%	337 20.3%	520 31.4%	**1657 (65.3%)**
Working days	257 50.2%	97 18.9%	158 30.9%	**512 (20.2%)**
3 - 4 days	144 68.6%	29 13.8%	37 17.6%	**210 (8.3%)**
1 - 2 days	60 65.2%	12 13.1%	20 21.7%	**92 (3.6%)**
Seldom	53 81.6%	6 9.2%	6 9.2%	**65 (2.6%)**
Total	**1314 (51.8%)**	**481 (9.0%)**	**741 (29.2%)**	**2536 (100.0%)**

Note: Number of Missing Observations = 77

TABLE 11 Preference for Improvement of Bicycle Transport in Shanghai

Preference	Frequency	Percentage	Rank
1. Increase number of exclusive lanes for bicycles in the central area.	742	31.0	1
2. Increase number of parking spaces in the public area.	724	30.3	2
3. Improve the safety aspects of the bicycle.	351	14.7	3
4. Reinforce the traffic consciousness of bicycle users to ensure safety and efficient flows of traffic.	274	11.4	4
5. Provide central parking in the residential area.	170	7.1	5
6. Reduce the price of bicycles.	74	3.1	6
7. Control bicycle traffic in the city center.	58	2.4	7
Total	2,393	100.0	

Note: Number of missing observations = 220.

This problem has been mentioned by other researchers (*9,12*). Shortages of parking spaces are evident in Shanghai. Some bicyclists parked their bikes along the sidewalks, and many parked illegally at different places. It is recommended that the concerned authorities not overlook this problem, because this is not only intruding on the pedestrians but could extend to other vehicular traffic.

The safety aspect, though not ranked first, was mentioned by nearly 15 percent of the users interviewed. A moderate number of cyclists (11.5 percent) expressed the need for bicycle users to be more aware of traffic regulations. A very small percentage (3.1 percent) of total users interviewed wished to reduce the price of the bicycles. Thus, it can be concluded that bicycle users in Shanghai were highly concerned about bicycle facilities and worried about the safety aspect.

CONCLUSION AND RECOMMENDATIONS

Bicycles have been used by people regardeless of sex or age. They rode their bicycles as a form of private transport for various purposes, not just for pleasure or recreation, but mainly for work and other essential daily needs. Despite some dangers involved in riding their bikes, the majority of bicylists still used their bicycles because of convenience and reliablity. Bus transit did not receive substantial support from the local commuters. Whereas the only means of attracting more users to the transit system may be to improve its services, bicycles will remain a versatile transport mode in Shanghai.

Much attention has been given to searching for measures to prevent the deterioration in environmental conditions. One interesting question concerns whether to encourage or to discourage the popular usage of bicycles in Shanghai. The latter can be achieved through the improvement of bus services or by introducing larger capacity in the rail transit system. Whereas many motorized communities have been attempting in vain to discourage the usage of the more polluting and the least energy-saving vehicles, private cars, some encourage their commuters to shift to the pollution-free mode, the bicycle. Is it premature to consider a proposal to discourage the usage of bicycles in Shanghai? Is there any alternative transport mode to cater efficiently to the needs of the commuters? Standard of living, expected earned income, ability to substantiate the higher transit fare, and traditional way of life are related issues. Of course, this study cannot provide the solution to this argument, but it may be appropriate to inquire whether it is time for transportation engineers and planners to seriously consider the theory related to bicycle traffic and design facilities.

The highway capacity manual has been published since 1965 and revisions have been made twice, yet no bicycle capacity manual exists in any motorized or nonmotoritized city. When such a manual materializes, it is strongly recommended that, whether practices or standards are put forward, the culture and characteristics of the populace be considered.

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Pedestrian Characteristics and the Promotion of Walking in Kuwait City Center

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The rapid economic growth in recent decades in Kuwait has had a significant effect on the socioeconomic level and life-style of the people. In Kuwait City, the infrastructure, urban form, and transportation system have been completely transformed. Continuous out-migration of Kuwaitis from the City Center has changed the composition of the population and the land use activities in this area. Policies and decisions favoring the private automobile have made this the predominant mode of urban travel. Direct and indirect results of these policies have had a negative effect on the pedestrian mode of travel in the City Center. The general characteristics of Kuwait City and the study area (the City Center) are presented. The results of an ongoing study concerning pedestrian flow characteristics in the City Center are discussed. Existing pedestrian network and system deficiencies are identified, and recommendations for the promotion of pedestrianization in the City Center are made.

The objectives of this paper are to determine the characteristics of pedestrian flow and network and to recommend measures for the promotion of walking in Kuwait City Center.

Pedestrian trips account for a significant portion of urban travel (*1*) in spite of decades of domination by motorized transportation systems. As the competition between pedestrians and motorized traffic for space on urban roadways increases, pedestrians take a heavy toll in terms of injuries and lives lost. Worldwide, accidents involving pedestrians account for from 15 to 45 percent of total road accidents, depending on the country (*2*). In Riyadh, Saudi Arabia, 50 percent of fatal road accidents were inflicted on pedistrians (*3*).

In the rich developing countries, where the automobile has been favored as the predominant mode of urban travel, the recognition of the social, economic, and environmental benefits of walking is still in its infancy. This is in spite of the fact that the central streets of major urban areas in these countries are often crowded with pedestrians, many of whom are low-income expatriates who do not have cars or local driver's licenses.

The Iraqi invasion of Kuwait in 1990 resulted in the complete destruction of the infrastructure of Kuwait City. The need to reestablish transportation and other institutional components in Kuwait has provided a unique opportunity to lay the foundation for the inclusion and promotion of walking as a major mode of urban travel.

CHARACTERISTICS OF THE CITY CENTER

Kuwait City is located at the northern end of the Persian Gulf at a latitude of 29° 20′N. Climatically, it is classified as a marine arid zone, which combines typical desert conditions (hot, windy, and dry) with proximity to the sea.

The total area of Kuwait City Center, the area under consideration, is approximately 805 hectares (nearly 2,000 acres). The roadway network in the City Center is 59 km (30 mi) long, with two to three lanes per direction and a median island separating the directional traffic. The geometric standards of the roadway network have provided generous space for vehicle flows but limited concern for the pedestrian. However, compared with pedestrian space allocations in most urban areas of the Middle East region, Kuwait City Center ranks favorably (*4*).

The general preinvasion socioeconomic characteristics of Kuwait City are as follows: population (681,288 Kuwaitis and 1,016,013 non-Kuwaitis), family size (8.9 persons per household for Kuwaitis and 5.0 for non-Kuwaitis), automobile ownership (3.5 automobiles per household for Kuwaitis versus 1.4 for non-Kuwaitis), and finally, monthly income (KD 584 for Kuwaitis and KD 390 for non-Kuwaitis) (*5*).

Over the last few decades, the City Center has witnessed a significant increase in the working population and a continuous decrease in the residential population. Recent preinvasion statistics indicate that the resident population of the City Center consisted mostly of low-income/single men expatriates. In 1980, out of 60,365 residents of the City Center, only 4,467 were Kuwaitis (*6*).

Pedestrian Flow Characteristics

Because of the recent Iraqi invasion and the looting and destruction of the physical infrastructure and institutional properties, no data could be found on the characteristics of the pedestrian mode of travel in Kuwait City. Therefore, a framework for a comprehensive study of pedestrian flow and characteristics of the City Center was established in late August 1992. The study sampling plan called for a series of origin-destination surveys and flow measurements at 34 locations, both on sidewalks and in indoor shopping malls in the City Center.

The sampling and monitoring locations cover a variety of commercial, governmental, recreational, and residential land uses in the study area. The survey time period includes both

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peak and off-peak hours [7:00 to 9:00 a.m., 11:00 a.m. to noon, 12:30 to 2:30 p.m., and 4:00 to 6:00 p.m. (on weekend nights, pedestrian flow is also monitored between 6:00 and 8:00 p.m.]. The sampling plan calls for a systematic random survey of approximately 2,000 pedestrians. A total of 864 sample questionnaires have so far been completed.

Information was obtained on pedestrian characteristics (age, sex, education, employment, and nationality), characteristics of the walk trip (origin, destination, purpose, modes of travel before and after the walk, and trip length), and characteristics of flow (speed, volume, and density).

A preliminary analysis of pedestrian flow data with respect to walking speed indicates that mean pedestrian speeds at sidewalks and indoor shopping malls were 71 and 46 m/min, respectively. The low figure for walking speed at indoor shopping malls is mainly caused by a large number of window-shoppers. The sidewalk speed is higher than the indoor mall speed at the 99 percent significance level. Analysis of the sample data also indicate that female pedestrians walk considerably slower than males especially at indoor shopping malls. The mean indoor shopping mall walking speeds for female and male pedestrians were 23 and 57 m/min, respectively. Again window-shopping may account for the significantly lower speed of the female sample population. The difference between the mean walking speeds at indoor shopping malls for female and male pedestrians was significant at the 99 percent significance level ($\alpha = 0.01$).

A comparison of mean walking speeds for pedestrians in different nations is presented in Table 1. Whereas pedestrians in Kuwait walk slightly faster than those in Riyadh, Saudi Arabia, their mean speed is considerably less than that of pedestrians in the United States, the United Kingdom, and, to some extent, Singapore (*4*). High temperatures may be the main cause for the low walking speed in Kuwait and Saudi Arabia. A comprehensive analysis of the data will be performed on completion of the sampling and monitoring surveys.

Existing Pedestrian Network Characteristics

In an urban area, the pedestrian network and the choice of walking as a mode of travel are greatly influenced by land use type, location of transportation-related facilities, and urban form (*7*). The existing urban form of Kuwait City Center may be characterized as follows:

- Nearly complete disappearance of the old traditional structures and passageways;
- Large vacant desert spaces that separate the built-up areas from one another, causing long walking distances with no protection from the sun; and
- Very large urban blocks on major commercial streets and on main arterial roadways.

The main reason for the existence of deficiencies in the urban form of Kuwait City is the fact that many sectors of the city have been partially rebuilt in accordance with different plans in a piecemeal fashion. Every initiative has followed its own independent course and has rarely taken into consideration the existing context.

The pedestrian network consists of two interrelated subnetworks. These include (*a*) the primary subnetwork, which follows the alignment of the street network (sidewalks) and is, therefore, a widely spaced grid walkway, and (*b*) the secondary subnetwork located within the block system, providing pedestrian access to various commercial land uses, office buildings, and car parks within each block. The two subnetworks are poorly connected to each other.

The souk (bazaar), which is the only surviving part of the city from the preoil era, contains a network of closely spaced pedestrian walkways that are closed to traffic, and it therefore provides the safest space for pedestrian movements in the City Center. Figure 1 shows the network of walkways in Kuwait City Center.

System Deficiencies

A preliminary survey and a subjective evaluation of the physical condition of the sidewalk network in the City Center (based on pavement condition, objects on the walkway, protection from vehicular traffic, continuity, and connectivity) indicated the following characteristics: approximately 30 percent of the network is in good physical condition, about 10 percent requires minor repairs, 5 percent is in need of major repairs, 1 percent is in poor condition (in need of reconstruction), and the remaining 54 percent is in acceptable physical condition but could definitely be improved.

In addition to its physical shortcomings, the pedestrian network in the City Center also suffers from a variety of indirect system deficiencies:

TABLE 1 Comparison of Pedestrian Walking Speeds (*5*)

City/Country	Author	Mean Walking Speed (m/min)
United States	Hoel	88
United States	Fruin	81
United States	Navin & Wheeler	79
United States	Sleight	82
London, England	Older	79
Singapore	Tanaboribeon et al.	74
Riyadh, Saudi Arabia	Koushki	65
Kuwait City	Koushki & Ali	71

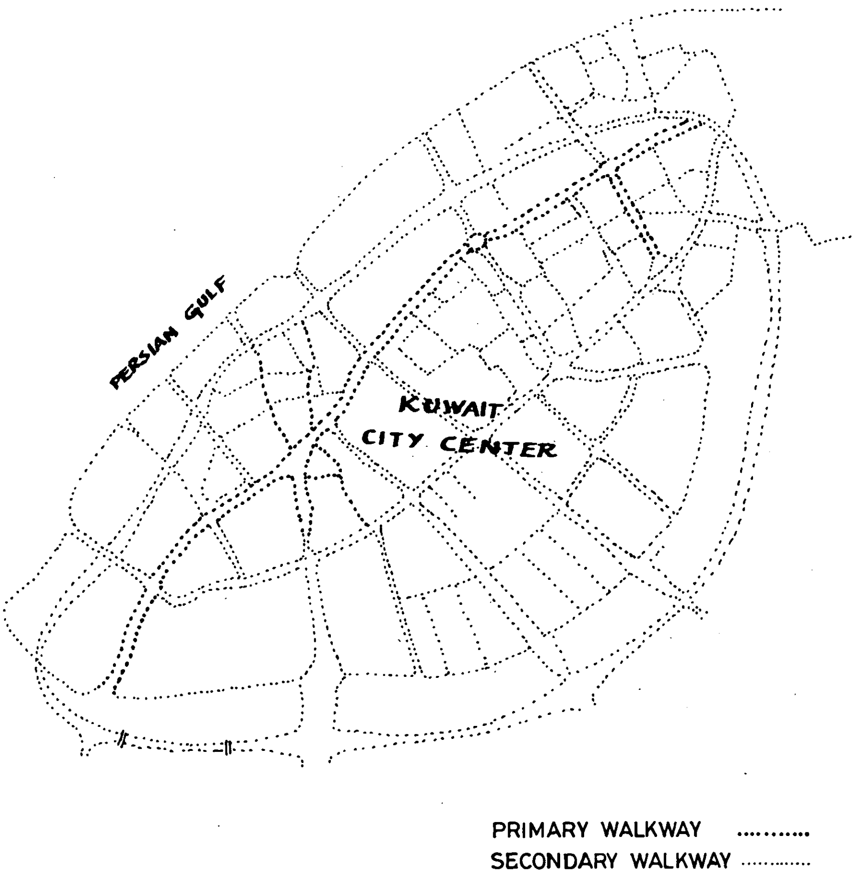

FIGURE 1 **Study area and walking network in Kuwait City Center.**

- Policies tailored to favor the automobile mode of travel have generally created difficulties and longer walking distances for pedestrians.
- Discontinuities in walkways force pedestrians to make long detours.
- Vehicles frequently infringe on pedestrian spaces and walkways.
- Crossing streets and intersections involves conflicts with hostile vehicular traffic.
- Lack of shade prevails at pedestrian walkways.
- The existence of large parcels of vacant land increases the distance between land uses and discourages walking.

RECOMMENDATIONS FOR IMPROVEMENT

Perhaps the greatest impediment to the promotion of the pedestrian mode in Kuwait City Center is the traditional policies and actions that favor automobiles and establish vehicular traffic as the predominant mode of urban travel. The inconsistency in urban forms, resulting from a piecemeal implementation of different urban design concepts over the last three decades, has also contributed to the present-day problems of the pedestrian mode in Kuwait City. These changes are, to a great extent, a consequence of the region's rapid and significant economic development in recent decades.

Recommendations for the promotion of the pedestrian mode of travel in the City Center incorporate three classes of improvement actions: immediate, medium-range, and long-term actions.

Immediate Actions

Actions in this category require a minimum of resources in terms of capital, materials, and time and include the following:

- Minor repairs in the walkway network;
- Improved walkway maintenance, such as cleaning, lighting and marking;
- Development of a driver and public education campaign emphasizing improved safety, health, energy, and positive environmental impacts of pedestrianization; and
- Enforcement of rules designed to protect pedestrian space from vehicular intrusions.

Medium-Range Actions

Actions in this category include the following:

- Continuation of immediate actions,
- Elimination of network discontinuities,
- Protection of pedestrians from the sun, and
- Development of a comprehensive walking network that incorporates the existing paths and expands to cover and fa-

cilitiate pedestrian movements and accessibility to various land uses.

Long-Range Actions

These include

- Continuation of immediate actions,
- Implementation of actions recommended by the comprehensive walking network plan, and
- Creation of a pedestrian-only area connecting the old souk and the main square (Safat) to the sea.

CONCLUSIONS

Because of the recent Iraqi invasion and looting, no data are available on the characteristics of the pedestrian mode of travel in the City Center. This ongoing study attempts to fill the gap.

The study indicates that, like many urban areas, the favoring of the automobile as the predominant mode of travel in Kuwait has created the greatest obstacle to the promotion of walking in Kuwait City Center.

A preliminary analysis of the data has shown that, similar to pedestrians in Riyadh, Saudi Arabia, pedestrians in Kuwait City Center walk considerably more slowly than those in the United States and England.

Immediate, medium-range, and long-range actions were recommended for the promotion of the pedestrian mode in Kuwait City Center.

ACKNOWLEDGMENTS

The authors wish to thank Engr. S. Behzad, from the Municipality of Kuwait, for his useful discussion of the pedestrianization of the City Center. Thanks are also expressed to Mrs. Mini and Mrs. Daisy for typing the manuscript.

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Sharing the Road with Bikers: The Nigerian Experience

FUNSHO OLAMIGOKE

Nigeria has dilapidated, overcrowded, and unsafe vehicles and motorcycles on its roads. A motorcycle operator may have as many as five or more passengers on board. The reasons for this situation are briefly described, and suggestions for improving safety are presented.

Many communities in Nigeria still depend on bicycles and motorcycles as a means of transportation. In some urban centers the services of the machines are even commercialized. This in itself is not as much a problem as the hazards from the modes of operation.

In most of the communities involved, bicycles are commonly used by women and girls, whereas motorbikes are usually operated by men. The women cyclists for the most part ride to run their businesses (often farming or, less often, trading). Those who are farmers are usually seen heading toward their farms in the morning. They have much more to carry on their way back later in the day. Unlike the women, the girls ride mostly to run errands around town or for pleasure. Their communities, however, do not have problems with heavy automobile traffic, as do bigger cities.

One danger does exist. In most cases interstate roads run through, and motorists drive on them carelessly. This has often resulted in knocking off cyclists who underestimate the speed of approaching vehicles as they attempt to cross the road. Such incidents apply not only to cyclists. Pedestrians and motorbikers have also been involved. In such instances, the vehicles involved make away where possible for one simple reason: to avoid being lynched by irate villagers.

Even in the cities, road designs are such that cyclists are put at a disadvantage with motorists. There are no pedestrian or cyclist paths as are found in most modern cities of the world. Cyclists as well as motorbikers are, therefore, left with no option other than to share the road with cars and trucks. Consequently, parents are very cautions to ensure that their children do not ride beyond their immediate (safe) neighborhoods. Children, especially in big cities like Lagos, are not allowed to go to school or run errands by cycling.

MOTORBIKERS

Unlike Europeans and Americans, who ride bikes at sporting meets and for pleasure, most motorbikers ride either as a means of getting to work (even to white collar jobs) or for a living. It is common to see as many bikers as motorists on the roads. In some cities, especially in the Delta areas of Nigeria, motorbikers tend to outnumber motorists. In others, taxicabs are almost nonexistent; instead, motorbikes are the major means of transporting commuters from one place to another (see Figures 1 and 2).

HISTORICAL BACKGROUND

Before the oil boom days in Nigeria, people were content to ride in buses. There were enough buses on Nigerian roads, particularly because most Nigerians lived in the countryside. More people then were involved in farming, producing cash and food crops. The major transportation need was to move their produce to the cities for sale. Inhabitants of cities were civil servants and those working in industry. There was enough food to go around then and prices were affordable.

With the oil boom of the mid-1970s, people abandoned their farms for the cities to seek white collar jobs. The jobs, incidentally, were there. The effect was not only a crash in the production of food crops but also an influx of people to the cities, which led to the beginning of recognizable inflation in Nigeria.

Then, with the strength of the Naira against major world currencies ($1 was equivalent to 0.75 Naira), Nigeria went on an import spree. Anything and everything was imported, including, of course, automobiles. Because they were so cheap, cars of different sizes, shapes, and makes flooded our roads.

It came to such a critical stage that the Lagos state government enacted a law regulating movement of vehicles on major roads on certain days of the week. Called the odd and even number edict, the regulation allows vehicles up to light trucks, except commercial vehicles, with registrations starting with an odd number to ply the roads only on Mondays, Wednesdays, and Fridays. Vehicles with registrations starting with even numbers are allowed on these roads only on Tuesdays and Thursdays. This, of course, is similar to high-occupancy vehicle lanes in America.

(Nigeria and America have something in common here. Whereas some countries are worrying about emission control possibilities from the overflow of automobiles, we have been concerned with congestion.)

This led to most people acquiring more than one car to beat the odd and even number edict. The government provided a park and ride system, which made it possible for motorists to park their vehicles at a central lot and ride to and from work in government buses.

Unfortunately, however, the downturn in the economy hit everyone like a bolt from the blue. Despite warnings from a few people, nobody ever really believed that the Nigerian

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Volkswagen of Nigeria Ltd., P.M.B. 12663, Lagos, Nigeria.

FIGURE 1 Queue of bikers waiting for passengers in Surulere, Lagos.

economy could get bad. At the end of the day, the Naira lost strength. The Naira, which stood at 0.75 to the dollar, is now 35.00 to the dollar (as of March 1993). Exchange rates became the yardstick by which market performance was measured. Prices shot up so much that today an average 1.8-1 saloon that was purchased for 6,000 Naira (pre–second tier foreign exchange market) today goes for not less than 395,000 Naira. In most cases, salary scales have hardly changed. Motorbikes now cost 10 times what cars used to cost.

Several facts are troubling. Very few people can now afford to buy personal cars. Those who still have one find difficulty in maintaining it properly. Public transportation standards are not what they should be. If vehicle "roadworthiness" regulations were enforced, most vehicles would have to be off the road and Nigeria would come to a standstill.

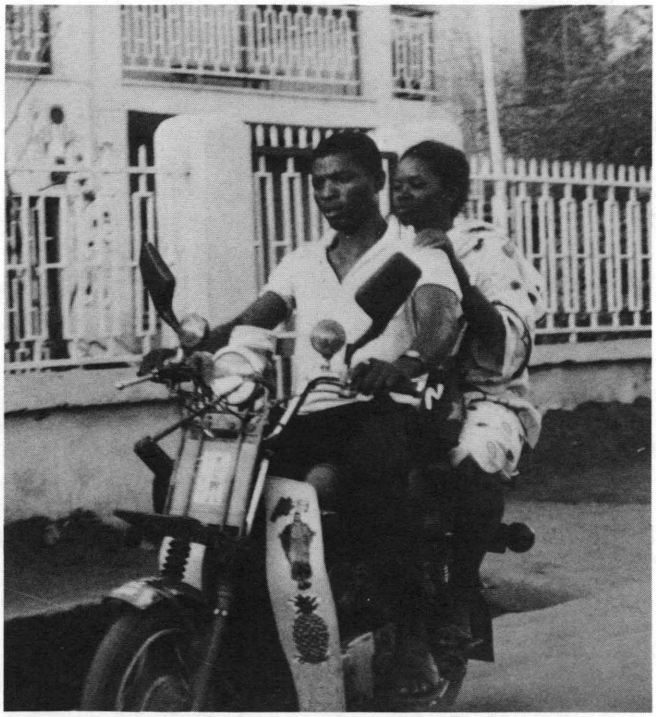

FIGURE 2 Biker with commercial passenger in Surulere.

SAFETY

It is also troublesome that law enforcement agents' hands have been tied with regard to roadworthiness regulations. Who wants to bring the economy to a standstill?

Consequently, dilapidated, overcrowded, and unsafe vehicles and motorcycles are on the roads. A motorcycle operator could have as many as five, sometimes more, passengers on board. They often include mothers with babies strapped on their backs.

A crash involving a biker can be devastating. All parts of the body are prone to various grades of injury, but head injuries are apparently the most feared by bikers. The campaign for protective wear has limitations, which result from the environment and the economy: the weather in the tropics is not conducive to wearing tight-fitting leather garments, and inadequate facilities lead to overcrowding. This is often reflected in more than one passenger riding on a bike without safety wear. In fact, families go to church on Sundays in their best riding four or sometimes five on a bike. Inevitably, safety is not given due consideration.

In our nationwide research into this subject, it was discovered that the cost of safety helmets and other riding gear has very little to do with why bikers are not wearing them. When originally enacted, the regulation on constant use of safety helmets by bikers and their passengers was enforced. This led to riders who intended to take on passengers being required to buy at least two crash helmets, but as time went by and passengers grew from the normal one to four, five, or six, the idea was abandoned.

The recommendations of our research work focused on eliminating the motive. That is, if commuters were given better alternatives, such as abundant buses, organized city cabs, a metro system, and ferries on waterways, fewer commuters would use bikes.

Whereas we look forward to eliminating a situation in which a family of four or five rides on a motorbike or bicycle at the same time, the use of bicycles is to be encouraged for two immediate reasons: it is cheaper by all standards, so more people can afford it, and it is ecologically friendly.

The one major problem we have always faced in Nigeria is the fact that we hardly ever plan ahead. We are used to waiting for crisis. More devastating is the fact that we are not good managers of crisis, by design. Consequently, most problems are tackled with the fire brigade approach.

Such were the transportation policies of the nation since independence in 1960 that today, in 1993, we still depend on automobiles for mass movement. This is especially so in urban transportation.

The current economic situation in Nigeria can only encourage more use of cycles. It is for this that our 10-min video program, Safer Cycling, addressed the major causes of bike accidents and suggested tips on how to deal with them. Field surveys into final scripting of Safer Cycling took place in major cities of the country. Locations for film recording were selected according to intensity of use of bikes. Therefore, cities like Lagos, Ughelli, Warri, Port-Harcourt, and a number of villages were featured.

These are peculiar communities with high volumes of bikes. In recent times, the use of bikes has grown a great deal in Nigeria as a result of the downturn in the economy. Although bad economic times are not welcome, this development is creating a friendlier and more pleasant environment for us to live in.

Since the roads still have to be shared with pedestrians and other motorists, it is necessary to awaken bikers and cyclists to the possibility of a crash. With enough awareness, bikers who are prepared and properly equipped are better off on the road than others.

The key word, therefore, is safety.

CAUSES OF BIKE ACCIDENTS

The primary cause of bike accidents in Nigeria is the fact that most riders, like their motoring colleagues, have no training. Whatever skill they have was acquired along the line.

It is common to see riders display unethical riding characteristics. It is common practice, for example, for riders to maneuver between cars in traffic rather than to wait in line. It is also common for riders not to be bothered by traffic regulations at intersections. The latter is so bad that bikers not only jump traffic lights but also ignore traffic policemen at intersections. It is a kind of immunity; the attitude is inherent. The regulations seem to be for automobiles only.

In the meantime, the video program, basically addressing motorists, suggests ways bike accidents can be minimized with the cooperation of motorists.

ACKNOWLEDGMENTS

This work was funded by Shell Petroleum Development Nigeria, Limited, with developmental support from Overend Nigeria, Limited, Lagos.

Statewide Bicycle Planning in the United States

ERIK FERGUSON AND DAWN INGLIS MONTGOMERY

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) significantly enhances opportunities for bicycle planning, funding, and coordination at the state level. Georgia Tech designed, implemented, and analyzed the results of a survey of state transportation departments regarding bicycle planning and related activities. The survey was mailed to all 50 states and the District of Columbia in March 1992. By June 1, 43 responses had been received (84 percent). Statewide bicycle planning activities increased in the early 1970s, the late 1970s, the early 1980s, and more recently after the passage of ISTEA. Most states treat bicycles as legal vehicles on state highways. About half of the states surveyed have a bicycle department or position and a citizen-led bicycle advisory committee or provide funding for bicycle programs and projects. Few states currently have comprehensive statewide bicycle plans. Several states are in the process of developing such plans. Legalization of bicycle usage on streets and highways is a clear national trend not critical to the adoption of statewide bicycle plans. Funding and institutionalization appear to be more supportive of state bicycle planning. Bicycle advisory committees often are associated with more active state involvement in bicycle planning. This may be due to the importance of recreational and tourist activities in bicycle system utilization, at least in some states. Bicycle facilities designed to serve these types of travel generally require a broader than purely local perspective to achieve success in systems planning and design.

Bicycling is becoming more and more popular in America, both for recreational purposes and as a means of regular transportation. Despite the growing numbers of U.S. bicyclists, fewer than half the states have bicycle planning programs. One impetus for change is the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), which encourages far greater bicycle planning efforts at the state level (*1*).

ISTEA also provides funding and requires the creation of a bicycle coordinator position in each state department of transportation (DOT). Now that federal funding is available, many states will need to move their bicycle planning efforts forward and adopt comprehensive state bicycle plans. For many states without bicycle programs, the best guide is to study key elements of successful programs already in existence in other states. A national survey of state bicycle programs was conducted by Georgia Tech to determine the extent of state bicycle planning activities. This paper discusses the results of the survey.

ISTEA has several key provisions that apply to bicycle planning at the state level. The provisions relate to planning, funding, and bicycle coordination. Each of these provisions is important in establishing an active state bicycle program (*2*).

PLANNING

Several provisions of ISTEA apply directly to bicycle planning. Sections 1024 and 1025 create a new planning process for states and metropolitan areas in the preparation of long-range transportation plans and transportation improvement programs. The transportation improvement program identifies all improvements designated for a specific time period, indicates an area's transportation priorities, groups projects by staging periods, and estimates total program costs and revenues. States are required by ISTEA to include bicycle transportation facilities in such programs. Bicycle facilities will be incorporated into the transportation planning process of all states, increasing the probability that bicycle facilities will be built.

Under ISTEA, state transportation plans shall consider "strategies for incorporating bicycle transportation facilities and pedestrian walkways in projects where appropriate throughout the state." This is very important for the provision of bicycle facilities, since they often can be incorporated into major road projects through the construction of wider curb lanes. If state highway projects are reviewed automatically for the inclusion of bicycle facilities whenever new roads are constructed and existing roads are repaved, the number of miles of bicycle facilities quite probably will increase. In addition, the need for wasteful duplication of transportation facilities should decrease.

Under ISTEA, states shall develop long-range plans for bicycle transportation and pedestrian walkways in appropriate areas of the state. These plans shall be incorporated into the state's long-range transportation plan. A state bicycle plan is a key element of successful state bicycle planning programs already in existence. State bicycle plans outline existing policies and conditions and define the direction bicycle planning should take in that state. This provision of ISTEA will provide an impetus for the creation of many much more active state level bicycle programs.

FUNDING

Adequate and secure funding sources are important for the development of a state bicycle program. Funding determines whether bicycle facilities and related activities are even possible. ISTEA makes bicycle facilities eligible for National

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Highway System funds, authorized at approximately $3.6 billion annually. Bicycle and pedestrian facilities are also eligible for Surface Transportation Program funds, authorized at approximately $4.0 billion annually. Of each state's Surface Transportation Program funds, 10 percent must be spent on 1 or more of 10 separate transportation enhancements, one of which is bicycle facilities. Transportation enhancement funds are authorized at approximately $3.3 billion over 6 years. These various flexible funding provisions of ISTEA could provide states with the incentive necessary to develop more active state bicycle programs.

COORDINATION

The final key ISTEA element for bicycles is the requirement for creating a bicycle and pedestrian coordinator position within the DOT of every state. ISTEA allows the use of federal funds to pay for this required position. A state bicycle coordinator is an important addition to any state DOT. The coordinator is responsible for making sure that bicycles are adequately considered in all state transportation projects. In addition, the coordinator often is responsible for handling all of the department's other bicycle concerns. The bicycle coordinator should serve as a strong advocate for bicycle facilities and activities throughout each state.

DATA AND RESEARCH METHODOLOGY

Georgia Tech conducted a survey of state bicycle programs in the United States in March 1992. Surveys were mailed to state bicycle coordinators or the equivalent in all 50 states. We obtained the list of bicycle coordinators used in mailing the surveys courtesy of FHWA. All survey responses received before May 1, 1992, were included in the data base and subsequent analysis. A total of 40 surveys were returned, yielding an overall 80 percent response rate. Survey questions were developed from a previous comparative case study analysis of 10 active state bicycle programs chosen from an FHWA list of 15 more active state bicycle programs (*3*). The survey questions and a list of the states responding to the survey are contained in the project final report (*4*).

The national survey consisted of nine questions regarding the state's past, present, and future bicycle planning activities:

- Legal vehicle: Is the bicycle considered to be a legal vehicle? In what year was this law enacted? In states where the bicycle is considered to be a legal vehicle, bicyclists have the same rights and responsibilities as do drivers of any other type of vehicle.
- Bicycle department or position: Is there a bicycle department or position? Where is it located, administratively? In what year was it established? How many staff positions does it have? What is its annual budget? What are its responsibilities? The bicycle department or position is usually the focus of a state's bicycle planning activities.
- Other departments: Are other departments involved in bicycle planning? Which ones? In what ways? Quite often, multiple departments share bicycle activities, programs, and responsibilities. When bicycle responsibilities are scattered among different departments, the absolute level of bicycle activity may increase, but coordination may become more difficult, and duplication of effort can occur.
- Bicycle advisory committee: Is there a bicycle advisory committee? In what year was it established? Who are its members? What are its objectives and accomplishments to date? Bicycle advisory committees can provide valuable citizen input and clearer policy direction to many state bicycle programs.
- Types of funding: What are the sources and amounts of funding used to support state bicycle activities? The amount of funding available is one of the key elements in determining the range of activities a bicycle program can afford to be involved in.
- Types of projects: What types of bicycle capital projects have been implemented? What are their associated costs? At what level are such projects initiated? Bicycle capital projects can be used to enhance the physical environment and to increase the likelihood that bicyclists will ride.
- Types of programs: What types of state level bicycle programs have been implemented? What topics do such programs cover? Bicycle programs show the range of promotional activities that states engage in and indicate the types of bicycle activities that states consider most important.
- State bicycle plan: Does a state bicycle plan currently exist? In what year was it adopted? What topics and activities does it cover? State bicycle plans identify existing conditions and provide guidance and direction for improving the future of bicycling in the state.
- History: What is the history of bicycle planning in the state, briefly noted? The history of bicycle planning in a state may provide an indication of how the state reached its current level of bicycle activity.

LEVEL OF ACTIVITY

Many states were not actively involved in planning bicycle facilities at the time the national survey was conducted. For example, only 16 percent had a state bicycle plan in place. More than half (51 percent) had a bicycle advisory committee, 58 percent had a bicycle department or position, 60 percent had a dedicated source of funding for bicycles, and six out of seven (86 percent) gave bicycles full status as legal vehicles.

To compare states in terms of their level of activity, we developed a simple activity index based on the following five factors:

- Is the bicycle treated as a legal vehicle by the state?
- Are state funds available to support bicycle activities?
- Is there a state bicycle department or position?
- Is there a state bicycle advisory committee?
- Is there a state bicycle plan in place?

If a response was not provided for any question, a negative response was assumed. The activity index is the simple summation of answers to all five questions, with a "yes" scored as 1 and a "no" as 0. This creates an index ranging from 5 for most active to 0 for least active (Table 1).

- Only five states (12 percent) exhibited the maximum score of 5: Delaware, Florida, Minnesota, Oregon, and Washington.

TABLE 1 Level of State Bicycle Activities

	Percentage of States					
Activity Index	Legal Vehicle	State Funds	Depart./ Pos.	Advisory Comm.	State Plan	N States
5	100	100	100	100	100	5
4	100	100	88	100	13	8
3	73	82	73	64	9	11
2	90	40	50	20	0	10
1	100	0	0	0	0	7
0	0	0	0	0	0	2
All	86	60	58	51	16	43

- Eight states (19 percent) had an activity index of 4. All eight treated the bicycle as a legal vehicle, provided funds for bicycling activities, and had a bicycle advisory committee. One of these states lacked a bicycle department or position, whereas the other seven lacked a state bicycle plan.
- Eleven states (26 percent) had an activity index of 3. Only one had a state bicycle plan.
- Ten states (23 percent) had an activity index of 2. None had a state bicycle plan.
- Seven states (24 percent) had an activity index of 1. All seven treated the bicycle as a legal vehicle, and that was it.
- Only two states (5 percent) had an activity index of 0.

On the basis of these results, it appears that making the bicycle a legal vehicle may be a prerequisite for greater state involvement in bicycle planning activities. Similarly, the development of a state bicycle plan seems to require the previous existence of all four other factors making up the activity index. This hypothesis will be explored further in the next section, which deals with history.

HISTORY

A total of 35 states provided information on the history of bicycle planning in their state. Ten states (28 percent) indicated that there had never been any bicycle planning in the state. Five states (14 percent) had been involved in bicycle planning in the past but had nothing recent to report. Seven states (19 percent) reported minimal effort at bicycle planning in the past, solely in conjunction with other projects. Seven states (19 percent) reported state bicycle planning from the recent past. Seven states (19 percent) had a long history of bicycle planning at the state level to report.

North Carolina is an excellent example of a state with a long history of bicycle planning (*5*). North Carolina had its first bicycle week in 1975. In 1978 it developed comprehensive policies for the planning, design, construction, maintenance, and funding of bicycle facilities. The first bicycle project was included in the North Carolina transportation improvement program in 1979. In 1982 enforcement was a focus, and in 1984 safety was a focus. Funds were allocated for independent bicycle projects beginning in 1985, with funding increasing to more than $1 million in 1990. Safety education in schools was a big push in 1986. In 1991 North Carolina substantially revised its original bicycle policies. North Carolina provides an example of a program with a long history of bicycle planning that has encompassed a wide array of activities including encouragement, enforcement, engineering, and education.

Although 37 states indicated that the bicycle was a legal vehicle in their state, only 25 (59 percent) were able to provide the year in which this doctrine was established. Far fewer states indicated having bicycle departments or positions, bicycle advisory committees (BACs), or bicycle plans in place, but a much higher percentage of these states could provide the year in which such activities were first established (Table 2). Bicycles tended to be established as legal vehicles first, with the creation of departments and BACs following much later. Too few states had developed state bicycle plans to make the mean year of plan creation comparable.

These results lend further credence to the view that state bicycle planning occurs incrementally over time, following a fairly set pattern of events. According to this scenario, the bicycle must first be legalized as a vehicle with full access to highways and streets. Funding (preferably dedicated), institutionalization (creation of department or position), and citizen participation (creation of bicycle advisory committee) would follow. Finally, with all of the other pieces to the bicycle planning puzzle in place, a state bicycle plan could be, and sometimes was, formally adopted.

Although there are certain tendencies among states that lean in this direction, the order in which the ingredients of a

TABLE 2 History of State Bicycle Planning

Type of Activity	N States Yes	N States Year	% States Year	Year of Occurrence	
				Range	Average
Legal Vehicle	37	22	59	1926 to 1991	1971
Department or Position	25	19	76	1971 to 1992	1981
Bicycle Advisory Committee	22	20	91	1972 to 1992	1984
State Bicycle Plan	7	6	86	1977 to 1991	1981

successful bicycle planning process are finally put together is by no means cast in stone. Only three states provided dates for all four bicycle planning parameters identified in Table 2: Florida, Oregon, and Washington. None of these three followed the expected chronological sequence exactly. Florida completed all four steps within a 4-year period, beginning with the creation of a department and a BAC in 1979, followed by a plan in 1981 and legalization in 1983. Oregon completed all four steps at a more leisurely pace, beginning with the creation of a bicycle department in 1971, formation of a BAC in 1973, legalization in 1983, and statewide plan adoption in 1988. Washington created a department and a BAC in 1978 and followed up with legalization and plan adoption in 1991. Clearly, local conditions are important in determining the exact sequence of events leading up to the adoption of a statewide bicycle plan.

LEGAL STATUS

In states where the bicycle is a legal vehicle, bicyclists generally have the same rights and responsibilities as do drivers of any other type of vehicle on public streets and highways (*6*). Most states treat the bicycle as a legal vehicle (Table 1). The few states that do not are often much less active in promoting other bicycle activities as well. None of these states has a state bicycle plan, for example. Only 21 of 37 states (59 percent) where bicycles were treated as legal vehicles were able to provide the year in which that legislation was enacted. The year of enactment ranged from 1926 to 1991, with the average year of legalization being 1971. Seven states (32 percent) passed legislation before 1970. Only two states (10 percent) passed legislation during the 1970s. Eleven states (50 percent) passed legislation during the 1980s, and two states (9 percent) passed legislation in the 1990s.

FUNDING

The nature of activities in which a state bicycle program can participate is to a large extent a function of the availability of funding (*7*). Thirty states provided information on sources and amounts of bicycle funding. Twenty-two states (73 percent) had some funding available and identified the source. Of the states that had bicycle funding available, 17 (77 percent) used state funds, and 12 (55 percent) used federal funds. Few states had funding available from local, private, or other sources.

Twelve states provided the amount of funding available from the state. This ranged widely, from just $4,000 to more than $15 million, with a median of about $500,000 annually. Five states spent more than $1 million, and five spent less than $100,000 annually on their bicycle programs. Few states identified the amount of funding received from sources other than the state.

Nine of 33 responding states (27 percent) indicated that dedicated sources of funding were available for bicycle activities. Four states had dedicated bicycle revenue sources under $400,000. Two states had dedicated sources of more than $1 million annually. Three states had dedicated funding from a specific revenue source, such as 1 percent of the state gasoline tax. Dedicated funding helps ensure that bicycle activities will be carried out in a timely fashion.

Bicycle capital projects enhance the physical quality of the bicycling environment (*8*). When bicycle facilities are safe and readily available, more cyclists are likely to ride (*9–11*). Fourteen states provided information on the number and costs of bicycle capital projects funded annually by the state. The number of projects identified in the survey ranged from 1 to 13, with a median of 2. The number of bicycle projects completed by each state is obviously quite low compared with other types of transportation capital improvement projects, such as those for highways or transit. The total annual cost of bicycle projects identified by responding states ranged from as little as $100,000 to more than $11 million, with a median value just under $1 million. The average cost of bicycle projects varied from less than $50,000 to more than $5 million, with a median value of more than $500,000. Bicycle capital projects clearly are often quite low, though more ambitious projects were funded before the passage of ISTEA.

Twenty-six states provided information on the types of bicycle capital projects funded by states. Five different types of bicycle capital projects were identified (multiple responses were possible for each state):

- System improvements [major bicycle projects, including separate bike paths, bike lanes, recreational trails, shoulder widening, and bikeways (79 percent)],
- Incidental improvements [minor bicycle projects, usually implemented in conjunction with major highway projects, including reoriented gratings and curb cuts (36 percent)],
- Crossing facilities [bicycle undercrossings and overpasses (18 percent)],
- Destination facilities [bicycle parking and rest stops (14 percent)], and
- Route marking [projects that focused on route marking or signing, without any other facilities improvements (7 percent)].

Twenty-nine states identified the origination of their bicycle capital projects, whether at the federal, state, local, or other level. In most states (86 percent), at least some bicycle projects originated at the local level. Many, but by no means all, states (62 percent) had bicycle projects originating at the state level. Few states (17 percent) had bicycle projects originating at the federal level. Only one state (3 percent) had bicycle projects originating at other levels.

Bicycle programs are different from bicycle projects (*12–14*). Bicycle projects deal with physical changes to the bicycling environment. Bicycle programs deal with other aspects of bicycling. Bicycle programs can be grouped into five general classifications: education, engineering, enforcement, encouragement, and "other." Thirty-four states provided information on the types of bicycle programs available in their state, as follows: education [development of safety classes and bicycle curricula for schools (59 percent)], engineering [development of bicycle facility design standards (47 percent)], enforcement [development of courses on ticketing for code violations, safety enforcement, and bicycle law enforcement (41 percent)], encouragement [development and implementation of state bike week, helmet campaigns, bike rodeos, bicycle maps, bicycle conferences, and the dissemination of tourist information (38 percent)], and evaluation [collection of accident data and preparation of special bicycle studies (38 percent)].

No single program category stands out, indicating the wide diversity of bicycle programs developed independently by individual states before ISTEA.

PLANNING AND PROGRAMMING

The bicycle department or position usually provides the focus of and impetus for all of a state's bicycle activities. The bicycle department or position is important in ensuring that bicycles are considered in all state projects and in handling all of the department's bicycle concerns. A total of 25 out of 43 responding states (58 percent) indicated that they had a bicycle department or position currently in place. Thus, almost half of all responding states lacked the basic foundation for a more active state role in bicycle planning and programming. Of the 25 states with a bicycle department or position, 19 (76 percent) provided the year in which the department was established. The year of establishment ranged from 1971 to 1992, with the average being 1981. A total of 10 states (53 percent) established the bicycle department or position in the 1970s, 4 (21 percent) in the 1980s, and 5 (26 percent) in the 1990s. The majority of state bicycle positions were established in the early 1970s or just the last 3 years.

The number of staff in state bicycle departments ranged from as low as 5 percent of one person's time up to seven full-time positions. The average number of staff was two. The median number of staff was one. Only three state bicycle departments had more than two full-time staff positions. Most states have very small bicycle departments, with only a limited number of bicycle planning positions. The size of the professional bicycle planning staff limits the amount of bicycle planning that can be accomplished.

Four states had no separate budget for the bicycle department or position. Eight states had annual budgets of $100,000 or less. Only three states had annual budgets of more than $1,000,000. The median annual budget was $83,000. The average annual budget was $1,437,281. The median budget more accurately reflects state-level activity, because the three states with unusually large budgets push the average well above the median value.

Departmental responsibilities varied considerably from state to state. Nine separate types of departmental responsibilities were identified from the survey responses, with multiple responses possible:

- Evaluate and develop bicycle planning guidelines and procedures, review projects for bicycle compatibility, and manage ongoing bicycle projects (72 percent);
- Coordinate bicycle issues with other agencies, coordinate the department of transportation's bicycle responsibilities, and assist local agencies (61 percent);
- Analyze data, maintain bicycle library, respond to tourist inquiries, and maintain information on other state's bicycle programs (50 percent);
- Review bicycle legislation and bicycle policy (44 percent);

Carry out long-range planning and project planning and develop statewide bicycle plans (39 percent);

- Prepare route maps for general distribution (28 percent);
- Recommend projects for funding and identify funding sources (22 percent);
- Develop education programs and safety materials (17 percent); and
- Encourage other agencies to develop bicycle programs, participate in bicycle conferences, and promote bicycling (17 percent).

The most common departmental responsibilities dealt with policies, procedures, planning, intergovernmental coordination, and information. These responsibilities appear to be more essential to the function of bicycle departments. The remaining responsibilities were far less widespread, but they may be as important to more active bicycle programs. The majority of bicycle departments or positions and their associated activities are located within the department of transportation, with a few activities scattered among other state departments. When activities are located in different departments, each department may establish its own "territory" including certain specific types of bicycle activities. When activities are scattered among many departments, it may be more difficult to coordinate efforts, and duplication of some efforts may also occur. With the increased emphasis given to bicycle planning in ISTEA, qualifications for statewide bicycle coordinators have shifted away from basic technical assistance and support to higher-level managerial responsibilities.

More than 90 percent of all states with bicycle activities had at least some of these activities located within the state DOT. Other state departments mentioned frequently as having at least some responsibility for bicycle activities included natural resources, police, parks and recreation, and education. State natural resources and parks and recreation departments generally focused on the recreational aspects of bicycling. As much as 50 percent of all bicycle trips made and miles traveled are for recreational purposes (*15,16*). State police and education departments often focused on bicycle safety issues. Bicycle conflicts with trucks and automobiles seem to have increased in many places as a result of the increasing popularity of this mode of travel for recreational and other trip purposes (*17,18*).

CITIZEN PARTICIPATION

Citizen participation in state bicycle planning usually is accomplished through the creation of a statewide BAC (*19*). The BAC can provide invaluable assistance to professional bicycle planning staff on a variety of local concerns, including the interests of citizens, bicyclists, and others concerned with bicycle issues (*20*). In some cases, it appears that the development and promotion of state bicycle programs was assisted greatly by the creation of an active BAC (*21*).

The BAC typically is called on to look broadly at the current rate of bicycle usage and resource allocation within the state and to recommend policy changes or new activities to meet the existing and future needs of state bicyclists. The BAC often seems to be a critical link in the path to establishing more active bicycle planning programs and activities. Overall, 22 of 43 responding states (51 percent) reported either having or having had a BAC.

Twenty of 22 states with a BAC (91 percent) were able to provide the year in which it was originally created. The year of BAC formation ranged from 1972 to 1992, with the average being 1984. No BAC was created before 1970. A total of seven states (35 percent) created their BACs in the 1970s, eight states (40 percent) created theirs in the 1980s, and five states (25 percent) created theirs in the 1990s. ISTEA does not require the formation of a BAC, as it does a state bicycle coordinator. Nonetheless, it seems likely that many more BACs will be created as a result of ISTEA.

Eighteen states provided the composition of BAC membership. BAC members were classified as public, private, or nonprofit. Most states (94 percent) had members that were public or private. Only 28 percent of BAC members were nonprofit. Public members included representatives from other state agencies, federal agencies, legislators, and local governments. Private members included user groups, bicycle clubs, environmental groups, and citizens with specific qualifications, such as being under age 21.

Seventeen states listed the objectives of the BAC. The objectives can be grouped into eight broad classifications, with multiple responses possible for each state:

- Advise on policy issues, recommend low-cost policies, programs, and projects, and recommend statewide trails (71 percent);
- Assist bicycle program in daily work, review bicycle programs, and recommend changes (47 percent);
- Promote bicycle activities and related programs (47 percent);
- Coordinate efforts in the public and private sectors and between state agencies and provide a communications link between bicyclists and state agencies (41 percent);
- Develop estimates of current and future needs, analyze bicycle facility development potential, evaluate current resources, and inventory existing trails (41 percent);
- Identify safety concerns (29 percent);
- Identify education needs (24 percent); and
- Collect bicycle data and prepare reports (18 percent).

BACs generally are much more policy driven than are state bicycle departments. "Other" BAC objectives tend to reinforce this policy orientation, with project planning and programming details generally left to the professional bicycle planning staff. Twelve states listed the accomplishments of their BACs to date. The accomplishments fell into six general classifications, with multiple responses possible for each state:

- Development of model legislation, facilities planning guidelines, or procedural recommendations that apply throughout state government (75 percent);
- Development of bicycle program reports, reports on current conditions, case analyses of successful projects, standard planning documents, and state bicycle plans (58 percent);
- Public workshops, conferences, official bike weeks, safety classes, and helmet campaigns (33 percent);
- Adoption of an annual bicycle construction program and recommendation of specific projects (25 percent);
- Development of bicycle maps, bicycle signage, and related promotional brochures (17 percent); and
- Development of guidelines for state financial participation in bicycle projects, mini-grant programs for local governments, and grants for statewide recreational trails (17 percent).

Policy recommendations, often in the form of an annual report or draft state bicycle plan, are often the most tangible accomplishment of BACs. Funding is less often accomplished by or the direct objective of BAC activities.

STATE BICYCLE PLANS

State bicycle plans outline existing conditions and policies and provide direction for the development of expanded bicycle programs and activities in the future (*16,22,23*). Only 7 of 43 responding states (16 percent) indicated that a state bicycle plan was currently in force. Five additional states (12 percent) indicated that a state bicycle plan was in development.

- Delaware has just completed a draft state bicycle plan, which covers a wide range of topics: encouragement, information, recreation, funding, property acquisition, planning and design, maintenance, safety education, law enforcement, and legal and legislative affairs (*24*).
- Florida had an old state bicycle plan adopted in 1981 and completed a new comprehensive state bicycle plan in 1990.
- New Hampshire has a state bicycle plan adopted in 1977 that includes a statewide bikeway system plan, design and maintenance of bike lanes, and the primary objectives of the bicycle program.

Tennessee has a plan called "Bicycling in Tennessee" adopted in 1974 and 1975. The plan includes an inventory of users, facilities, and programs; a framework for establishing state policies; a plan for bicycle facilities and programs; and a planning and design manual.

- Oregon had an old state bicycle plan adopted in 1988 and a proposed
plan for adoption in 1992. The new plan is supposed to serve as a complete bicycle modal element in the state transportation plan (*25,26*).

State bicycle plans try to be comprehensive in dealing with all statewide bicycling planning concerns. Some states have developed shorter or more generic bicycle policies, which provide some guidance on the future of bicycle improvement programs without specifying detailed planning requirements at the state level (*27–29*).

CONCLUSIONS

Only about half the states surveyed had active bicycle planning programs. Only about a quarter of responding states could be considered very active in bicycle planning. For states embarking on expanded bicycle activities, perhaps for the first time, the information provided in this paper may prove to be useful.

The process of expanding state bicycle planning activities often is associated with the passage of legislation making the bicycle a legal vehicle, but this is by no means required. The establishment of a bicycle department or position, the formation of a bicycle advisory committee, and the identification of funds, preferably dedicated at their source to bicycle activities, all are conducive to increased state involvement in the encouragement of greater use of bicycles for recreational or other transportation purposes. The development and adoption of a comprehensive statewide bicycle plan generally seem to require all or at least some of these middle steps in order to transpire.

As the planning requirements of ISTEA are clarified, state bicycle planning programs should expand. The change in the level of state bicycle planning and related activities should assist in meeting the needs of bicyclists more rapidly than in the past. As the general environment for bicycling becomes safer and more accessible, bicyclists should increase in number, bringing with them the benefits of cleaner air, less noise, more efficient use of energy resources, and more effective use of existing state transportation systems.

ACKNOWLEDGMENTS

The authors thank Kevin Heanue of FHWA for his thoughtful assistance in identifying the location of state bicycle planning programs and coordinators in the United States, without which this survey research project could not have been conducted successfully. An earlier version of this paper, authored by Dawn Inglis, won the first annual Award for the Best Student Paper in Transportation Planning from the American Planning Association, Transportation Planning Division.

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Transportation in Developing Countries: Obvious Problems, Possible Solutions

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Solving transportation problems is one of the chief tasks confronting governments in developing countries. Despite large expenditures on urban transport systems, ranging from 15 to 25 percent of their total annual expenditures, the current problems have not eased; on the contrary they seem to get worse. Developing countries, therefore, have a major crisis on their hands. The scale and nature of the mobility problem in the Third World and the role of nonmotorized and intermediate-type motorized modes in meeting the mobility needs of the growing population are discussed. Background on the transportation situation in developing countries is provided. The prevailing transport policies are examined, and the basic characteristics of nonmotorized and intermediate-type motorized transportation with respect to speed-distance-time relationships are described. City size and city form vis-à-vis nonmotorized transport are examined. What constitutes a good environment for nonmotorized and intermediate motorized modes is discussed, and transport projects that would benefit the poor are described.

Regardless of how we view the future, we cannot ignore it, for as Harmon reminds us, it is where we are going to spend the rest of our lives (*1*). It is useful then to start our discussion by considering the size and nature of the mobility problem confronting developing countries. Urbanization is occurring all over the world, and the most reliable forecasts indicate that by the turn of the century almost half of humanity will live in urban centers. The rate of population growth in the developing countries is 2.5 percent per year as opposed to 1 percent in the developed world, and this disparity is phenomenal. Just over the last 65 years, the developing world's urban population has increased 10-fold, from around 100 million in 1920 to 1 billion in 1985. And between 1985 and 2000, cities in the Third World are very likely to grow by another three-quarters of a billion. These figures suggest that developing countries must increase their capability to supply and effectively manage their urban infrastructure by at least 75 percent merely to maintain their current level of service, which, to say the least, is woefully inadequate (*2*). Solving transport problems has thus become one of the chief tasks confronting governments in the developing countries. Despite large expenditures on urban transportation systems, ranging from 15 to 25 percent of their total annual expenditures, the current problems have not eased; on the contrary they seem to get worse. Indeed, few city governments in the developing world have the power, resources, and trained personnel to provide adequate services to improve the current situation. Developing countries, therefore, have a major urban crisis on their hands (*2,3*). A majority of developing countries cannot provide sufficient investment in public transportation to keep up with population growth, and even if such transport were provided, a large proportion of the poor would not be able to afford it. The poor can only afford to walk or bicycle (*4,5*).

This paper focuses on modes of transportation and relevant projects that directly help the poor in developing countries, and therefore the major focus is on nonmotorized modes. The paper provides a brief background of the transportation situation in developing countries; examines the transport policy implications of developing countries; describes the basic characteristics of nonmotorized transportation, in particular the speed-distance-time relationships; examines city size and city form vis-à-vis nonmotorized transportation; investigates what constitutes a good environment for nonmotorized and some intermediate motorized modes; and describes transport projects that would benefit the poor.

BACKGROUND

The importance of transportation lies chiefly in its contribution to the large economies of scale and specialization associated with urban areas. Transportation facilities expand the options for work, education, health, and other amenities and directly affect the economic efficiency of cities and the well-being of their inhabitants. Provision of the minimum transportation facilities within the various limited resources available is the most critical problem in developing countries.

However, other aspects of transportation need to be noted. Transportation modes used in developing countries around the world are highly diverse. It is estimated that 600 million person-trips a day are made by city buses and that a similar number are made by rail and rural buses. A quarter of a billion trips are made by 50 million automobiles. In contrast, several billion bicycle trips per day are made by well over half a billion bicycles in developing countries, and daily pedestrian trips exceed 10 billion per day (*3*).

The frequency and choice of a mode depend on such diverse factors as infrastructure design, topography, climate, socioeconomic conditions, income levels, land use patterns, subsidies, taxes, and tariff policies. However, everybody is affected by acute transport problems, particularly because of the scarcity and the high cost of transportation. The proportion of income spent by the poor on transportation is about 1/10 of their total income. Naturally, the proportion of trips made on foot and by bicycling is high. Although alternative transport is available, the urban poor in developing countries must resort to nonmotorized modes. The concept of the value

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of time and the utility of time savings is generally not a significant factor for the poor and is put into practice only in emergencies (*6,7*).

TRANSPORTATION POLICY IMPLICATIONS

It may come as a surprise that most developing countries do not have a stated policy on passenger mobility per se. The main focus is on the movement of freight traffic to fulfill output targets set by the countries in their 5-year plans. When transportation projects are planned and budgets allocated for implementation, little attention is paid to passenger travel. This policy has led to a progressive deterioration of traffic conditions for practically all modes of passenger transport in developing countries. Most ironically, developing countries seem to focus on encouraging motorization and appear to be indifferent or even opposed to low-cost, nonmotorized modes, despite the vital role they play in the local economies and the mobility and accessibility they provide for low-income inhabitants (*5*).

Even when it comes to transportation planning, developing countries generally adopt the methodologies conventionally practiced by developed countries, and the results have been very discouraging (*8*). Prud'homme (*9*) confirms this craze in developing countries for using the questionable classical set of models, used in the Western world, based on the concept of quantifying trips instead of critically considering in their analysis such items as poverty, human fatigue, cultural values, and equity.

NONMOTORIZED TRANSPORT CHARACTERISTICS

The degree of motorization in developing countries is associated with the level of income of a city (and the country it is located in). A strong relationship exists between the average per capita income in a developing country and the number of automobiles per thousand population. According to recent estimates, walking trips account for two-thirds of the total trips in large African cities such as Dar es Salaam, and walking and cycling trips account for between 40 and 60 percent of the total trips in several large cities on the Indian subcontinent (*10*).

The predominance of the nonmotorized modes should come as no surprise; they are some of the most efficient. Examination of the capacities of modes indicates that a sidewalk can carry more people per foot width per hour than any other form of track except exclusive bus lanes or rail track (about 1,100 can be accommodated at a speed of about 2 mph). Low speeds and fatigue can of course limit walking trips to about 2 to 3 mi. However, the demand for walking trips is the highest. Bikeways are also relatively inexpensive and yet efficient. At speeds of about 8 mph, the capacity of bikeways can reach 450 per foot-width, or 1,800 persons per bike lane, which easily exceeds that of automobiles and equals that of fully occupied buses. Thus, bikeways offer a great potential for developing countries (*3*).

SPEED-DISTANCE RELATIONSHIPS

Transportation planners are well aware of the high correlation between trip length and the demand for speed in people's daily experiences in choosing a mode of travel. For example, in the developed world it has been observed that when the time of travel is doubled, the distance covered increases 10-fold, whereas the speed increases 5-fold (*11*). Planners are cognizant of the "refusal" distance of an average pedestrian, who will not choose to walk more than 400 m (or ¼ mi). Beyond 400 m the majority of pedestrians in North America would demand some type of mechanical system to transport them. But, since bicycling or riding a bus is not popular in the United States, the pedestrian in our case is most likely to hop into a car to cover the distance! There is ample evidence that the trip maker's choice of mode is not based on cost alone, but also on travel time; subconsciously, distance is connected with time. Research conducted by Kolbuszewski (*12*) and Khisty (*13*) has resulted in simple relationships connecting T, the time of travel (min), d, the distance covered (km), and v, the speed (km/hr): $T = 6.6d^{0.30}$ and $d = 0.043v^{1.42}$. This phenomenon generally produces the three dominant modes in the Western world: walking for short distances, driving a car for medium distances, and the airplane for long distances. This dominance also produces several "transportation gaps." Table 1 indicates how the three dominant modes take care of the entire spectrum of transport in the developed world, particularly the United States.

The transportation modal hierarchy in the developing world is radically different from that of the developed world. Whereas time is certainly equivalent to money, a reduction in travel time means an increase in speed; and speed costs money. But since the average income of developing countries is low, the speed-distance relationship depends heavily on the perceived relative value of time, which again depends on cultural, social, and economic characteristics of the population.

A comparison of some of the principal modes of travel available in developed and developing countries, based on time (T), speed (v), and distance (d) parameters, is given in Table 2. The most striking conclusion from this comparison is that the value of time in developing countries in general is not as crucial as that in developed countries. For example, whereas the "refusal" distance of the walking mode in developed countries is 0.4 km (¼ mi), the corresponding distance for developing countries is 2 km (1.25 mi). Similar ranges for the bicycle mode are 1.5 km and 9 km.

TABLE 1 Transport Distance-Speed-Time Functions for the Developed World

Distance (km)	Time (min)	Theoretical Speed (km/hr)	Mode Alternative
0.4	5.0	5	Walk
1.0	6.6	10	Bicycle[a]
4.0	10.0	25	Car, bus[a]
10.0	13.2	50	Car
40.0	20.0	120	Car
100.0	26.4	225	Car
400.0	40.0	600	Small plane
1000.0	52.8	1125	Jet

[a] This mode used by a very small percentage.

TABLE 2 Comparison of Modes in Developed and Developing Countries in Terms of Time/Speed/Distance

Modes	Developed			Developing			Countries						Ownership	Person Capacity per meter width/hr
							Indonesia			India				
	Speed (km/hr) v	Dist (km) d	Time (min) T	Speed (km/hr) v	Dist (km) d	Time (min) T	Speed (km/hr) v	Dist (km) d	Time (min) T	Speed (km/hr) v	Dist (km) d	Time (min) T		
Non-Motorized														
Walk	5	0.4	5	4	2	30	5	2	25	5	2.5	30	Personal	3600
Bicycle	12	1.5	7.5	12	9	45	12	9	45	11	5.5	30	Personal	1500
Bicycle-Rickshaw (3-wheel)	--	--	--	8	4	30	8	4.5	35	8	4	30	For hire	Variable
Motorized														
Scooter	25	4	10	20	10	30	25	30	75	20	10	30	Personal	100-200
Auto														
City	25	4	10	20	20	60	25	30	75	20	20	60	Personal	120-220
Arterial	50	11	13	65	130	120	50	102	120	65	130	120	Personal	750
Freeway	80	22	16.5										Personal	
Bus														
City	18	2.5	8.5	12	12.5	60	18	18	60	17.5	5.0	17.2	Public	2700
Express	80	22	16.5										Public	5200
Auto-Rickshaw (3-wheel)	--	--	--	20	20	60	20	22	65	20	20	60	For hire	Variable
	$T = 6.6d^{0.30}$ $d = 0.043v^{1.42}$			$T = 19.74d^{0.36}$ $d = 0\ 22v^{1.48}$			$T = 18.34d^{0.41}$ $d = 0.12v^{1.70}$			$T = 13.57d^{0.45}$ $d = 0.14v^{1.56}$				

What this shows is that nonmotorized modes—walking and bicycling—in developing countries offer a much wider trip-length range, and this fact by itself emphasizes their importance. In India, for example, as in several other developing countries, a variety of transport modes fill the gap between walking and the private car, and the distance range afforded by this variety needs to be taken advantage of in providing the transportation network and city form. Note that bicycles, bicycle-rickshaws, scooters, and other intermediate technology vehicles are ubiquitous in most developing countries, providing the needed mobility and accessibility in terms of the prevailing socioeconomic and cultural circumstances. Also, it is evident that the urban use of the automobile is inappropriate to its intrinsic speed, power, and size characteristics and has unfortunately led to a number of serious problems.

CITY SIZE AND CITY FORM

In almost all Third World countries, ideas about land use and transportation planning are firmly rooted, and, unfortunately, motorization is still seen as a key indicator of economic progress (*14*). It is remarkable that in the last 1,000 years, planners have been discussing the optimum size of a city and have ironically come up with a broad range for a city from about 50,000 to about 200,000 population. From a sociological standpoint, smaller cities outperform larger ones in any number of social variables such as absence of crime, health, mental health, recreation, and education. Economically, annual expenses per capita for a city of 1 million are 300 percent greater than for a small city of 50,000 to 100,000 (*15*). From a transportation viewpoint it is well known that the quantity of movement (person-miles traveled or ton-miles transported) grows geometrically as city size increases (*16*). Trip lengths vary from about 2 mi for a city of 50,000 to about 6 mi for one of 1 million. The important fact is that more trips have to be made by motorized means as city size increases, resulting in proportionally higher operating costs. It has therefore been proposed, time and again, that the growth of population and economic activities should be shifted from large agglomerations to small and medium-sized cities. Maunder's research indicates that restructuring of land use by locating the place of work as close as possible to the workers' residences (or vice versa) could lead to a 30 percent reduction in the number of trips by bus and over a 100 percent increase in trips by bicycle and walking (*17*). Another way of reducing trip lengths is by not having single-function zones. Single-function zones result in excessively long trips, not to mention excessive energy consumption and adverse environmental impacts. Thus, mixing residential, commercial, and certain low-pollution industrial land uses improves mobility and access to employment opportunities for the low-income population, which relies solely on nonmotorized transportation (*18*).

WHAT CONSTITUTES A GOOD ENVIRONMENT FOR NONMOTORIZED TRANSPORT?

Since walking is the dominant mode in developing countries and is influenced by trip length, weather, and the availability and cost of alternative modes, pedestrians need safe, comfortable, direct, and accessible routes covering the city. Enhancing the pedestrian domain involves reducing travel distances; increasing land use flexibility; eliminating pedestrian barriers and obstacles; leveling walking routes; ensuring continuity of travel; providing protection from wind, rain, noise, cold, heat, and pollution; eliminating conflict with other modes of travel; and increasing character through visual diversity and amenity. This list may seem at first sight to be unrealistic, but the objectives are justified by the fact that in hundreds of cities in the developing world almost 50 percent of the trips are made by walking, not for keeping fit, but primarily because of poverty. Imagine, for a moment, how different these cities would be today if 50 percent of all funding allocated for transportation improvement (in proportion to pedestrian usage) were used to improve the pedestrian domain! Local climatic conditions should be reflected in the detailed planning and design of sidewalks and routes used by pedestrians because a large majority of pedestrians will be among the poorest and most debilitated of the poor. For them, the shortening of trip lengths and provision of reasonable walking comfort should be considered not just as matters of convenience but as factors affecting basic productivity (*8,19*). The advantages of walking and bicycling relative to other modes have long been recognized and include absence of capital costs for vehicles, absence of any foreign exchange requirements, and the need for very inexpensive infrastructure.

The bicycle is one of the most convenient and energy efficient forms of individual transport. It is available to everybody, especially the poor, because costs are low for both the user and the government. Operating cost per bicycle-mile is lower than for walking because of the value of time. Bicycle use can be easily encouraged by providing lightly surfaced paths parallel or adjacent to local streets. Simple parking structures with bicycle racks can be provided in center city locations. In some cases, where the demand for bicycling warrants it, exclusive bike lanes may be provided, and this kind of construction may be an excellent means of preserving future rights-of-way for an expanded transportation network (*20*).

Although most cities in developing countries lend themselves to bike commuting, bicycles in general do not perform well on streets having gradients in excess of 3.5 percent or on poorly surfaced roads. The fact that most bicycles in the third world are equipped with only single gears calls for particular attention to good surface conditions. Separate bikeways for high-demand corridors is probably the best solution.

The bicycle rickshaw, pedicab, or "becak" is essentially a nonmotorized mode of public transport. These pedal-powered vehicles constitute a predominant element in the street traffic of cities like Dacca, Bangladesh, and account for both passenger and goods movement. In India, Pakistan, Thailand, Indonesia, and other countries around the world the rickshaw has attained similar importance. It is an economical vehicle and fills a valuable role in the nonmotorized hierarchy because of the following characteristics: (a) its low capital cost and easy licensing arrangement are a source of employment for the poor; (b) its size allows this three-wheeler to negotiate narrow streets and alleys and other areas of the city where few vehicles would be able to go; and (c) its versatility allows it to carry produce to market, children to school, and commuters to work (*5,20*).

The three-wheeled bicycle rickshaw has been thoroughly studied by researchers from the socioeconomic and transportation points of view. The general conclusion is that this form of transport provides a flexible and personalized service (*5,21,22*). Also, the manufacture, maintenance, and operation of these vehicles provide a steady supply of employment to workers ranging from highly skilled to unskilled. Improvement of the rickshaw through the addition of a motor has advantages discussed later in this paper. Bicycle rickshaws require a smooth riding surface and grades not exceeding 2 percent; motorized rickshaws are able to handle grades up to 3 percent (*20*).

Animal-drawn and human-powered carts (handcarts) are an important part of the nonmotorized spectrum of vehicles plying the roads and streets of developing countries. Because they require low capital investments, the cost of haulage of goods by this mode is often competitive with (and at times cheaper than) mechanized transportation. Their unit capacities make them relevant for small-scale operation at ports, warehouses, shopping centers, and other terminals. In addition to being able to withstand low standards of road surfaces, they are able to access narrow alleys and lanes in densely populated areas of the inner city. Despite their low speed, they serve a useful function.

OTHER TRADITIONAL MOTORIZED MODES

Whereas traditional modes bear a variety of local names, according to nationality, they generally provide adaptable forms of transportation at relatively low capital cost. The production, maintenance, and repair of these vehicles also provide a useful source of low-skilled employment. In some respects these traditional modes resemble bicycle usage, because they serve widely dispersed destinations and can be readily adapted for use in various environments (*20*). The key to effective urban transportation, particularly in developing countries, is flexibility, and the most striking feature in southeast Asian cities is the variety of transportation modes, particularly vehicles with two, three, or four wheels that supplement and complement pedestrian travel. These vehicles, called variously helicaks, minicars, bemos, mebeas, autorickshaws, four-seaters, tempos, cycle-motors, lambros, and samlors, offer a range of technological sophistication. Most of these transport forms have arisen spontaneously in response to social needs, illustrating the diversity of solutions available to the problem of moving people and freight around a city with a minimum of resources. This is an example of the effective adoption of appropriate technology that is ideally suited to these societies, because the marginal cost of additional transportation capacity is small for the entrepreneur and, for the government, often nothing. Therefore, intermediate motorized modes need to be encouraged and may possibly lead to the future deemphasis of private automobiles (*8,23*).

PROJECTS AND MODES THAT AFFECT THE POOR

The fact that a large sector of the population of developing countries cannot afford any form of motorized transportation underlines the necessity of providing facilities for nonmotorized travel. Attention should therefore be placed on projects that provide transportation directly to the urban poor. It may be useful to begin by considering the purpose of transport projects that will benefit the poor: (*a*) to provide jobs and accessibility to jobs, (*b*) to distribute essential commodities used by the poor and to keep the distribution cost as low as possible, (*c*) to facilitate access to essential urban services, (*d*) to facilitate social interaction, (*e*) to increase the supply of land suitable for settlement by the poor, and (*f*) to allocate land use so that the average trip length is as short as possible and can be accomplished by nonmotorized transportation as far as possible (*20*).

With the scarcity of resources available, it may be highly improbable that major road projects will be undertaken. Instead, there is the possibility of small projects that can help improve conditions for the poor almost immediately, such as paving improvements, minor changes to road geometrics, widening of streets and lanes, and addition of sidewalks or bicycle lanes. Streets in urban areas of developing countries are generally used for a wide variety of purposes. Contrary to views of utility in the West, where nonmotorized transport is considered to belong to the nuisance category, multiple uses of street space, particularly where light traffic prevails, should be viewed as an efficient use of public capital. All road improvement projects need to be analyzed to reflect the variety of functions served by street space, including right-of-way space. This analysis would help uncover methods of encouraging employment of the poor in construction and maintenance of the roadway and accompanying facilities. Pedestrian and bicycle movements on and across major streets should be controlled through proper placement and enforcement to increase the safety of nonmotorized traffic.

In improving existing or proposed facilities for nonmotorized transport, three aspects of planning should be kept in mind: (*a*) the general nature of non-Euclidean metrics, as opposed to Euclidean metrics (which is the length of the shortest possible path joining a pair of points), (*b*) the sensitivity of nonmotorized movement to delay and hazards on account of motorized traffic, and (*c*) the use of plastic space (i.e., the relationship between time space and geographic space) in exploring efficient forms of spatial organization and reorganization. These ideas have been addressed in detail in recent literature (*24–26*).

In summary, cost-effective transportation system management strategies can improve mobility and accessibility and reduce accidents. The question that almost always arises is, should one repair, rehabilitate, reconstruct, or replace existing facilities? These decisions should be based on evaluations of life cycle considerations and costs, preferably early in the life of a transport system, because these evaluations influence the entire useful life of the facility and determine its true cost to the public (*27*).

CONCLUSIONS AND RECOMMENDATIONS

Urban transportation planning in developing countries is still in its infancy, and criteria for identifying appropriate planning methods and formulating appropriate projects are urgently needed. The scarcity of resources and the mounting pressure to provide transportation facilities to a rapidly growing urban population require that major changes be made in priorities for selecting projects for the urban poor. Changes are also needed in transportation policy making in developing countries. Opportunities still exist to achieve resource-efficient transportation service without resorting to capital-intensive projects. The following recommendations are worth considering:

1. Attention should be paid to the distance-time-speed relationships prevalent for nonmotorized and some intermediate-type motorized modes. Energy and road capacity issues connected with these modes should be critically examined.
2. City size, city form, and issues connected with mixed land use need to be kept in mind, considering the fact that the distance ranges of nonmotorized modes are far more flexible in Third World countries than in the developed world.
3. Projects that fall under the rubric of transportation systems management (i.e., construction, operation, and institutional tasks to make the most productive and cost-effective use of transport facilities) should be undertaken, particularly those benefiting the poor.

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Policy Making and Planning for Nonmotorized Transportation Systems in Third World Cities: A Developmental Approach

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A developmental approach to planning for nonmotorized movement in urban areas is advocated as a basis for the formulation of more acceptable and appropriate policy frameworks for transportation systems in Third World cities. To illustrate some of the points raised, general reference will be made to Asian countries, and specific reference to Indonesia. Given current changes in emphasis toward environmentally more conscious planning and the needs of the urban poor, three areas of concern are highlighted: the call for a recognized and planned role for nonmotorized urban transportation systems within the broader spectrum of urban transportation networks; the need to acknowledge the productive and survival-support functions of nonmotorized transportation and identify ways that may be used to better assess them; and the requirement to link planned attempts at meeting nonmotorized travel needs with urban development planning and environmental protection efforts. Addressing these areas of concern by means of advocating a developmental approach to urban transportation planning, as opposed to an accommodative approach, offers an opportunity to reshape policy making and planning for urban transportation in a way whereby broader goals of sustainable development can be better achieved. An approach of this kind pays more attention to the "lowerarchy" of city transportation systems traditionally ignored by conventional planning and so important to nonmotorized movement.

It is apparent that a broad consensus is at last emerging in influential quarters of international development agencies that sees the past preoccupation with motorized and high-technology transportation systems as detrimental to almost all else—not only a partial view of urban transportation developments but a damaging one.

The inclusion of nonmotorized travel and environmental impact issues on the Asian urban transport agenda—along with the more conventional concerns for transportation operations efficiency and economic viability—is a belated acknowledgment by the international banking community that there are unacceptable costs to unlimited motorization. Significantly, many of these costs occur outside concepts of transportation systems optimization and optimal fiscal management usually associated with the sector. These external costs, as they are sometimes also known, have to do with less easily quantifiable concerns about the decline in quality of life, increased health hazards, and doubts about the survival of an ever-increasing number of underprivileged urban inhabitants. Unless adequately addressed, these costs bring about social and political disruptions in the face of single-minded efforts to increase productivity and economic growth.

To ensure that the new concern by international development agencies for nonmotorized travel and environmental impacts of transportation systems receives the full institutional support of such agencies, a strategy (indeed a package of strategies) is needed to rationalize the role of nonmotorized travel. To be effective, such a strategy must be linked to sustainable urban development policies (including environmental and social justice goals), economic productivity targets, and the more conventional operations efficiency concerns of multimodal urban transportation systems. The developmental approach to urban transportation planning advocated here is a strategy of this kind.

ASIAN URBAN TRANSPORTATION ISSUES

One of the most recent and well-researched accounts of current trends in Third World urban transportation is the report *Urban Transport in Asia* (*1*) published by the World Bank. Some of the key observations and conclusions of this report are summarized below.

Nonmotorized Transportation and the Urban Poor

It is common knowledge that the poor are most dependent on nonmotorized means of transportation for both personal and goods movement, particularly walking and cycling. Measures that address the needs of this kind of movement inevitably affect the opportunities of the underprivileged.

According to World Bank statistics, some 70 percent of the world's poor may be found in the Asia and Pacific (ESCAP) region. This implies that 700 million people in this region earn annual incomes below $370 (US). Although estimates indicate that Asia's share of the globe's poor will decline to 53 percent by 2000 (*2*), an increasing proportion of the poor is projected to reside in urban areas.

In 1988, one quarter of Third World urban inhabitants (some 330 million people) were estimated by the World Bank to be poor. By the turn of the century the urban population of Asia will increase by 420 million, from 1.2 billion to 1.6 billion.

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On this basis, assuming the same proportion of poor living in urban areas of Asia, some 400 million Third World urban inhabitants will be poor by 2000. This represents a huge increased dependence on nonmotorized means of travel in cities, which has a number of serious ramifications. Among these is not only the much discussed mushrooming of motorized traffic in many Asian cities but also the rapidly mounting demand for affordable transportation facilities by the urban poor.

City Motorization Trends

Asia is endowed with the widest diversity of transportation modes in the world, especially nonmotorized means. There is, however, according to the aforementioned World Bank Report, only limited evidence of specific measures being taken to accommodate the needs of nonmotorized movement. More worrying is the growing evidence that this type of travel is increasingly constrained by governments to facilitate the needs of motorized traffic.

The rising tide of motorization that fuels traffic congestion has its roots in the high rates of urbanization and economic growth and increases in personal incomes in the region. The paradox of the Asian region is that it contains some of the highest and lowest motorization rates. At present Asia has just over 10 percent of the world's automobiles and over 25 percent of the global truck and bus fleet. In addition, numbers of motorcycles are also increasing dramatically [this mode is seen by some as a logical progression from the bicycle and a much faster alternative to the crowded public bus (*1*)].

According to the World Bank study, over the last decade the region has experienced a significant reduction in the number and use of nonmotorized vehicles outside China—although the converse is true within China. Overall, the most widespread mode of nonmotorized transportation in the whole region is the bicycle. There are at present some 300 million in China, 66 million in Japan, 45 million in India, and 6 million in Korea. Together, they account for more than 50 percent of the world's estimated total bicycle population of 800 million.

Other Emerging Problems

The problems associated with the motorization trends identified above manifest themselves in widespread traffic congestion and resultant declining travel speeds in the downtown areas for increasingly longer periods of the day, greater fuel consumption, rising pollution levels, and negative effects on the productivity of cities, estimated in Asia to often contribute to more than 50 percent of gross domestic product. These problems are further aggravated by the reluctance of politicians to deter rising vehicle ownership levels among the middle classes, which is seen as both a reward of modernization and a source of government revenue.

The results are unacceptable levels of vehicle emission, rising traffic accidents (costing in some cases as much as 1 percent of gross national product), declining levels of service of bus transport, and intolerable noise levels in urban areas. Perhaps most sinister of all, the World Bank study concludes, is that many new roads in Asian cities are beginning to separate rather than link people.

In attempting to provide capacity for more motor vehicles, many Asian cities have sacrificed their footpaths to widen roads and have neglected on a grand scale the "lowerarchy" of their city transportation systems, including the streets in squatter areas and alleyways of older parts of the city not easily accessible by motorized traffic.

Fortunately, the World Bank and other international development agencies are belatedly recognizing what many NGOs have long been arguing: that nonmotorized vehicles not only offer low-cost personal mobility but are also nonpolluting, users of renewable energy, labor intensive (and thus offer greater employment opportunities), and well suited for short trips (the largest number in urban contexts). As a result, there is now widespread acknowledgment that nonmotorized vehicles need to be planned and managed as an integral part of a city's entire transportation system and that technical guidelines of the kind advocated in the latter part of this paper are needed.

Proposed World Bank Strategy

Given the circumstances described, the World Bank study advocates a six-point strategy to tackle the challenges currently emerging in the region's urban transportation sector:

1. Subordinate urban transportation lending to overall urban development objectives and policies;
2. Clearly articulate the role of transportation in enhancing economic productivity, the personal mobility of the urban poor, the urban environment, and financial viability;
3. Take into account the performance of the entire urban transportation system when making specific investment decisions;
4. Lend on the basis of both traffic demand management and environmental management;
5. Make urban transportation lending more responsive in terms of timing; and
6. Achieve faster responses in lending operations and greater sustainability.

For this strategy to work, the agency recognizes that it cannot operate alone but rather that it should play a catalytic role in the urban transport sector by providing a forum, framework, and rationale for future action. It is hoped that the ensuing discussion will contribute to these efforts.

TRANSPORTATION AND SUSTAINABLE DEVELOPMENT

Changes Needed

It is clear from both the preceding and other writings [also see Replogle (*3*)] that major changes are needed in urban transportation priorities in the Third World if development is to meet a broader spectrum of human needs rather than primarily benefiting the current elite. Similar conclusions (from a different perspective) were arrived at by Newman and Kenworthy (*4*) in their international study of automobile dependence in cities of the industrialized world.

The belief that it is time to recognize the need to incorporate social as well as economic development considerations in urban transportation planning exercises is similar to concerns expressed elsewhere by the author (*5*) that a new direction in urban transportation planning be taken in which nonmotorized modes have a significant role.

Sustainability and the Urban Transportation Sector

Before outlining the developmental approach to planning for nonmotorized transportation as an appropriate response to the concerns discussed earlier, it is appropriate to define what sustainable development is and what the ingredients of a sustainable transportation strategy are.

A recent low-cost travel mode study in China funded by IDRC (*6*) describes sustainable development as

> a key term in the vocabulary of many organizations and planners [where] . . . there is a general agreement sustainability reflects a concern for reducing resource and material consumption to ensure the ability of future generations to sustain themselves.

Replogle (*3*) claims:

> Sustainable transportation calls for a more holistic approach to policy and investment planning to achieve a diverse and balanced mix of transportation modes and sensible arrangement of land use that enables conservative use of energy and capital to fulfill mobility needs. Sustainable transportation strategies are those that can meet the basic mobility needs of all and be sustained into the foreseeable future without destruction of the planetary resource base.

The literature on the subject indicates that the ingredients of such a strategy display a concern, among other things, for the following:

1. The provision of modal diversity and integration of urban transportation systems;
2. Lower-cost transportation systems and the planning and management of the "lowerarchy" of urban transportation networks, especially for pedestrian and bicycle movement;
3. The movement needs of the urban poor and underprivileged;
4. The distributional impacts of urban transportation investments;
5. The proportion of foreign exchange consumption by the urban transportation sector, particularly in the case of Third World countries with limited reserves;
6. Employment opportunities associated with transportation (directly and indirectly) both in the formal and informal sectors;
7. The limited investment in research and development in nonmotorized travel and low-cost, energy-efficient transportation systems;
8. Land use configurations that encourage heterogeneous patterns at a small scale and mix of housing types at different cost levels; and
9. Efforts to minimize the need to travel and associated negative environmental impacts.

DEVELOPMENTAL APPROACH TO PLANNING FOR NONMOTORIZED URBAN TRAVEL

Approach

The developmental approach to planning for nonmotorized travel in urban areas is part of a broader developmental approach to urban transportation planning that has regard to the translation of principles of development planning into the urban transportation sector first advocated by Dimitriou and Safier (*7*) and subsequently expanded upon in two recent publications (*6,8*).

The components and principal characteristics of the approach are shown in Figure 1. The approach relies on matching settlement and community size considerations with developmental policy contexts and the use of appropriate urban transportation technology. What essentially differentiates the developmental approach to urban transportation planning from more traditional methodologies is that the former relies much more on using transportation planning as an agent of planned development rather than merely as a tool of transportation systems optimization.

To ensure that urban transportation planning is subservient to efforts designed to achieve wider development goals (and is therefore developmentally effective), the complexities of the development context need to be better reflected within the transportation planning process. Development goals as well as development costs and benefits not only must be clearly stated (and wherever possible quantified) but also must be capable of disaggregation for targeted socioeconomic groups (such as the urban poor and nonmotorized travelers) and particular geographical areas.

The implementation of a developmental approach to planning for nonmotorized travel looks to measures aimed at improving the productive potential of cities, achieving a better distribution of urban opportunities, and improving the social life and physical environment. This approach, which was applied to Indonesian cities of differing sizes in Java (*9*) (discussed further later in this paper), advocates a strategy that focuses on the importance of nonmotorized movement, efforts at achieving strategic self-sustaining economic growth, the use of urban transport in the service of basic needs, and the integration of urban development efforts.

Matching Transportation Technology to Settlement Hierarchies

To encourage urban transportation technologies that are developmentally effective and simultaneously operationally efficient for the environment in which they are to be used, it is essential to discriminate between these two levels (and types) of transportation performance criteria, highlighting the subservience of the latter to the former.

"Developmentally effective" transportation technologies contribute to and are consistent with indigenous (national and local) development objectives that facilitate sustainable economic growth in a manner sensitive to development (including ecological) constraints. "Operationally efficient" transportation technologies, on the other hand, optimize the use of transportation facility capacities and resources at minimum

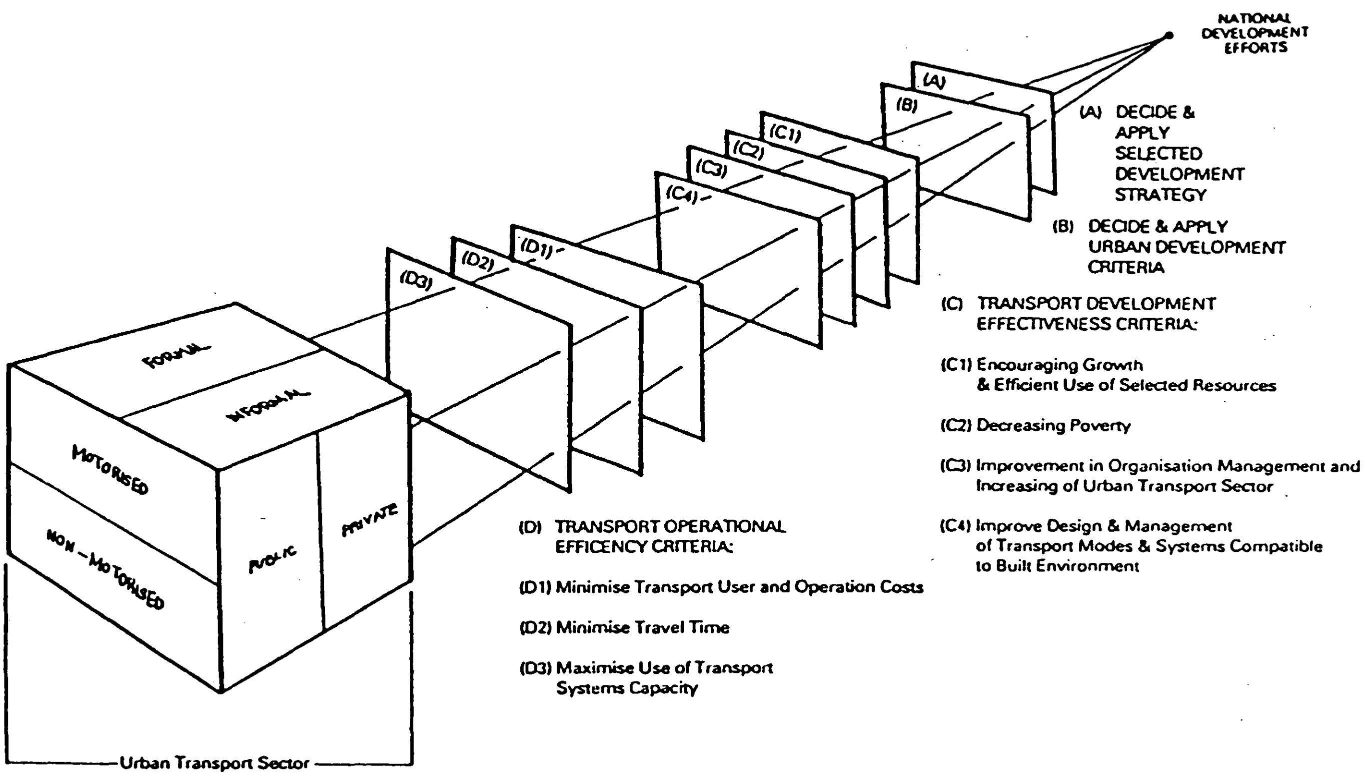


FIGURE 1 Developmental approach to planning urban transport (*5*).

cost to users and operators—this being typically measured in terms of capital, operational and user costs, systems revenues, and engineering efficiency.

Transportation Technology and Operations Efficiency

Bouladon (*10,11*) in research investigating the operational engineering efficiency of various transportation systems based on speed/distance and acceleration limitations, arrived at a "unified theory of transport" in which each transportation system is placed into its rightful role from the point of view of the engineering requirements it is to satisfy. He divided the transportation field into five areas (see Figure 2) and claimed that there should be an optimum means (in engineering terms) of transportation in each.

Bouladon's research indicated that in practice this is so in only three areas—those areas in which the pedestrian, the car, and air transportation dominate. He concluded that there are in fact two transport gaps—one between the pedestrian and motorcar users and the other between the conventional airplane and the space rocket. Between these areas, many other methods of transportation are currently in use but give less satisfaction in operational efficiency terms.

What is particularly significant about these conclusions is that had Bouladon's research been conducted in Asia, rather than in an industrialized world context, he would have identified a host of nonmotorized means of travel and would not so readily have concluded that there is a transport gap between the pedestrian and motorcar users. However, the type of infrastructure and transportation hardware investments presently being made in Asia suggests that a gap of the kind identified by Bouladon at the city scale is rapidly in the making and that the absence of a unified theory of transport integrating the use of various transportation modes will rapidly duplicate the type of unbalanced transportation systems that many Western cities have created.

Transportation Technology and Settlement Hierarchy

Sasaki (*12*) further developed Bouladon's theories regarding the operational efficiency of transportation systems by correlating transportation technology efficiency criteria with settlement and community size considerations.

Sasaki hypothesized that a given type and size of settlement requires a consonant type of transportation mode and that if the settlement's internal community organization follows a hierarchical pattern, it may have several types of transportation systems, each serving different functions and distances operating at maximum operations efficiency. He further argued that the absence of transportation technologies consonant with the needs of a settlement hierarchy is the fundamental cause of many urban transportation problems, and that since settlement growth and transportation developments are closely interrelated, urban transportation technologies must match the needs of the settlements they serve.

Viewing the role of nonmotorized travel in Asia (indeed in any context) from this perspective highlights how much more significant nonmotorized travel is for cities than conventional urban transportation planning practice has led us to believe. This is especially true at the local community level and in the context of providing linkages to urban public transportation services of all kinds.

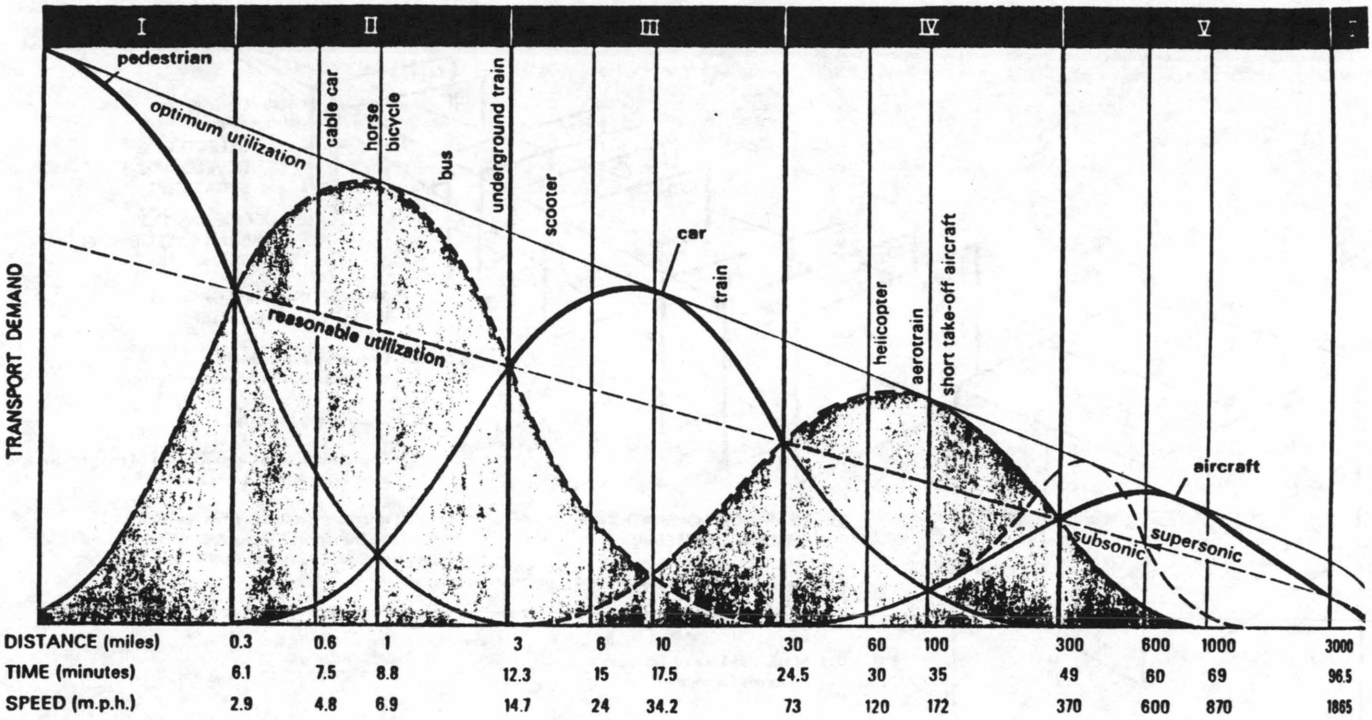


FIGURE 2 Transport gaps (*10*).

Sasaki elaborates on his propositions by claiming that one may positively relate the hierarchy of a settlement (with its constituent communities) to the hierarchy of trip distribution patterns for each type of community. From this, he deduces, different kinds of communities within the same settlement generate a demand for consonant means of transportation of which nonmotorized transportation is a critical component.

Importance of the Development Context

The conclusions presented by Bouladon and Sasaki are, as already pointed out, based on industrialized world experiences. For their conclusions to become more pertinent to Asian cities, there is a need to pay more attention to the development context of urban transportation technologies adopted, especially with regard to the following:

1. National development policies, priorities, and planning systems of the country or region in question;
2. The institutional and political contexts of the place; and
3. The resource constraints and riches of the location, especially vis-à-vis financial resources, per capita income levels, and skilled labor and management capabilities.

Different combinations of the above contextual considerations generate different development contexts within which urban transportation technologies operate and city growth takes place. For example, a specific transportation system may be considered the most appropriate in engineering and urban planning terms in accordance with Bouladon and Sasaki's technical criteria for a city of a particular size in Japan, but the unavailability of local technical expertise to manage, operate, and maintain this same system in Vietnam may make it developmentally unsuitable for this country until measures are taken to overcome these constraints.

INDONESIAN CASE STUDY

An UNDP/UNCHS study (*9*) that sought to apply a developmental approach to transportation planning to cities of varying sizes in Java and that greatly emphasized aspects of nonmotorized transportation [also see Soegijoko and Horthy (*13*)] found that speed/distance relationships went a long way toward explaining many of the observed travel patterns and transportation modes used in such settlements. The analysis conducted for this study revealed a hierarchy of typical trip distances (see Table 1). The hierarchy suggested that for settlements of less than 150,000 persons, trip lengths below 2.1 km fall within the range that can be considered appropriate for nonmotorized travel. Interestingly, problems of motorized

TABLE 1 Typical Community Size and Trip Length Characteristics (*9*)

Community Level or City Size	Median Population	Median Area (ha)	Typical Trip Length (km)
Rukun Tetanggas	250	2.5	0.08
Rukun Warga	1,500	15	0.19
Kelurahan	10,000	100	0.5
Kecamatan	70,000	700	1.3
Medium City	300,000	3,000	2.8
Large City	750,000	7,500	4.4

traffic in such settlements were found to be mainly derived from interurban and peripheral traffic flows rather than from traffic generated within the settlement.

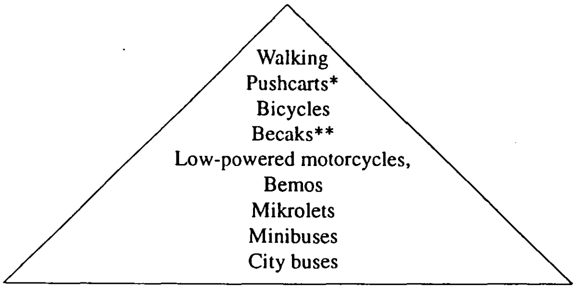
Urban Communities and the Road Hierarchy

Indonesian cities are administratively divided into large communities (kecamatans), which are in turn divided into smaller "urban village communities" (kelurahans and rikan wargas), and these are further broken down into neighborhoods (rukun tetanggas). This provided a good opportunity for testing the application of Sasaki's thesis and the relevance of Bouladon's premise regarding the use and misuse of transportation modes in urban areas. These "urban villages" are typically serviced by narrow, often unpaved walkways wide enough only for pedestrian and two-wheeled movement. Next up the road hierarchy are footpaths 1 to 2 m wide, which again are only able to accommodate pedestrians and two-wheeled vehicles. The next higher level is community roads 2.5 to 4 m wide, sufficient to allow one pedicab to pass another. Some roads are wide enough to accommodate four-wheeled motorized vehicles, but access to them is dangerous because of the competing pedestrian and other nonmotorized movement. These roads generally connect with local roads serving motorized travel, which in turn are linked to major and minor arterials.

Transportation Modes To Be Encouraged

An examination of the Javanese settlements revealed a rich choice of nonmotorized transportation modes on offer. It provided an opportunity to draw up a comprehensive hierarchy of preferred dominant transportation modes (see Figure 3) to be matched against Indonesian settlements and communities of different sizes, simultaneously indicating modes considered to be inappropriate at the local community level. Such vehicles included certain animal-drawn vehicles, high-powered motorcycles, motorized pedicabs, and motorcars.

The observed absence of continuous routes for nonmotorized travel at the local community level led the UNDP/UNCHS study to recommend the introduction of "continuous transport networks" based on different "speed bands" (see Tables 2 and 3). The provision of such routes, it was argued, has the benefit of relieving the higher-class roads of modal conflict and much unnecessary traffic congestion as well as air pollution. The recommendations particularly emphasized the development of the "lowerarchy" of city transport networks, especially those servicing the needs of nonmotorized travel, including the following:



* Gerobag or kakilima

** Substituted by bajajs where road gradients make bekaks inefficient

FIGURE 3 Proposed hierarchy of public transport modes in Indonesian cities (*9*).

1. Urban village footpaths and community roads with no motorized or restricted access,
2. Local roads with a low volume of motorized traffic,
3. Sidewalks and nonmotorized lanes along roads with higher traffic volumes,
4. Pedestrian and nonmotorized crossings at roads with higher traffic volumes, and
5. Pedestrian bridges or underpasses at roads with the highest traffic volumes.

The underlying principal of the recommended system was the provision of greater segregation of fast-moving motorized modes from slow-moving modes (as well as pedestrian movement) at all levels of the road hierarchy. This, it was believed,

TABLE 2 Speed Bands for Urban Transport Modes in Indonesia (*9*)

Speed Band (Range 1-4)	Speed Range (km/hr)	Transport Mode
Speed Band 1	About 5	walking pushcarts
Speed Band 2	10-20	bicycle becak
Speed Band 3	25-40	bemo bajaj low power motorcycle
Speed Band 5	50-100	mikrolet minibus city bus motor car

TABLE 3 Matching Speed Bands with Urban Road Hierarchy in Indonesia (*9*)

Speed Band	Road Hierarchy/Infrastructure
Speed Band 1 uses only:	Sidewalks along any kind of road Pedestrian bridges, pedestrian crossings, and narrow footpaths (less than 1.5m wide) in densely populated residential areas
Speed Bands 1 & 2 share:	Community roads (2m to 4m wide), Low density bike lanes (where there is no footpath)
Speed Band 2 uses:	Bike lanes and bike lane crossings
All Speed Bands share:	Local roads with very low traffic volumes
Speed Bands 2,3 &4 share:	Local roads with footpaths
Speed Bands 3 & 4 share:	Indonesian Class III roads
Only Speed Band 1 uses:	Indonesian Class I and II roads

would favor both fast-moving traffic at the higher levels of the urban road hierarchy and slow-moving traffic at lower levels.

To successfully implement such recommendations, however, it was concluded that the priority for pedestrians and other nonmotorized means of travel at the lower levels of the urban transportation system needs to be incorporated into both infrastructure design and enforcement of traffic regulations. These measures, in turn, need to be accompanied by a vibrant and aggressive educational publicity campaign designed to reverse current trends of transportation mode and infrastructure misuse. The campaign should highlight the rightful place of nonmotorized transportation in enhancing sustainable urban growth within environmental constraints.

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Nonmotorized Transport Choice Model and the Effect of Lower Bus Fares on Different Income Groups

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Government expenditures in the transport sector are usually discussed as though they were neutral with respect to the benefits they provide to various income groups. A choice model for alternative transport modes, including nonmotorized vehicles, is presented, with emphasis on the relationship between income levels and relative prices. The derivation of the model, based on individual preferences, is described in detail, and its application to aggregate data is made explicit. The application is for passenger trips to work in four cities in Indonesia in the early 1980s. The scenario whereby the government intervenes in the provision of public transport services, for example, by subsidizing bus fares, is simulated, and shows the sensitivity of each income group, in the short run, to such an exogenous shock.

Government expenditures in the transport sector are usually discussed as though they were neutral with respect to the benefits they provide to various income groups. The purpose of this paper is to provide an analysis of the demand for alternative transport modes, including nonmotorized vehicles and walking, with particular emphasis on the relationship between income levels and relative prices. The theoretical framework consists of a choice model based on individual preferences, and the application is for passenger trips to work in four cities in Indonesia in the early 1980s. The focus of the analysis is on policies that may affect relative prices, such as government intervention in the provision of public transport services. If bus companies are subsidized to provide cheaper services, will the demand for other low-cost modes and services decrease? How will the effect vary by different income groups?

THEORETICAL FRAMEWORK

Although choice probabilities can be defined for individuals, a series of choice situations for single individuals is seldom observed. Rather, the choices made by some set of individuals, such as the proportion of people choosing an alternative over an entire sample population, are usually observed. The objective of this paper is to analyze modal shares by income groups, such as the share of bus trips taken by individuals in a high-income group relative to the bicycle trips taken by individuals in a low-income group. Since few surveys exist on mode choice for individuals (stratified by income groups), it is difficult to estimate a model based on these individual shares. However, if we assume that the individuals observed to choose alternative modes are independent random samples from the total population, the proportions by income groups can be written as a conditional probability based on the total shares. That is,

$$P_i = \sum_{g \in G} P_g P(i|g) \qquad (1)$$

where

P_i = probability that a randomly observed trip is by Mode i,
P_g = probability that a randomly sampled trip maker is in Group g, and
$P(i|g)$ = probability that a randomly observed trip is by Mode i given that the trip maker is in Group g.

If we assume a functional form for the choice probabilities of the individuals in the income groups, $P(i|g)$, and assume that the probability of a randomly observed trip maker belonging to Group g is proportional to the population in Group g, a model in which the P_i's are observed can be estimated on the basis of the trip maker's indirect utility function. This indirect utility is described in more detail below. Let

$$Y_{in} = Y(W_n, C_i)$$

be the indirect utility function for Individual n choosing Alternative i, where W_n is the wage level of Individual n and C_i is the cost of Alternative i.

The indirect utilities used in this paper have been derived from individual preferences regarding various combinations of goods and leisure, subject to budget and time constraints. Their derivation is given elsewhere (*1*, pp. 24–26).

Assume that Y_{in} consists of a systematic component that is observable, V_{in}, and an idiosyncratic component, e_{in}, that is not observable. Assume also that we do not observe variation across individuals' systematic components or variation of choice sets within the same income group. More formally,

$$n, n' \in g \Rightarrow V_{in} = V_{in'} \equiv V_{ig} \quad \text{and} \quad C_n = C_{n'} \equiv C_g$$

Hence all individual variation is in the (unobserved) idiosyncratic component, and we can rewrite the indirect utility as follows:

$$Y_{in} = V_{ig} + \varepsilon_{in} \qquad \forall\, n \in g, \quad i \in C_g \qquad (2)$$

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The conditional probability that a randomly observed trip is by Mode i, given that Individual n is in Group g, is then given by

$$\begin{aligned} P_{i|g} &= Pr(Y_{in} \geq Y_{jn} \qquad \forall j \in C_g, j \neq i) \\ &= Pr(V_{ig} + \varepsilon_{in} \geq V_{jg} + \varepsilon_{jn} \qquad \forall j \in C_g, j \neq i) \end{aligned} \tag{3}$$

If we now make an assumption regarding the random components e_{in}, namely, that they are identically and independently distributed with the extreme value distribution (*2*, p. 53), the probabilities can be written as a logit function:

$$P(i|g) = \frac{\exp(V_{ig})}{\sum_{j \in C_g} \exp(V_{jg})} \tag{4}$$

Recalling that we do not observe $P(i|g)$ but that we do observe P_i, the total number of people choosing Mode i from the population, we need one more assumption to estimate the model: each individual is equally likely to be the observed trip maker. That is,

$$P_g = \frac{M_g}{M} \tag{5}$$

where M_g is the population of Group g and $M = \Sigma_g M_G$.

Substituting Equations 4 and 5 into Equation 1, the observed proportion of the population choosing Alternative i can be written as

$$P_i = \sum_g \frac{M_g}{M} P(i|g) \Rightarrow P_i(\beta) = \sum_g \frac{M_g}{M} \frac{\exp(V_{ig})}{\sum_{j \in C_g} \exp(V_{jg})} \tag{6}$$

where V_{ig} is the observable component in the trip maker's indirect utility function.

THE INDIRECT UTILITY FUNCTION

The indirect utility function (Y_{in}) that is estimated in this paper attempts to capture the effects of cost (c) relative to income (W). Recall that it consists of a systematic component (V_{ig}) and an idiosyncratic component (e_{in}).

$$Y_{in} = \beta_i - \beta_g\left(\frac{C_i}{W_g}\right) + \varepsilon_{in} \tag{7}$$

The indirect utility includes a constant or intercept term, β_i, for each mode, which mitigates to some extent the independence of irrelevant alternatives (IIA) underlying logit models. Train gives an example of the IIA property and the function of the mode-specific term (*2*, pp. 22–23). Variations on the functional form above, including ones with time of travel and an estimated loss in wages variable, were also estimated but are reported elsewhere (*1*). This one was chosen because its estimated coefficients are the most significant and because it clearly illustrates the differences in the demand elasticities by income groups, discussed in the next sections.

APPLICATION

The estimates are based on aggregate data and are for work trips in four Indonesian cities, where it has been possible to approximate incomes of users and relative costs and attributes of a handful of nonmotorized and motorized modes. The intent is to illustrate how mode choice estimates stratified by incomes can be obtained from such data and how simulation of the effects of changes on various groups might be calibrated with more detailed surveys.

The data have been compiled from Leinbach and Sien (*3*, Tables 8.5, 8.6, and 8.7) and from other sources available from the author. The four cities are Jakarta, Surabaya, Bandung, and Yogyakarta during the period 1978 to 1982. The data reflect the choice of six possible modes: automobile, bicycle, bus, motorcycle, pedal trishaws or becaks, and walking. The estimated populations were 6.41 million for Jakarta, 2.3 million for Surabaya, 1.4 million for Bandung, and 0.36 million for Yogyakarta.

Becaks are pedal-driven tricycles that carry two or three passengers and can also carry goods or luggage. Becaks and nonmotorized modes make up a large proportion of the vehicles owned in Indonesia. In Yogyakarta, nonmotorized modes made up 52 percent of the total registered vehicles. Motorcycles accounted for another 33 percent of the vehicles in 1974 (*4*, p. 28). The bus category includes minibuses and jitneys, all following a fixed route. The jitneys are remodeled automobiles, such as the Colt, Honda, or Opelet, and usually carry up to 17 passengers. A third type of public transport, the bemo or motorized becak, is also used in some areas, but the percentage of bemos was not available for most of the cities and was allocated partially to the bus category and partially to the becak category in the case of Jakarta.

The observed data given in Table 1 are the proportion of people who choose each of the six modes for their trips to work, assuming only one mode is chosen.

The cost (c_i) per day is an unweighted national average of the final purchase price of either the vehicle or the transport service. Strictly speaking, the cost of walking should be valued as lost wages due to travel time, but for this paper, specifications using travel time have not been included. Assigning zero cost to walking is equivalent to assigning all the relative utility of the mode to the constant (or intercept term). Instead, by choosing a nonzero cost for walking, we allow the constant to capture other unobserved utilities and the cost parameter to reflect the effect of a very low-priced mode. Thus, the cost of walking was assigned an almost negligible value, roughly equal to the price of a pair of shoes, or U.S. $10 per year at real prices. Although the estimates used here are reasoned but very rough ones, they are consistent with independent estimates based on a detailed cost study for the entire Yogyakarta province (*5*, p. 17).

The proportion of people in each income group (M_g/M) is based on the average income level of Indonesia relative to the world average income level and the Gini coefficient of income distribution. Approximately 67 percent of the popu-

TABLE 1 Proportion (P_i) of People Choosing Each Mode (percent)

P_i (%)	Auto	Motor Cycle	Bus	Becak	Bicycle	Walking
Bandung	5.8	17.3	17.7	9.7	5.6	43.9
Jakarta	12.0	8.0	23.7	3.2	1.1	52.0
Surabaya	7.5	21.0	17.5	9.5	9.5	35.0
Yogyakarta	2.2	15.2	10.5	3.4	23.2	44.6
Cost rps/day	1553	332	74	34	25	12

TABLE 2 Estimated Coefficients and Standard Errors

Observations=24	Coefficient (Std.error)
Auto	58.88 (13.01)
Motorcycle	22.89 (4.40)
Bus	6.59 (1.60)
Becak	0.68 (0.55)
Bicycle	-0.51 (0.92)
Cost/Wage	-61.40 (14.94)
SSE	0.0568

lation earn less than two-thirds of the world average income level, 22 percent earn between two-thirds and four-thirds of the average, and 11 percent earn more than four-thirds of the world average income level. A description of the income distribution estimates is given elsewhere (*1*,*6*). The world average income, equal to $3,768 in 1985, was calculated on the basis of real gross domestic product per capita in 1985 prices for approximately 130 countries (*7*). In addition to the proportion of people in each income group, the actual income levels in each group (W_g), expressed in national currency units (rupiahs), are as follows: low, 1,252; middle, 3,755; high 6,258.

The exchange rate in 1980 was 627 rupiahs per U.S. dollar, and the purchasing power (PPP) of the rupiah relative to the dollar was 45 percent of the exchange rate (285 rupiahs per U.S. dollar). This means that a basket of goods costing U.S. $1.00 in the United States could be purchased for U.S. $0.45 in Indonesia. The relative prices and income levels used in this paper have been converted using the PPP rather than the exchange rate, since this is more appropriate for international comparisons.

RESULTS

This section discusses the results of the estimated choice model and the demand elasticities by income groups.

$$P_i(\beta) = \sum_g \frac{M_g}{M} \frac{\exp\left[\beta_i + \beta_g\left(\frac{C_i}{W_g}\right)\right]}{\sum_{j\in C_g} \exp\left[\beta_j + \beta_g\left(\frac{C_j}{W_g}\right)\right]} \qquad (8)$$

The maximum likelihood estimates of the coefficients are presented in Table 2.

Recall that the mode-specific constants capture the average effect of each mode relative to walking (the base mode). It is high and positive for the motorized modes (automobiles and motorcycles) and negative for bicycles. The coefficient on the (cost/wage) variable is negative, as expected, and also significant.

If bus companies are subsidized and fares decrease substantially, will the demand for services vary by different income groups? The arguments against subsidies are that the poorest people cannot afford to use public transport even when it is subsidized and that subsidizing transport makes the geographical areas that it serves attractive to large businesses. These arguments imply that subsidies are not effective as transfer payments to the poor. It has also been argued that government regulation and subsidies would reduce the demand for paratransit, or intermediate transport modes that are often informal and unregulated but numerous in many South Asian cities. One of the ways to model such questions is to simulate changes in parameters and to estimate the proportional change in demand, thus showing the short-run effect of an exogenous shock to the system.

The estimated coefficients shown in the previous section allow us to calculate the proportion of users in each income group $P(i|g)$ on the basis of the cost, time, and income variables. That is,

$$P(i|g) = \frac{\exp\left[\beta_i + \beta_g\left(\frac{C_i}{W_g}\right)\right]}{\sum_{j\in C_g} \exp\left[\beta_j + \beta_g\left(\frac{C_j}{W_g}\right)\right]}$$

If we now assume that there is an exogenous shock to the system, such as the subsidized decrease in bus fares discussed above, the proportions $[P(i|g)]$ can be estimated a second time with the new fares. The difference between the new, simulated proportions and the original proportions, expressed as a percentage of the original ones, is equal to the expected change in demand by income groups, or elasticities of demand.

The cost of the average bus fares was decreased by 25 percent simulating the scenario whereby the government subsidizes bus services. The increase in demand for low-, middle-, and high-income groups was 56, 21, and 16 percent, respectively. This suggests that the low-income groups are more sensitive to changes in fares than the middle- and high-income groups.

Clearly, the elasticities vary by income group and are higher than unity for the poorest group. Similarly, the effect of an increase in fares would decrease the demand for public bus services proportionally more in the lowest-income group. Given that in this analysis only the nonmotorized modes are cheaper than buses, the low-income groups would switch to pedal trishaws (or becaks), bicycles, and walking.

CONCLUSIONS

Although there are several data constraints on the estimated models and the models themselves are limited to simple assumptions about individual behavior, the results show how changes in relative prices of modes have a varying effect on different income groups and how the demand for alternative modes is not necessarily neutral across income levels. Thus, although it may be argued that subsidies are not always effective as transfer payments to the poor, especially in the case of marketable goods, it may be useful for transportation planners to analyze the use of subsidies in the provision of both motorized and nonmotorized bus services. They are less likely than goods to be transferred and can thus be more effectively targeted to the low-income groups. This is especially relevant in developing countries where informal transport services are an essential component in urban transport services and where there are potential benefits to investors and lending organizations in analyzing the more modest infrastructure requirements for nonmotorized vehicles and transport services.

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Economic Incentives and Mode Choice

MARK E. HANSON

Economic incentives are an important determinant of mode choice. Nonmotorized and mass transit modes are placed at a particular disadvantage in the United States and elsewhere by the subsidies provided in the form of the externalities of private motorized travel, which are not included in user fees. In addition, there are transfers at the local government level in the form of property and other taxes used to pay for roads under local jurisdiction. The nature and magnitude of these incentives for private motorized travel are described on the basis of existing literature. The literature on the social costs of highway use is limited. Few comprehensive treatments exist that attempt to include all social costs. Research on specific areas of social costs is also uneven. Some areas, such as the costs of highway crashes, are well treated (although without distinction between societal and social costs), and others, such as the costs of water pollution, are quite limited. Research recommendations are proposed to better understand these incentives and to develop economically efficient user fees that would encourage greater use of nonmotorized modes.

Nonmotorized transport has begun to attract the attention of transportation professionals and the lay public in the United States and internationally. Evidence to support this assertion ranges from growing interest in local governments in the United States to interest at the World Bank. The secretary designate of the U.S. Department of Transportation has signaled his interest in nonmotorized modes in press reports.

There are several reasons for this interest. Local governments are struggling with the problems posed by increasing vehicle-kilometers being traveled and the concomitant congestion. Many local governments are also faced with severe air pollution problems, which are gaining attention under the Clear Air Act Amendments of 1990. National governments are contending with the emerging issue of greenhouse gases and global climate change. The traditional solution to congestion of adding capacity is giving way to more sophisticated strategies with multiple elements, including demand management, land use planning, provision of alternative modes, as well as added capacity. The dynamics of community development have shown the traditional "build two more lanes" solution to be ineffective or even counterproductive in many instances. Traditional solutions are becoming less affordable as costs continue to be transferred to local governments.

If nonmotorized modes and mass transit are to play important roles within a multimodal transportation context, it is important to understand the basis for mode choice. It is particularly relevant that nonmotorized mode use decreases in importance with income. The industrialized nations tend to have the greatest dependence on motorized, particularly private, transport. Similar trends toward motorized transport are evident in developing countries where urbanization and incomes are both increasing. These trends raise the question, Are these trends inexorable, or can economic growth be consistent with maintaining a significant role for nonmotorized transport?

This paper considers some of these questions by exploring the economic incentives in the United States for private motorized travel. It critiques the role of government in influencing modal choice, particularly subsidies and transfers to private motor vehicle users. The general finding of this research is that the patterns of subsidies and transfers, along with the mix of transportation infrastructure, are heavily skewed in favor of private motorized travel over nonmotorized modes and mass transit. It is apparent that market forces are often prevented from playing their normal role in choice of transportation mode.

ECONOMIC FACTORS IN MODE CHOICE

Traditional models of transportation behavior focus heavily on out-of-pocket costs and time. Other determinants include safety, prestige, comfort, convenience, physical fitness (i.e., in the course of walking or biking), and pleasure whether derived from walking, biking, or driving. Residential location, which in turn is influenced by transportation infrastructure, is an important determinant of available transportation options and the costs associated in using those options. An important issue in nonmotorized mode use is the provision of safe rights-of-way. For example, in other parts of the industrialized world, such as northern Europe, where provision is made for bicycle use on separated right-of-way, there is considerably greater use of bicycles.

Government policy plays a dominant role in the determination of the transportation infrastructure provided and in the incentives for the modes and type of travel. The incentives are structured through the transportation funding, management, and expenditure processes. In the case of roadway funding, user fees often provide only half of the funding required. The remaining costs are provided by transfers from other revenue sources, such as the local property tax (*1*,*2*). In addition, extensive externalities are not accounted for in user fees, although some regulations such as emissions control requirements limit the extent of environmental and safety externalities. Whereas subsidies are also provided for mass transit and to a lesser degree for nonmotorized modes, aggregate subsidies are considerably less than for private roadway use.

Since highway users do not face appropriate user fees, they receive incorrect economic signals and, by implication, make inferior travel and land use choices. New highway and other investments, in turn, are based on travel and associated traffic counts and congestion levels resulting from the underpricing

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of roadway use. In other words, there is more travel and land use dispersal than is efficient. It is notable that average cost or marginal cost principles are used in pricing other basic infrastructure, such as electricity, natural gas, water, sewer, and telecommunication services. Transportation, however, is not held to the same market standard.

There is a growing interest in bringing to transportation the same set of principles and incentives used in the privately operated economy. In a paper on congestion pricing, Orski (*3*) cites a report by the Bay Area Economic Forum contending that market-based approaches would bring about a more efficient and less costly means of achieving air quality standards than the current regulatory approaches of Southern California. Orski goes on to contend that the awakening interest in private market mechanisms is responsible for the revival of interest in congestion pricing.

The interest in market-based approaches to transportation-related problems correlates with the growing interest in the broader issue of the social costs of highway use. It also appears that parallel developments in planning methods in electric utility planning (integrated least-cost planning) are influencing the field of transportation planning.

Long-standing government policies that skew economic incentives and infrastructure in favor of private motor vehicle travel have resulted in exaggerated levels of private motor vehicle travel and diminished use of nonmotorized modes and mass transit. It is not known how much travel patterns have been distorted, and it is impossible to estimate with existing methods and models the magnitude of the effect. It is hypothesized, however, that considerably more nonmotorized travel and mass transit use would occur with pricing based on full cost. A different mix of infrastructure and land use patterns less adapted to private motor vehicles would be expected. It has been argued that establishing a pricing system that reflects the true cost of travel is a straightforward way of improving transportation efficiency (*4*).

Although the magnitude of distortion in travel is not amenable to estimation, it is possible to estimate the magnitude of many of the economic incentives in favor of private motor vehicle use.

The focus of this paper is on the nature and magnitude of the incentives, in the form of social costs and transfers, in the United States. Government policy to encourage motorized travel and discourage nonmotorized travel is also common in many industrialized as well as developing countries.

NATURE AND MAGNITUDE OF SOCIAL COSTS OF ROADWAY USE

The literature discussing the nature and magnitude of social costs of highway use is surprisingly limited in certain respects and extremely broad in others. However, the total volume of literature that explicitly adopts the formalism of economics in treating social costs of transportation is small considering the magnitude of the social costs and the importance of the highway system to the U.S. economy and to the fabric of contemporary American society.

Where social costs are explicitly addressed in economic terms, the focus is usually on particular aspects or impacts of the transportation system. For example, the Urban Institute recently completed a far-reaching but focused study that addresses both societal and social costs of highway crashes (*5*). The literature pertaining to some basic environmental areas is limited. There are very few cost estimates of the highway damage to surface water and groundwater resources despite widely acknowledged impacts resulting from storm water runoff (including oils and greases, road salt, and sediment loadings) and deposition of airborne pollutants.

The societal cost of highways includes all of the cost categories shown in Figure 1, whereas the social costs are those noted under the externalities branch of Figure 1. Few studies attempt to integrate all the different aspects of highway social costs into a comprehensive analysis of the social costs of highway use.

The literature that does not follow a formal economic treatment is immense, and the coverage is very broad. The difficulty raised by this literature is that, although it treats a wide range of issues pertinent to social costs, the material is not amenable to summarization, particularly in terms that measure social costs or lead to the establishment of efficient user fees. Efficient fees are "those which would ensure that the price paid by the roadway user is equal to the increment of social and private costs resulting from the highway use" (FHWA, statement of work for Contract DTFH61-91-01345).

This paper focuses primarily on the literature treating the social costs of highways in economic terms. The approach used follows "taxonomies" of the costs of highways shown in Figure 1. The literature is summarized and assessed in qualitative terms. It would be useful to systematically update the social costs of highway use on the basis of the literature reviewed and ongoing work, but such an effort is beyond the scope of this paper. A brief compendium of aggregated cost estimates provides a range of values.

Definitions

An efficient user fee that would alter existing incentives favoring private motorized travel, such as a highway toll, would include social costs as conventionally defined plus other transfer payment costs that are external to the market transactions of highway use but that are currently paid for out of pocket. Road construction paid for by public funds such as property taxes is an example of a transfer payment cost that is paid for out of pocket, as shown in Figure 1.

It is also important to distinguish between externalities imposed on individuals not using the highway system versus externalities imposed on individuals using the system coincidentally. Conventional external costs, as shown in Figure 1, include loss of aesthetics, odor, noise, water pollution, air pollution, climate change, and so forth. An externality that is primarily imposed on other coincidental users of the roadway system is congestion, as is shown by the separate branch under externalities in Figure 1. However, congestion costs, such as interference with pedestrian movement, may also affect non–system users, as shown in Figure 1.

Completing the externalities portion of Figure 1 is the category "external cost to nonbenefitting public." This distinction is drawn to bring attention to the fact that some impacts, such as acid deposition and climate change, may affect populations that do not benefit from the mobility that is the source

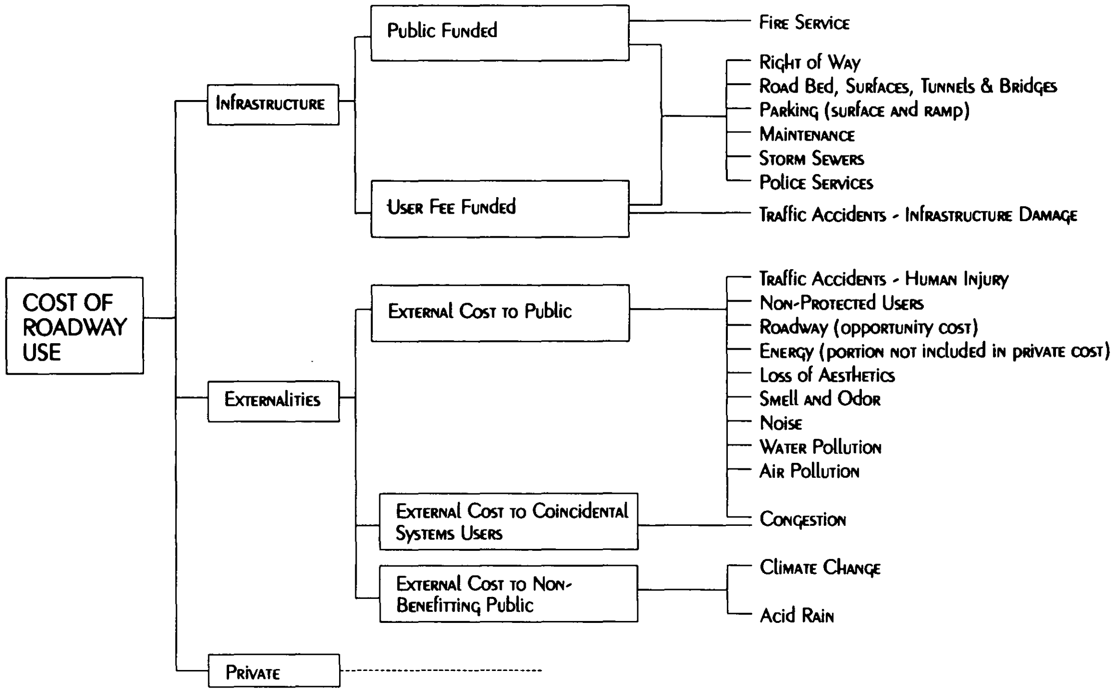

FIGURE 1 Taxonomy of costs of roadway use.

of the externality. Within the urban area, it can be plausibly argued that urban residents benefit, at least indirectly, from the travel of others. (If the social costs of highway use are considered, say at a national level, the boundary between the public benefitting and not benefitting changes. However, in a world where the vast majority of households do not own a motor vehicle, the issue of impacts on the nonbenefitting public remains, particularly for climate change.)

The social costs included under the "externalities" branch of Figure 1 are the primary focus of this paper. The establishment of efficient prices, however, will require the inclusion of other costs of the highway system that are not currently included in highway use prices. In Figure 1, these subsidies or transfers include those identified as "public funded" costs under the "infrastructure" branch. These costs include road construction, bridge construction, signalization, repair, maintenance, storm sewer construction and maintenance, police services, right-of-way acquisition, and various planning and administrative costs associated with these services. The payment of these costs currently comes from both user fees and other, general revenue sources such as the property tax.

The "private" cost branch of the diagram is not delineated but is included to indicate the complete picture of the societal costs of roadway use. Private costs include insurance costs and the pain and suffering of injuries and deaths, which amount to enormous societal costs. The fact that these private costs are as large as they are and individuals still travel at their current rates is indicative of the benefits to society of highway use. Whereas health costs and human pain and suffering are largely private costs, two aspects are considered social costs in this paper. The first relates to impacts on "nonprotected" individuals such as pedestrians and bicyclists. The second is the loss to society of individuals' work-related and non-work-related production. These two social costs are included under externalities in Figure 1.

Summary of Literature on the Nature and Magnitude of Social Costs

A summary evaluation is presented in two parts. The first is an overall assessment of the state of the literature. This is followed by a category-by-category review following the structure of Figure 1.

Overall Assessment

The state of knowledge of the social costs of highway use as reported in the literature is only fair at best. This conclusion reflects in part the size, numerous facets, and complexity of the topic. The definition and measurement problems are enormous. The overall size of the issue lends itself to segmented approaches.

The meager state of knowledge reflects a prevailing lack of interest, until quite recently, in applying market principles to the pricing of highway use. After all, if market principles were not being applied, a segmented approach focusing on specific, important problems (e.g., reduction of accident occurrence and severity of injuries) made sense.

The net result is that very few systematic economic treatments of the overall social costs of highway use exist, and treatment of the specific aspects is uneven. The work of Hanson (*2*) and Ketcham (*6*) is a starting point for assembling an aggregate picture, at the urban or the national level, of the social costs of highway use. The Hanson work explicitly excludes a number of social cost items that need to be developed. Coincidental with the publication of that work, FHWA published a major study by Miller et al. (*5*) on the cost of highway crashes that provides considerable information to fill in some of the exclusions in the Hanson work.

The Ketcham work provides an estimate, for selected localities and at the national level, of the total costs of transportation ($1,658 billion in 1990, which is equal to about one-third of the U.S. gross national product) and for social costs ($860 billion). However, definitional questions as to what is an externality or social cost versus a private cost are left unanswered and need to be addressed. Other aggregate studies have been done at the municipal level, including the work of Hart (*7*) and Kinney (*8*).

Recommendations for future research include development of a national aggregate social cost estimate and establishment of a set of highway social cost accounts on the basis of environmental accounting. Such work appears to be under way under the auspices of the Economic Analysis Division of the U.S. Department of Transportation's Volpe National Transportation Systems Center. Such a set of accounts would provide time series data measuring developments in externalities, publicly funded infrastructure costs, and some private societal costs not routinely reported.

Categorical Costs—Externalities

Traffic Accidents The health costs attributable to highway accidents have been the subject of recent work at the Urban Institute (*5*). This work is thorough and extensive. An issue not treated in the Urban Institute report but critical to this review is which of the costs considered should be labeled social costs and which are exclusively private costs. An important cost, which in many instances can be considered a social cost, is the impact on nonprotected users (i.e., pedestrians and bicyclists). This subject is treated in some depth in the European literature (*9*).

Roadway Opportunity Cost The literature review found few studies presenting systematic economic estimates of roadway opportunity costs. The issue is identified by Giuliano in an October 1989 report to FHWA, *Literature Synthesis: Transportation and Urban Form* (DTFH61-89-P-00531). Because this is a complex issue relating to past decisions and requiring specification of alternative land use patterns and their value, this does not seem to be a promising area for research.

Energy (Portion Not Included in Private Cost) The issue of nonprivate energy costs is largely one of the tax treatment of the oil industry. The tax benefits are reasonably well known and do not make up a large cost item (*2*). The indirect environmental impacts and hence social costs of oil and natural gas production are much larger, with both routine and episodic events (e.g., the *Exxon Valdez* spill in Prince William Sound). As a matter of convention in the literature reviewed, studies estimating indirect effects were not included.

Loss of Aesthetics Loss of aesthetics results from the influence of highways on urban and rural landscapes and from visibility losses attributable to motor vehicle emissions. There are qualitative discussions of aesthetic loss, but this review did not find systematic attempts to place an economic value on aesthetic losses. The loss of visibility has been evaluated in research, notably by Crandall et al. (*10*) and Freeman (*11*). Current work dealing with visibility losses (not associated with transportation sources) in the Grand Canyon has arrived at some very high estimates of damages using contingent valuation. Such approaches are controversial.

Odor The literature provided no economic estimates of the social cost of odor from highway sources beyond qualitative treatment.

Noise The primary references in the literature approach valuation and noise impacts by associating the loss of property values with noise levels, using hedonic property price methodologies. The difficulty presented by this literature is that it focuses only on specific highway segments and conditions. There were no reported attempts in the literature to derive urbanwide values other than that of Ketcham (*6*).

Water Pollution Water pollution associated with highway construction and use is frequently addressed in the literature. There is little in the way of economic evaluation of the impacts, however, beyond the work of Murray and Ernst (*12*).

Air Pollution and Climate Change The social costs of air pollution are possibly among the three largest categories of social costs of highway use. The two other leading categories are traffic accidents and congestion costs. The importance of the subject is reflected in the Clean Air Act of 1990. There is, however, considerable uncertainty about the cost of air pollution in the literature.

The review found a few recent studies attempting to update transportation-related social cost estimates for air pollution since the 1970s and early 1980s. Some recent estimates are provided by MacKenzie and Walsh (*13*), which use a $10 billion per year estimate. The authors consider this estimate to be conservative, citing the work of Sperling and DeLuchi (*14*), which cites a range of $10 billion to $200 billion, and the American Lung Association (*15*), which estimates costs due to pollution at $40 billion to $50 billion from all sources on the basis of health care costs and work time lost. Ketcham (*6*) reports $30 billion for health care costs alone due to transportation air pollution.

Some recent studies have examined the benefits of air pollution control in the California South Coast Air Quality Management District (*16–18*). The estimated benefits from pollution reduction with the district plan ranged from $2.4 billion to $20 billion per year by 2010 for all sources, including transportation. In evaluating those studies for the district, Krupnick and Knopp (*19*) arrived at a wide range of estimates of up to $4 billion. In the same study, the authors found a range of benefits nationwide of $250 million to $1 billion for volatile organic compound emissions control only, to reduce ground-level ozone. This national study was based on an Office of Technology assessment study (*20*), which excluded transportation control plans, and considered acute health effects only.

Difficulties in using these studies to estimate transportation damages include the following:

- Some do not distinguish between transportation-related damages and other damages;
- Some consider the benefits of emissions reduction, not the total cost of damage from all emissions present; and
- Some do not estimate damages from all emissions, particularly the study by Krupnick and Knopp.

If global climate change is included under air pollution social costs, air pollution social costs could be much greater. The climate change literature [e.g., Abrahamson (*21*)] indicates considerable scientific uncertainty as to the changes in climate and sea level that may occur. It is well established that atmospheric carbon dioxide concentrations are increasing and that the ozone layer is being depleted, with holes appearing over the poles. It is less certain what the climatic consequences will be, but there is considerable literature suggesting that significant changes are possible. Some of the studies indicate massive economic disruption and damage. Transportation is one of the major contributors to global carbon and chlorofluorocarbons emissions, important precursors to climate change.

Congestion Costs are large and rapidly growing in many large urban areas. Ketcham (*6*) uses various sources including the 1982 FHWA cost allocation study to provide a national estimate of congestion costs for 1990 of $168 billion. Hanks and Lomax (*22*) and DeCorla-Souza and Kane (*23*) assess costs for specific cities and specific highway facilities in urban core areas and urban fringes.

Acid Rain Acid rain is a growing concern in the northeastern United States and eastern Canada and more recently in parts of the western United States. Although sulfur species are the most important precursors, nitrogen oxides are the next largest, and their emissions are strongly associated with motor vehicles. As total sulfur emissions decline nationally, the role of nitrogen oxides may become more significant. As damage estimates are developed, attention should be given to the transportation contributions.

Publicly Funded Infrastructure Costs

Publicly funded infrastructure costs represent large transfers from society in general to highway users. The benefits of the transfer increase with increasing private use of highways. Recent forecasts by FHWA (*24*) indicate that highway user fees will account for 61 percent of the $80 billion in highway receipts for calendar year 1992. Of this total, $19 billion (23 percent) is estimated to come from property taxes, general fund appropriations, and other taxes and fees, representing a significant transfer.

An increasingly popular theme in the literature is that if market principles are to be applied to transportation, these infrastructure costs should be borne by highway users along with the social costs. Whereas there is a significant body of information on these costs at the federal level [see, for example, the discussion of DeCorla-Souza and Kane (*23*)], the work of Hanson (*2*) suggests that the costs could well be higher than reported in the FHWA data. Data collection procedures and definitions should be reviewed to identify means of collecting data on costs that are currently being missed or underreported. These data should be collected as part of the highway social cost accounts.

RESEARCH NEEDED TO QUANTIFY SOCIAL COSTS

Overview

An underlying rationale for research in the area of social costs of highway use is movement toward establishing economically efficient user fees. This goal implies a research program that would assist in the design and establishment of such user fees. Such fees are an important feature of multimodal transportation strategies that substantively support nonmotorized modes. Efficient user fees are also an essential element in transportation demand management (TDM).

On the basis of the review of existing literature, five areas of research would serve such a research program:

1. Studies on aggregate social costs at urban and national levels, with supporting research in water pollution; the social costs of crashes, including unprotected users; and differences in per capita travel within urban areas;
2. Development and implementation of a set of social cost accounts linked to conventional transportation data and accounting systems;
3. Support for publicly and privately funded TDM actions and infrastructure projects where highway pricing or other traffic demand aspects are important parts of the project (this research support program would also evaluate social costs of specific highway segments or other transportation infrastructure where these costs are unusual in type or magnitude);
4. Review of successful nonmotorized mode development in industrialized and developing nation settings; and
5. Evaluation of the application of integrated least-cost planning (developed and now extensively used in the electric and gas utility industries) to transportation planning.

In addition, it is recommended that a center for research on least-cost transportation planning be established. Such a center would both undertake and fund research in areas including highway social costs, highway user charges, and TDM. The center would emphasize the appropriate role of nonmotorized modes in least-cost, multimodal transportation planning. The center could be a new, stand-alone entity or could be established by assigning an additional discrete focus to one of the centers in the University Transportation Centers Program.

The recommended research agenda recognizes certain critical underlying conditions. It is evident from the literature that the social costs of highway use are uncertain, but very large. Some further estimation is useful to fill in important gaps. Whereas sufficient scientific information exists to establish average minimum user charges for urban areas or for states, perceived political realities do not permit higher user charges. Such user charges include tolls, fuel taxes, excise taxes, or other charges, possibly utilizing intelligent vehicle/highway systems that would account for all existing direct costs in most instances. This ignores the even larger social costs, which would raise highway tolls or other user fees by an even greater amount.

Whereas minimum average costs can be determined at this time, marginal cost pricing is the ultimate goal in establishing efficient highway tolls. More information will be required to determine marginal costs and establish user charges at specific times and places. Where congestion costs are dominant, this information can be collected and partial marginal cost fees established on the basis of lost time. More work would be required to include marginal energy use and emissions costs.

Within this context, it is prudent to focus some research on urban areas where innovative highway charges and nonmotorized modes could be implemented in the near future. Areas include nonattainment areas under the Clean Air Act and tolls for new highways, tunnels, and bridges under public or private ownership being built to meet congestion relief needs. This market-oriented research focuses on issues of consumer acceptance of TDM and the social and economic effects of various TDM measures. This in turn lays the groundwork for future program and project designs.

This research agenda also recognizes that the development of social accounts will, over time, provide a basis for monitoring the evolution of social costs and environmental impacts associated with transportation without necessarily expressing those costs in monetary units. Such an accounting system is useful for considering environmental and other social implications of the transportation system and lays part of the framework for estimating social costs as they become better defined, measured, and understood. As actions are taken to reduce urban emissions, such accounts will provide a baseline against which progress can be measured.

Specific Recommendations on Research Needs and Approaches

Urban and National Level Social Costs

Some aggregate estimates of urban and national level social costs have been made since the 1982 Federal Highway Cost Allocation Study. These studies include the estimates of DeCorla-Souza and Kane (*23*), Hanson (*2*), Hart (*7*), Kinney (*8*), Ketcham (*6*), and most recently MacKenzie and Walsh (*13*). In the light of the social costs not included in these studies, some of which have been recently treated [the cost of highway crashes (*25*)], it is recommended that an updated range of national estimates be developed. Such an effort should be augmented by work delineating the social cost portion of the social costs of crashes and by work in water pollution. The work would establish a new bench mark range of estimates of the social costs. The current estimates of costs appear to be in the range of $60 billion to $860 billion per year as indicated in Table 1. Excluding some costs that arguably should be deleted from the high estimate and including costs explicitly excluded from the lower estimates, the plausible range might be narrowed to $200 billion to $400 billion per year.

TABLE 1 Estimates of the Social Costs of Highway Use

Source:	$ Billion/Year
American Public Transit Association (automobile only) (Developments Vol. 1, No. 2, Spring Summer 1990)	300
Hanson (2) (excludes highway crash, congestion and greenhouse costs) (uses conservative estimates for all cost categories)	64
Hart as cited in (13)	60
Ketcham (6) (most inclusive estimate) (includes costs which are self insured and greenhouse effects)	860
MacKenzie, Down and Chen (13)	300

In conjunction with the estimate of national social costs, a set of urban and rural area costs should be developed to better understand the diversity of costs across the United States and within urban areas. Urban area estimates should take into account the highly variable travel patterns in different parts of urban areas. One reason for measuring the difference in per capita travel in different locations is to estimate the costs that residential (and possible industrial and commercial) locations impose on society. Locations that demonstrate higher per capita travel levels might be subject to user or impact fees according to the "capacity" that development in those locations demands. Capacity-related fees of this type are common in utilities.

A 1983 study for FHWA (*26*), for example, revealed that residents living in exurban rural areas of Dane County, Wisconsin, traveled twice as much as urban (Madison urban service area) residents. Residents in outlying cities and villages traveled more than urban residents but less than their rural neighbors. Similar findings are reported by Newman et al. (*27*) for Perth and New York City. These findings may imply some revisions in the national personal transportation survey to better understand the role of residential location in influencing travel patterns and social costs.

If new survey work is to be undertaken, an initial pilot survey and analysis of a small cross section of cities will require perhaps 2 years. This research should concentrate on the level and location of travel and estimates of the burden on public infrastructure and social costs. This type of information would be useful for the design of tolls and toll collection systems.

Development and Implementation of Highway Social Costs Accounts

Increasing attention has been given by the environmental science community to the issue of environmental accounts. Environmental accounts include more than social accounts. The rationale is that there is a need for consistent information on environmental burdens (i.e., emissions, effluents, and resource use) and effects (e.g., health effects, materials damage, and ecosystems impact). Environmental accounts in conjunction with routinely collected transportation system information would provide a more complete picture of the direct consequences of transportation systems investments and use. From an economic perspective, the measured and perceived benefits of choices of transportation system investment, management, and use could be better weighed against the private and social costs.

Many environmental indicators could be included in a transportation environmental accounting data base. As a matter of consistency, environmental accounts should be collected and published by existing, responsible units within the U.S. Department of Transportation and FHWA. The design of the environmental accounts, however, should be the subject of a research effort that would recommend the contents of such accounts, including specific measures, units, and means for collecting the data.

Initial guidelines for such an accounting framework should rely on existing secondary data sources as much as possible and emphasize aspects in Figure 1 that are known to have large social costs, such as urban air pollution, congestion, and highway crashes.

TDM Research Initiative

There has been a nationwide increase in TDM projects. Projects include measures in five broad categories:

1. Managing flows on specific segments with such measures as computerized signalization and high-occupancy vehicle (HOV) lanes;
2. Altering time of travel with such measures as staggered shifts and flexible hours;
3. Altering modes of travel by vanpooling, transit of various kinds, bicycling, and walking;
4. Altering parking incentives by imposing or increasing fees, providing equal compensation for transportation support for all employees (e.g., an employee using transit or walking would receive compensation equal to the cost of providing parking for those driving), or preferential locations for HOV parking; and
5. Marginal cost road pricing for new or existing roads, bridges, areas, and so forth.

What is often missing in these TDM projects, which are frequently experimental in nature, is a research design by which more useful knowledge can be gained. Information, such as responses to specific measures, would be useful in improving the management of the projects as well as in establishing a base of knowledge from which other TDM projects and communities could benefit.

It is recommended that a TDM research initiative be established, which would include a research fund to which project implementers can apply for carrying out the research design, data collection, and analysis aspects of TDM projects. It is also recommended that a center for least-cost transportation planning be established. The purpose of the center would be to conduct research on TDM and other transportation planning functions, to administer the TDM research fund, and to gather information on least-cost transportation research, planning, and management, including the use of tolls and other user fees.

Analysis of the Application of Utility Least-Cost Planning to Transportation Planning

The electric and gas utility industries have gone through major changes during the last decade in the planning and management of their investments and operations. Many of the changes have come about because of the adoption of integrated least-cost planning (also known as integrated resource planning or simply least-cost planning). An important feature of least-cost planning has been the elevation of demand-side measures to equal status with traditional supply-side measures. If the marginal cost of a demand-side measure (including social costs, where they have been measured) is less than the marginal cost of new supply, the demand-side measure is preferred. Another important feature of least-cost planning is the emphasis given to the social implications of investment choices, including such issues as employment and air pollution.

Many elements of utility least-cost planning are directly applicable to transportation planning in general and to the issue of social costs in particular. A review of the applicability of utility least-cost planning to transportation planning is recommended. An important benefit of the application of least-cost planning to transportation is the potential for placing the issues of highway social costs and highway tolls in a broader economic and planning framework. Such a framework would have an urbanwide or regional focus (similar to a utility service area) rather than a static, segment-by-segment focus.

A review of the applicability of utility least-cost planning to the field of transportation planning would specifically address such questions as the institutional differences in ownership and regulatory authority, the greater difficulty in measuring and metering use of highways, and the large federal funding role. Energy utilities, whether privately or publicly owned, derive their revenue from their service territory, and in the case of investor-owned utilities are subject to state regulation. Despite these differences, an analysis of the application of utility least-cost planning to transportation is timely.

CONCLUSION

The social costs of highway use and transfers are plausibly in the range of $200 billion to $400 billion per year. The exclusion of these costs from highway user fees creates an important incentive to private motor vehicle use. Efforts to include these costs in economically efficient user fees will serve to reduce the demand for private motorized travel and encourage alternative modes, including nonmotorized modes. The magnitude of the impact on travel behavior in the long run cannot be estimated with current models. However, the enormous size of the social costs and transfers suggests that major behavioral changes could result from efficient user fees.

ACKNOWLEDGMENT

This work was funded in part by FHWA. The author would like to thank FHWA for its support and comments on the project report (*1*).

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Pedestrian Speed-Flow Relationship for Central Business District Areas in Developing Countries

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Pedestrian speed-flow relationships for central business district (CBD) areas in developing countries were developed. Data were collected from Irbid, Jordan, which is considered a city typical of those in developing countries. In the analysis, pedestrian flows were analyzed on the basis of effective sidewalk width rather than the lane concept. Results indicate that the capacity of bidirectional CBD sidewalks was 18.22 pedestrians/min/ft (3,590 pedestrians/hr/m). On the basis of this result, the capacity value specified in the 1985 *Highway Capacity Manual* is not applicable to developing countries even if a reduction factor is applied to consider the bidirectional effect. In addition, the results indicate that a considerable percentage of pedestrians walk along streets beside sidewalks. Therefore, in the design of CBD sidewalks, it is recommended that the pedestrian demand to capacity ratio be limited to 0.5.

Most developing countries suffer from a lack of well-organized pedestrian facilities, and large cities in these countries expanded without suitable planning. The central business district (CBD) of any city encompasses most trading and local governmental activities. Because of the insufficiency of reasonable sidewalks, some pedestrians are forced to use the congested streets. This problem not only creates traffic delay and other adverse environmental effects but also can increase the probability of pedestrian and traffic accidents.

In Jordan, various measures have been taken either to control or to improve pedestrian flow. One of these measures is the fencing of sidewalks beside streets in the midblock strip. However, in spite of this action and media directions, some pedestrians jump over fences and flow into streets. Thus, fencing as a control measure is not effective, because the available sidewalks cannot accommodate pedestrian demand at an acceptable level of convenience. In an attempt to improve pedestrian flow and safety, some municipalities provided traffic-free areas. After the implementation, however, traders and business owners claimed that pedestrianization adversely affected their commercial life. Consequently, the time given to evaluate this kind of improvement was insufficient.

Thus, under these circumstances the only logical solution is to provide adequate sidewalks that can accommodate the expected demand at a reasonable level of convenience, safety, and economy. This can be achieved by widening the available sidewalks in the CBDs. To do so, speed-flow and speed-space relationships must be developed. These relationships are readily available in the *Highway Capacity Manual* (*1*). They were developed through studies carried out in some developed countries under certain spatial, temporal, and pedestrian preferences. Therefore, there is a need to develop the basic relationships for the flow of pedestrians in developing countries similar to Jordan.

PURPOSE AND SCOPE OF RESEARCH

The primary purpose of this research is to study and develop the basic relationships for CBD pedestrian sidewalks in Jordan. The secondary purpose is to compare the results of this study with those developed in previous research in the developed countries.

The scope of this research is limited in two ways. First, mixed pedestrian traffic was considered, because it is very difficult in the CBD to classify pedestrians according to trip purpose. Second, in the CBD, the directional distribution of pedestrians changes in a short time. Therefore, bidirectional flow was considered in this study.

The study was conducted in Irbid's CBD. Irbid is located in the northern part of Jordan and can be considered typical of cities in developing countries. Irbid has a population of 250,000. The city is the business center of Irbid Governorate, which has a population of about 750,000.

STUDY METHODOLOGY

Three criteria were adopted at the commencement of the study. First, the developed speed-flow relationship must be based on short-time variation of pedestrian flow. Second, the selected time period must be sufficient to take reasonable measurements according to available measurement techniques. Third, to assess the relative degree of convenience, both pedestrian preferences and engineering judgment must be considered. On the basis of these criteria, the following procedure was followed:

1. A manual technique was used to collect pedestrian traffic flow and speed data. Pedestrian flow and speed measurements were carried out by two observers equipped with stopwatches. Observers were positioned outside the sidewalk. One ob-

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server counted the number of pedestrians that passed a line of sight across the width of the sidewalk during a specified period of time. The other measured the time required by randomly selected representative pedestrians to traverse a specific length of the sidewalk during the same specified period of time. The pedestrian flow rate was computed as the number of pedestrians per minute per foot of effective sidewalk width. The effective width was determined according to 1985 *Highway Capacity Manual* practice. Pedestrian speed was computed as the average pedestrian walking speed (ft/min).

During the initial phase of the study, it was noted that platoon patterns occurred during midday (11 a.m. to 2 p.m.). Thus, the study of short-term variations of pedestrian flow was carried out at 1-min intervals. Since a 1-min interval is not practical for speed measurements, a relationship between 1-min flow and average flow for longer periods of time, such as 5-, 10-, and 15-min intervals, is necessary to develop speed-flow relationships.

2. To assess the degree of convenience, three pieces of information were collected at each flow level. The information included the degree of convenience as judged by pedestrians, the degree of convenience as judged by an engineer, and the percentage of pedestrians walking along the street beside the sidewalk. Three observers working simultaneously were used to collect this information. Pedestrian flow was determined by the first. A number of pedestrians were selected randomly to give their judgment on a short questionnaire form distributed by the second observer. Since pedestrians do not know the meaning of a given level of service as A, B, . . ., or F, they were asked to judge whether the sidewalk over a specified length could be classified, from an operational perspective, as excellent (A), very good (B), good (C), fair (D), accepted (E), or unaccepted (F). The percentage of pedestrians walking along the street was estimated by the third observer.

STUDY AREA AND DATA COLLECTION

To achieve the objectives of this research, a major part of the Irbid CBD was selected. The selected part has an area of 75,000 m^2 and total street length of 2,500 m. The streets approximate a grid system with dimensions 80 × 120 m. Sidewalks are provided on both sides of each street. The sidewalks have widths ranging from 1.5 m (5 ft) to 2.4 m (8 ft). The selected sidewalks were considered to be in good condition. The study was conducted between the beginning of April and the end of July 1991.

Two major data sets were collected. The purpose of the first was to study the temporal variations of pedestrian flow. To determine peak flow periods, two sidewalk sites were monitored continuously during a week from 6:30 a.m. to 6:30 p.m. Pedestrian flows were recorded at 5-min intervals. In addition, six sidewalk sites were monitored continuously for 3 hr at different time periods. At each site, pedestrian flows were recorded at 1-min intervals.

The second data set was collected to develop speed-flow relationships and space requirements for CBD pedestrian traffic. The data were collected from six sidewalks. At each site, pedestrian flows were recorded continuously at 5-min intervals for 3 hr. Within 5-min intervals, average speed was computed as the mean of individual pedestrians' speeds. However, under low-flow conditions some observations were collected at 1-min intervals, and a few pedestrians were randomly selected to compute the average speed. Pedestrians' speeds were determined by measurement of the time required to traverse a referenced section of sidewalk 30 ft long. The length was determined so that the effective width of the sidewalk is constant.

To assess the relative degree of convenience and to quantify the adequacy of the available sidewalks, a supplementary data set was collected. It included two questionnaire forms, which were distributed at the same time in the field, one answered by a pedestrian and the other by an engineer. In each 5-min interval, three pedestrians who traversed the section under consideration were randomly selected to give their responses. In addition, the percentages of pedestrians walking along the street beside the sidewalk were computed at 5-min intervals.

DATA ANALYSIS AND RESULTS

Data were analyzed by using the Statistical Analysis System (SAS) computer package.

Temporal Variation of Pedestrian Flow

Figure 1 shows variations of pedestrian flow at one of the selected sites from 6:30 a.m. to 6:30 p.m. The peak pedestrian flow occurred from 11:00 a.m. to 1:00 p.m. Platoon flows were noted in the field. Therefore, speed-flow relationships for planning and design purposes should be developed on the basis of short time intervals. However, 1-min intervals were not sufficient to take a reasonable number of speed measurements. Thus, the first data set was used to develop the relationship between 1-min flow and the average flow in longer intervals.

The relationship between the maximum 1-min flow (F1) within a 5-min interval and the average 5-min flow (F5) was investigated. Regression analysis indicated that the relationship was linear with an r^2 value of 0.99. The resulting equation is

$$F1 = 3.535 + F5 \tag{1}$$

The relationship between the maximum 1-min flow (F1) within a 10-min interval and the average 10-min flow (F10) was linear with an r^2 value of 0.98. The resulting equation is

$$F1 = 3.764 + 1.015F10 \tag{2}$$

Also, the relationship between the maximum 1-min flow (F1) within a 15-min interval and the average 15-min flow (F15) was investigated. A linear regression model provided the best fit with an r^2 value of 0.96. The equation obtained is

$$F1 = 4.104 + 1.014F15 \tag{3}$$

Investigation of residuals in all previous models indicated that variances were consistent, but they increased with the increase in the average flow interval. In addition, no outliers

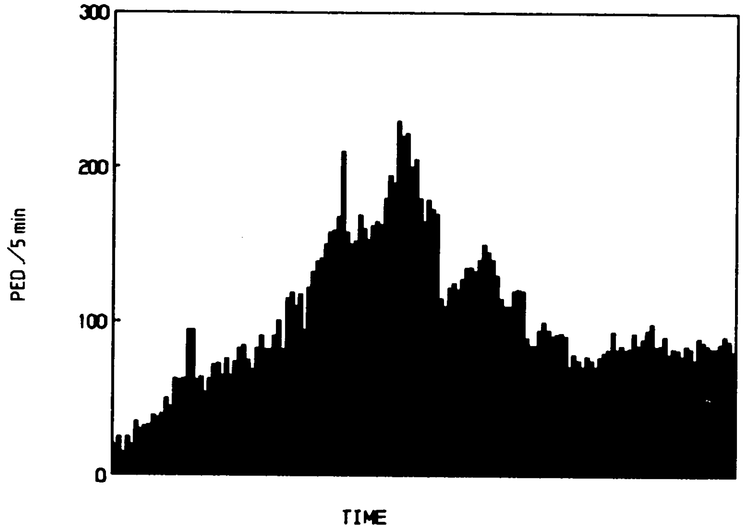

FIGURE 1 Pedestrian flow by 5-min intervals in Irbid (6:30 a.m. to 6:30 p.m.).

were detected if the average flow is more than 2 pedestrians/min/ft. Therefore, the previous relationships can be considered valid for average flows of more than 2 pedestrian/min/ft, as shown in Figure 2.

In conclusion, the maximum 1-min flow can be estimated from the average of 5-, 10-, and 15-min flows. The 5-min interval is characterized by lower variance and a higher coefficient of determination. Moreover, the 5-min interval provided ample time to take reasonable speed measurements based on manual techniques.

Development of Speed-Flow Relationship

The second data set was used to develop the speed-flow relationship. For flows in excess of 2 pedestrians/min/ft, flows

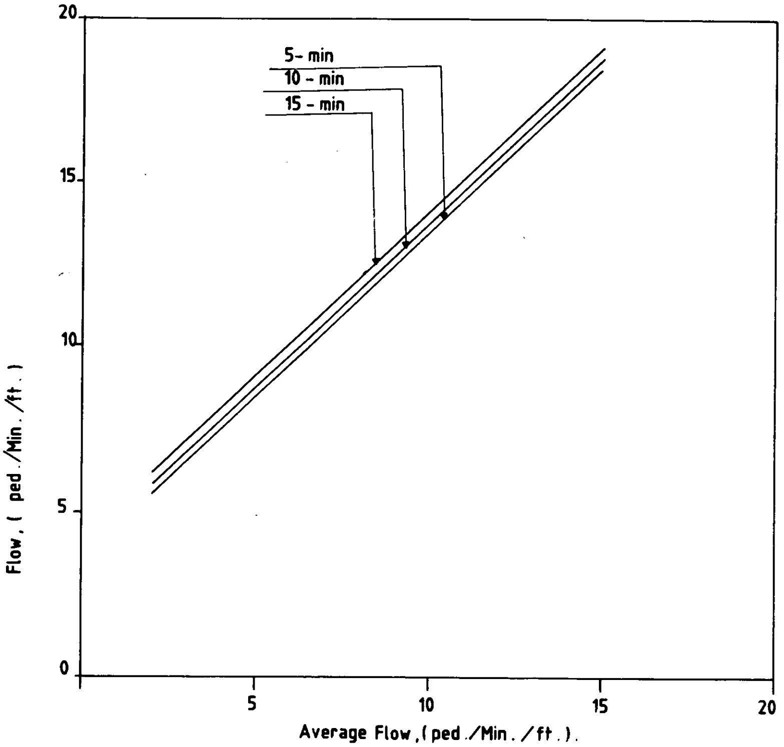

FIGURE 2 Relationship between maximum 1-min flow and the average of 5-, 10-, and 15-min flows.

were adjusted to reflect the maximum flow according to Equation 1. For low pedestrian flows, speed and flow collected at 1-min intervals were used. The following polynomial regression provided the best fit:

$$F = 5.816 + 0.1903S - 7.3 \times 10^{-4}S^2 \qquad (4)$$

where F is flow (pedestrians/min/ft) and S is average speed (ft/min). Results of the statistical model are given in Table 1.

The speed-flow relationship is shown in Figure 3. The free-flow speed was 288 ft/min (1.463 m/sec), speed at maximum flow was 131 ft/min (0.665 m/sec), and the maximum flow (capacity) was 18.22 pedestrians/min/ft (3,590 pedestrians/hr/m). The speed-space relationship is shown in Figure 4. The minimum space requirement was 5 ft² per pedestrian, and the average speed was almost constant if the space exceeded 120 ft² per pedestrian.

Evaluation of Relative Degree of Convenience

Analysis of data collected to evaluate the relative degree of convenience as a function of flow level indicated that the correlation between pedestrian response and engineering judgment was very low. This may be because engineering judgment was based on the available space per pedestrian and possibility of conflict within the selected sidewalk section, whereas pedestrian judgments might be affected by walking conditions throughout the trip rather than the specified section. For the most part, pedestrians underevaluated the relative degree of convenience.

The percentage of pedestrians walking along the street beside a sidewalk was analyzed as a function of flow level. The relationship between the percentage of pedestrians walking along the street beside a sidewalk and the demand flow as a ratio from capacity (18.22 pedestrians/min/ft) is shown in Figure 5. The results indicate that, even at low demand to capacity (V/C) ratios, there was a considerable percentage of pedestrians walking along streets. Also, it is clear that up to V/C equal to 0.5 the percentage of pedestrians walking along streets was below 5 percent, but for V/C more than 0.5 the percentages increased substantially.

DISCUSSION OF RESULTS

In this study, the manual technique was adopted because other techniques such as photography and videocamera are either

TABLE 1 Analysis of Variance and Estimate of Parameters for Speed-Flow Relationship

Source	DF	Sum of Squares	Mean Square	F-Value	Prob >F
Model	2	6281.357	3140.678	1472.040	0.0001
Error	237	505.653	2.134		
Total	239	6787.010			

Adjusted R-Square = 0.925

Parameters Estimates

Variable	DF	Parameter Estimate	Standard Error	T for Ho: Parameter = 0	Prob>|T|
Intercep	1	5. 816	1.5209	3.824	0.0002
Speed	1	0.1903	0.0164	11.621	0.0001
Speed-Square	1	$-7.3*10^{-4}$	$4.1*10^{-5}$	-17.711	0. 001

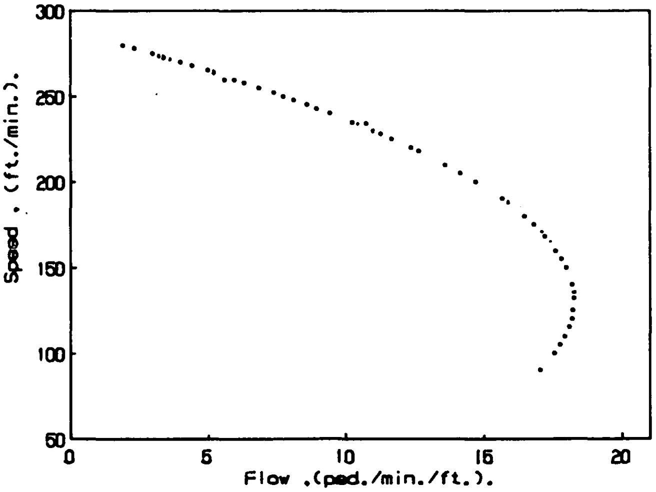

FIGURE 3 Pedestrian speed-flow relationship for CBD.

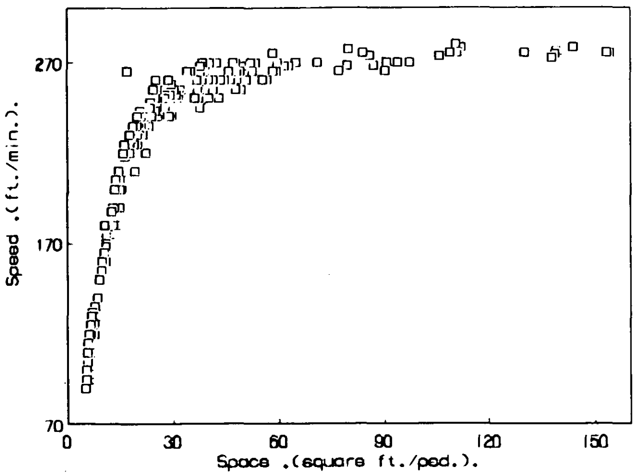

FIGURE 4 Pedestrian speed-space relationship for CBD.

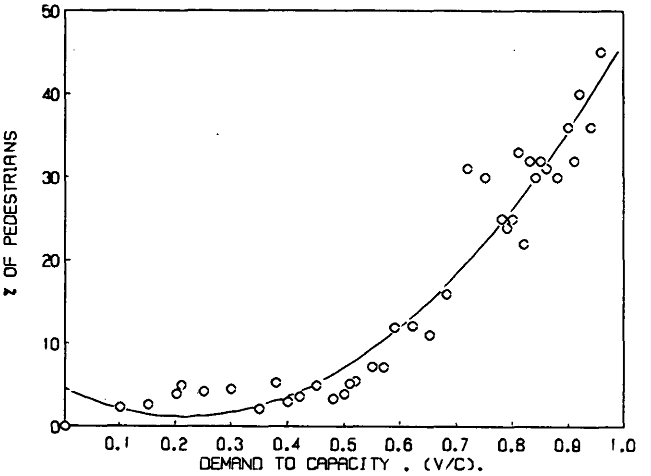

FIGURE 5 Relationship between percentage of pedestrians walking along streets and demand to capacity ratio.

very expensive or not validated for wide use (e.g., image analysis) (*2*). The manual technique is widely used, and any inherent uncertainties or inaccuracies in time and speed measurements due to human reaction time can be ignored for practical purposes. Pedestrian flows were analyzed on the basis of effective sidewalk width rather than the lane concept. The use of the lane concept is only reasonable under certain conditions, such as pedestrian arrival corridors (*3*).

Analysis of pedestrian flow variations in the CBD indicated that peak flow occurred from 11 a.m. to 1 p.m. This period is expected since most employers, workers, and schools terminate their working day. Because of inhomogeneity of trip purposes, platoon patterns were noted in this period. Thus, to take into account these patterns, a 1-min interval was adopted as a basis for flow study. Results of temporal variation of pedestrian flow indicated that maximum 1-min flow can be estimated from average flows of 5-, 10-, and 15-min intervals by using additive adjustment factors. However, the results indicated that the use of average 5-min flow to estimate maximum 1-min flow was more accurate than other intervals. According to the 1985 *Highway Capacity Manual*, if flow is more than 0.5 pedestrian/min/ft, platoon flow can be estimated from 15-min flow by using an additive adjustment factor of equal to 4.0 (*4,5*). In this study, it was found that if the flow is more than 2 pedestrians/min/ft, the corresponding factor will be 4.10. The discrepancy in the range from 0.5 to 2 pedestrians/min/ft is probably because platooning formation was only noted in the CBD at higher levels of flow.

The estimated capacity of the CBD sidewalks as shown in Figure 3 was 18.22 pedestrians/min/ft (3,590 pedestrians/hr/m). This value is very low compared with the 25 pedestrians/min/ft specified in the 1985 *Highway Capacity Manual*. The reduction in capacity was about 25 percent. One reason for this reduction is that in this study bidirectional flow was considered. Pushkarev and Zupan (*5*) pointed that a maximum reduction of 14.6 percent is possible if the ratio of opposing flows is 90:10. However, the results of this study are similar to the result of two-way passageways for London underground stations (*6*), 18.92 pedestrians/min/ft (3,725 pedestrians/hr/m). Pedestrian behavior may be attributed to other reasons: presence of luggage-laden pedestrians and density of shops in the CBD. Free-flow speed and speed at capacity obtained in this study are comparable with the values cited in the *Highway Capacity Manual* and passageways of London underground stations.

The survey of the relative degree of convenience based on evaluations by pedestrians and engineers did not provide adequate results. As mentioned earlier, pedestrians underevaluated the relative degree of convenience, and their judgments at the same level of flow were widely inconsistent. The inconsistency may be explained by the following factors: (*a*) pedestrians having different trip purposes gave different judgments specifically at higher levels of flow; (*b*) apparently, pedestrians gave their judgments about sidewalks in general rather than the specified sidewalk section; and (*c*) differences in education, age, and other factors might affect pedestrian evaluations.

The last measure used to evaluate the relative degree of convenience as well as pedestrian safety was the percentage of pedestrians walking along a street beside a sidewalk as a function of flow level. The result indicated that, up to V/C equal to 0.5, the percentage of pedestrians walking along the street was about 5 percent. For higher values of V/C, percentages increased substantially, probably because commuter pedestrians were seeking a higher level of service in terms of speed. For V/C less than 0.5, the percentage of pedestrians walking along a street was very low and can be reduced or eliminated through education and enforcement. For higher values of V/C it is clear that the increase was very high and cannot be afforded easily. Therefore, in the planning and design of CBD sidewalks, it is recommended that V/C be limited to 0.5. In addition, a study of accidents in the selected area indicated that pedestrian accidents were 23 percent of the total traffic accidents, and 45 percent of pedestrian accidents happened to pedestrians walking along streets. For pedestrians walking along streets, the study indicated that 60 percent of the relevant accidents occurred between 1 and 2 p.m. Thus, a period of high pedestrian demand associated with insufficient sidewalk width and a low degree of convenience was characterized by high pedestrian accidents.

CONCLUSIONS AND RECOMMENDATIONS

Studies of temporal variation of pedestrian flows and speed-flow relationships for CBD sidewalks were undertaken. The results of the studies led to the following conclusions:

1. The best pedestrian counting interval to estimate maximum 1-min pedestrian flow was the 5-min interval.
2. The capacity of a bidirectional CBD sidewalk was 18.22 pedestrians/min/ft (3,590 pedestrians/hr/m).
3. The speed-flow relationship developed in the 1985 *Highway Capacity Manual* overestimates the capacity of CBD sidewalks in developing countries even if a reduction factor is applied to consider the opposing flow.
4. A considerable percentage of pedestrians walk along streets even at low flow levels. Consequently, education and enforcement are needed.
5. In the design of new sidewalks or improvement of existing CBD sidewalks, it is recommended that the demand to capacity ratio be limited to 0.5.

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Bicycle Access to Public Transportation: Learning from Abroad

MICHAEL REPLOGLE

In the face of traffic congestion, air pollution, and inadequate fiscal resources, American communities need to consider new, more cost-effective strategies to expand transit use and reduce automobile dependence. Worldwide experience suggests that improving bicycle access to transit in the United States may be the most promising but neglected low-cost strategy to enhance air quality while increasing the freedom of travelers to chose alternatives to the automobile. Bicycles are the fastest-growing and predominant mode of access to express public transportation services in many European communities and in Japan. Provision of secure bicycle storage at rail stations, development of bicycle-friendly street networks, and the creation of a climate of community opinion supportive of bicycling are all important factors behind the success of bike-and-ride systems in these countries. U.S. transit access systems have increasingly relied on the automobile. However, park-and-ride systems have served only suburb–to–central city travel markets, which are of declining importance, while weakening transit system competitiveness in the growing suburb-to-suburb travel market. U.S. communities can learn valuable lessons from the foreign experience in creating balanced multimodal transit access systems that include the bicycle.

While the United States has been investing in costly park-and-ride systems that have made transit increasingly dependent on the automobile, European and Japanese communities have been strengthening the potential for people to walk and bicycle to and from transit, boosting ridership at a far lower cost. In Japan and much of Europe, the fastest-growing and often predominant access mode to suburban express transit services is the bicycle (*1*). Despite rapid growth in the number of motor vehicles, suburbanization, and the emergence of polycentric metropolitan areas, bicycle access to most European and Japanese railways has gained market share at the same time that bus and walk access has declined.

Access to and from public transportation is one of the most important roles for the bicycle in the late 20th century, especially in larger cities. Bike-and-ride services expand the potential market area of express public transportation at low cost without the very high air pollution emission and energy use rates per VMT, excessive space requirements, and high capital costs of automobile park-and-ride systems. Whereas park-and-ride enables those living in lower-density areas to travel from home to transit stop, bike-and-ride systems providing secure overnight bicycle parking can facilitate both access to and egress from transit, enabling travelers to get from transit stops to nearby workplaces and schools otherwise be unreachable by transit. Bicycle access can be invaluable in adapting transit systems to the emergent suburbanized polycentric metropolitan land use patterns found in Europe, Japan, and North America.

TRANSIT ACCESS IN THE NETHERLANDS

Bike-and-Ride: The Predominant Access Mode

Even in the 1960s and early 1970s, when bicycle use was declining in the Netherlands because of suburbanization and large highway investment, bicycle access to railways was growing. Today in the Netherlands, the bicycle is used as transport to the station for more than 35 percent of all train journeys, and 1 in 10 passengers uses a bicycle to travel from the station to the final destination (*2*). The Netherlands Railways anticipates that by 2010, it will require 330,000 bicycle parking spaces at stations, 75 percent more capacity than provided today (*3*).

As Figure 1 shows, guarded bicycle parking spaces account for the majority of all bicycle parking at Dutch rail stations today, with nearly 100,000 spaces nationwide, mostly at higher-ridership stations. The average size of a guarded bicycle parking facility is about 1,000 bicycles, although at 14 stations the capacity exceeds 2,000, at 7 stations it is less than 500, and some facilities are as small as 60 bicycle spaces. At stations with fewer than 1,500 boardings per day, roofed bicycle parking is the most common type of facility, usually accommodating 70 to 800 bicycles. Bicycle lockers are common only at lower-volume stations, where 10 to 50 units are typical, although six stations offer more than 100 bicycle lockers.

Costs of Bicycle Versus Automobile Access

Increasingly, new bicycle parking is being located under rail stations to maintain proximity to station entrances while reducing consumption of valuable adjacent land. The Dutch railways found that even relatively expensive underground guarded bicycle parking is less than 1/10 as expensive per space as automobile park-and-ride construction. Automated bicycle parking systems from Japan are currently being tested in the Netherlands to explore their potential for lowering operating costs and boosting bicycle storage density.

Bicycle rentals are also available at bicycle parking garages, at a cost to users of several dollars a day, providing out-of-town visitors and tourists with an inexpensive and comfortable way to access most destinations. Commuters holding a monthly rail pass can also purchase a monthly bicycle rental ticket

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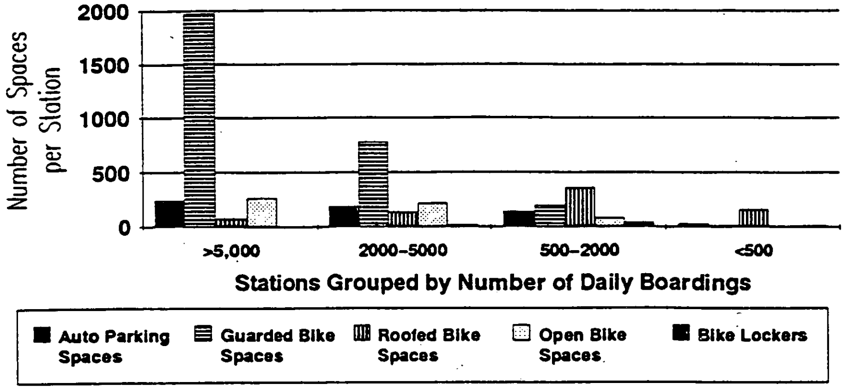

FIGURE 1 Average number of parking spaces at Dutch rail stations, 1989.

offering a deep discount. Such combined marketing of transit with the bicycle as a unified system is characteristic of Dutch transport policies, which also feature a nationally integrated public transportation fare system for trains, buses, and trolleys to make the use of nonautomobile modes as attractive and as easy to use as possible.

The typical cost of providing a single guard for one of the Netherland's 84 bicycle parking garages at a rail station is about U.S. $36,000 per year, including overhead. Garages typically are staffed by two or three persons over their operating day, and also rent, repair, service, and sell bicycles, providing a full-service center for bicycle transportation. User costs for parking at Dutch rail stations are about U.S. $0.75 per day or U.S. $75 per year, for either guarded parking or individual lockers. Revenues from parking cover roughly 40 percent of operating costs and are augmented by income to franchise operators from repairs and other services. [More information on costs is given elsewhere (*4*)]. In some towns, private-sector bicycle parking garages and bicycle rental services adjacent to rail stations are combined with other businesses, such as snack shops and convenience stores, spreading the labor costs for parking attendance over several enterprise activities.

Whereas park-and-ride systems are being developed in the Netherlands, they are accorded the lowest priority of all transit access modes because of low cost-effectiveness. Only four rail stations in the Netherlands offer more than 500 automobile parking spaces; the median station parking capacity is 48 automobile spaces. Across the whole of the Netherlands, there are fewer than 25,000 automobile parking spaces at rail stations—barely one-fourth the number of guarded bicycle parking spaces at stations.

Bicycle Network Development

A key factor supporting the high level of bicycle access to transit and the relatively low dependence on the automobile in the Netherlands, despite high automobile ownership, is the great attention that has been given by local governments to making streets pedestrian and bicycle friendly. Especially within the past 20 years, a major focus of local government traffic planners has been the introduction of more widespread traffic-calming measures in both residential and commercial areas, where automobile traffic has been slowed to give greater priority to pedestrians, bicycles, and traffic safety. In many places where it has not been possible to slow car traffic, bicycles and pedestrians have been given a separate right-of-way, with careful attention to the design of network intersections. In all of the Netherlands, there are 5,000 km of bicycle paths in urban areas and 10,000 km of bicycle paths outside these areas, compared with 105,000 km of roads, including 2,000 km of expressways (*5*).

Many communities, following the excellent example of Delft (a satellite city near The Hague and Amsterdam), have developed well-integrated comprehensive bicycle networks. These combine exclusive regional bicycle roads or paths on a ⅓- or ½-mi grid within the denser urbanized area. The bicycle roads are also combined with a subregional and local grid of bicycle-friendly streets, paths, and lanes on even tighter grids of ⅕ to ⅒ mi. At the local grid level, this network is composed almost exclusively of traffic-calmed or *woonerf* streets, where cars are allowed, but only at a very slow speed. In *woonerf* streets, pedestrians, cyclists, cars, playing children, and chatting neighbors all share the same space. Combined with the provision of neighborhood-level retail services within walking distance, this street pattern has produced a high level of walking and cycling for short trips of all kinds—shopping, access to public transportation, and daily recreation—while reducing automobile dependency.

Houten: A Model Suburban Development

Extensive research by the Dutch into pedestrian- and bicycle-friendly town planning has produced notable lessons for engineers, planners, and policy makers from other countries. For example, Houten, a new suburban town 10 min by commuter train from Utrecht, developed in the past decade, is an outstanding embodiment of contemporary Dutch town planning principles of proximity planning and pedestrian/bicycle priority in traffic system design. The diagonal grid of bicycle/pedestrian-only routes radiates from the central plaza by the rail station, where there are a bicycle parking garage and, close at hand, the town's retail shopping arcade and a modest automobile parking lot. High-density housing is close to the center, but most of the dwelling units are moderate-density town houses facing onto *woonerfs*, with ample gardens behind them. A traffic cell system, similar to those in many other European and Japanese communities, permits automobile traffic to generally move only radially, unless traveling to the outer circumferential ring road, thus creating an almost traffic-free town. Indeed, 8 out of 10 trips made within this new town are by foot or bicycle, despite a high level of household automobile availability.

Bicycles for Congestion Management and Pollution Prevention

Today, the bicycle is the second most important form of transport in the Netherlands after the automobile, accounting for more person kilometers of travel than trains. The bicycle is used for 8 percent of person kilometers of travel and 29 percent of all trips. Already the world's most bicycle-friendly country, the Netherlands is embarked on major new initiatives to further increase the use of bicycles to help stem acid rain and global warming, improve urban livability, and reduce the growth of transit subsidies. Without new policies, the number of vehicle kilometers of travel by automobile has been forecast to grow by 70 percent in the Netherlands by 2010. To help restrain the growth in automobile travel to 35 percent, in 1992 the Dutch parliament adopted a new bicycle master plan, with the 20-year objectives of a 30 percent increase in person kilometers of travel by bicycle and a 15 percent increase in person kilometers of travel by train through improved bicycle-transit integration (*5*). In Germany and Denmark, where bicycles also play a major role in transit access and short-distance travel, comparable major initiatives are under way.

TRANSIT ACCESS IN JAPAN

Bike-and-Ride: Efficient Suburban Access

In Japan, as in much of Europe, walking and bicycling account for a major share of trips in cities and towns, despite rapid growth in the number of motor vehicles and suburbanization. Since the early 1970s the use of bicycles for access to transit has been growing at an astounding rate across most of Japan, accompanying suburban growth and the decline of walking and buses as access modes to railways. By 1987 there were nearly 3 million bicycles parked at Japanese rail stations on typical November workdays, as Figure 2 shows.

As in Europe, access to public transportation in Japan has been undergoing a structural change as a by-product of suburbanization. Whereas in the early 1970s walking and collector buses were the major elements of the access system to suburban rail stations, by the late 1970s the bicycle had begun to penetrate the suburban rail access trip market on a footing nearly equal to or exceeding that of collector buses. Although walking continues to be almost the sole means of railway access in dense central city areas, bicycles account for roughly 1/10 or more of station access trips in suburban areas. In the newer and lower-density suburbs at the fringe of Japan's metropolitan regions, where much growth is being experienced, bicycle access trips account for as much as one-half of all station access trips, whereas walking and bus access shares continue to fall. In the Tokyo region, bicycles accounted for 4 percent of suburban rail transit access in 1975, 11 percent in 1980, and 13 percent in 1985. In the Chukyo region, bicycle access grew from 12 percent in 1975 to 23 percent in 1980 and 27 percent in 1985.

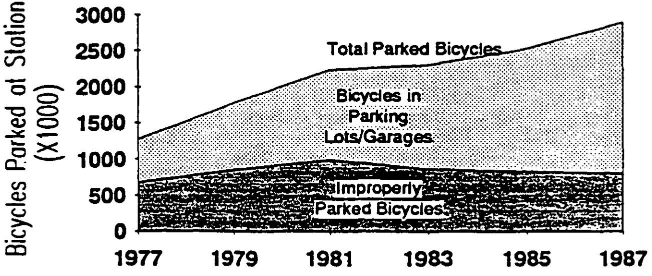

FIGURE 2 Growth in use of bicycles to reach Japanese rail stations.

The growth of bicycling for access to transit and other short trips in Japan has been facilitated by compact development patterns, high costs associated with the use of automobiles, well-developed transit networks, and substantial investments in pedestrian and bicycle facilities and traffic-calming measures (*6*). Low rates of bicycle theft and crime made it possible for Japanese bicyclists to leave their bicycles in any open area near station entrances without securing the bicycle to a fixed object, relying on nothing more for theft protection than a small metal lock that prevents someone from casually wheeling the bike away. Seeking lower housing costs, more people moved to distant, lower-density suburbs around major cities over the past two decades, in many cases beyond easy walking distance of rail stations. With the environmental movement in the early 1970s, attitudes toward the bicycle as a mode for the poor began to be replaced by new attitudes viewing it as appropriate for middle- and upper-middle-class mobility.

Encouragement of Parking Construction by Bicycle Pollution

By the early 1970s, the demand for bicycle parking in station squares began to outstrip designated capacity, leading to a "bicycle pollution problem" caused by thousands of improperly parked bicycles near station entrances. A model cities program for the development of bicycle parking at rail stations was initiated in Japan in 1973 and resulted in construction of 22,000 bicycle parking spaces at 107 stations. However, this proved inadequate to meet growing demand. The number of bicycles parked at rail stations more than doubled between 1975 and 1977, overwhelming both old and new bicycle storage facilities and occupying ever larger portions of station plazas (*7*).

In 1978 the Japanese Ministry of Construction initiated a major program to expand bicycle parking supply at stations. Bicycle parking capacity grew steadily from 598,000 spaces in 1977 to 1,333,400 in 1981 and 2,382,000 in 1987 and has continued similar growth since then. Municipal ownership of bicycle parking facilities at stations now accounts for three-fourths of the parking supply. Despite the massive expansion of parking capacity, the "improper parking of bicycles" outside of designated areas has continued to plague municipal authorities. In response to pressure from these authorities, the Japanese Ministry of Transport will be undertaking major new central government initiatives to develop bicycle facilities and stimulate use, beginning in late 1992.

Park-and-Ride in Japan

Limited automobile park-and-ride services have been developed at a few Japanese rail stations at the metropolitan fringe, but these have a low priority given their very high costs. In 1985 automobiles accounted for only 2 percent of Tokyo regional rail station access and motorbikes for about 4 percent. In the Chukyo region, park-and-ride accounted for 7 percent of station access and motorbikes for 6 percent. Whereas automobile park-and-ride use was growing in the late 1970s, since then it has decreased slightly in some regions of Japan and remained stable in others (*8*).

It is useful to contemplate what the implications would be if Japan were to pursue the U.S. strategy of park-and-ride, diverting bicycle access trips to automobile access. There would be demands for massive investments of capital for parking structures; land use densities adjacent to stations would be sharply reduced, depressing transit ridership, overall transit accessibility, and local tax bases; air pollution and traffic problems near stations would intensify; and the nation would need to import substantially more petroleum. Increased congestion would, in turn, impede feeder bus services already suffering from traffic delay. Diversion of bicycle trips to collector buses would similarly raise the cost of the metropolitan transportation system, requiring more peak capacity and higher subsidies for bus operation. These effects are indeed those being experienced in U.S. communities that have inadvertently weakened their transit systems and overall economic competitiveness by investing too heavily in park-and-ride systems, while neglecting bicycle and pedestrian access.

High- and Low-Tech Bicycle Parking Systems

A number of different types of bicycle parking are found at Japanese rail stations, from simple ground-level areas without a roof to partially or fully automated bicycle parking systems. Half of the official bicycle parking spaces provide weather protection. Spurred by high land costs to find space-efficient ways to accommodate more bicycles close to station entrances, Japan has developed a wider array of innovative bicycle storage systems than any other country. Even the most expensive fully computerized and automated bicycle parking systems have capital costs of less than U.S. $2,000 per parking space. This compares favorably with the cost of constructing U.S. automobile park-and-ride spaces, which typically amount to $4,000 to $18,000 per parking space. Automated bicycle parking facilities in Japan include merry-go-round storage systems, dry-cleaner type circulating racks, vertical rotating pallet systems, multiple-layer suspension systems, and several types using cranes or robots to lift bicycles into overhead storage areas that may be 60 ft or more in height. In 1987 there were 516 multistory garages for bicycle parking in Japan, along with 31 mechanical and automated bicycle parking facilities and 33 underground bicycle parking garages. Each of these types of facilities had an average capacity of 600 to 750 bicycle spaces. Since that time, there has been significant additional development of similar high-density bicycle storage systems across Japan.

Nearly two-thirds of bike-and-ride users park their bicycles free at Japanese rail stations. One-sixth of users pay between 1,000 and 1,999 yen (U.S. $8 to U.S. $16) per month for their parking, one-eighth pay between 2,000 and 2,999 yen (U.S. $16 to U.S. $32) per month, and the remaining 7 percent pay other amounts. User fees are most common when higher-quality parking is offered close to the station entrance. Occupancy rates for bicycle parking are highest also at facilities close to station entrances, averaging more than 92 percent for facilities within 100 m of entrances (which comprise 68 percent of all parking facilities).

Bicycle Rental Systems: Developing Efficient Shared Transportation Resources

The Japanese have also developed extensive bicycle rental facilities at railway stations. These typically use fleets of identical minicycles, which are bicycles with 20-in. wheels, a front basket for parcels, a built-in locking device, a light, and a bell. Seat height is easily adjustable over a wide range so that users of different stature can ride comfortably. All vehicles are painted bright lime green for easy recognition and theft deterrence. Although one-time rentals are possible, most customers contract for rental privileges on a monthly basis. They are then entitled to take a bicycle from the system whenever they wish, although it will often be a different bicycle than they used before. There are several advantages to this type of operation:

- Storage density of bicycles can be greater than is possible in other bicycle parking, since no provision for access to a particular bicycle need be provided.
- A vertically movable floor technology for bicycle storage can be used, with access only on the ground level, since all bicycles are the same.
- Bicycles used by clients commuting in the peak direction can be rented, at least in part, to clients involved in reverse commuting. Thus, a higher level of vehicle utilization over the course of the day can be achieved.

People who rent bicycles are given a magnetic card they can use to take a bicycle from the facility. The exit gates feature optical beams at chest height and wheelbase height connected to a security alarm. Users removing or returning bicycles run their magnetic card through a card reader at the gate. They are notified by this device at the gate if their rental agreement needs to be renewed. These rental bicycle systems have been growing significantly in the 1990s in several cities in Japan, with support from municipal authorities (*9*).

Traffic Calming and Bicycle Network Development

Whereas the availability of secure bicycle parking conditions at rail stations and shifts in community opinion that made it acceptable for middle- and upper-income people to ride bicycles were vital to the growth of bike-and-ride in Japan, the availability of increasingly bicycle-friendly street systems and land use has also been an important factor. Beginning in the early 1970s, local authorities have undertaken a major expansion of bicycle/pedestrian paths and bicycle lanes, creating more than 60 000 km of facilities by 1990. In the 1980s the Japanese began to adopt extensive traffic-calming measures to slow car traffic in residential and commercial districts to improve safety and promote walking and cycling through greater integration of slow and fast modes on low-traffic-volume streets. These policies, together with high user fees for automobile use and growth management, which has fostered relatively high-density, mixed land use patterns, help account for the 40 to 50 percent walk/bicycle mode shares observed in Japan. As a result, residents of Japanese cities use 1/10 as much gasoline per capita as residents of U.S. cities (*10*), enhancing Japan's economic competitiveness.

LESSONS FOR AMERICA

Park-and-Ride Overdevelopment: Weakening America's Transit Systems

The several billion dollar investment American communities have made in park-and-ride transit access systems has not been accompanied by balanced investment in pedestrian and bicycle access to transit. Indeed, in many cases, transit services have been reoriented to serve isolated parking lots rather than existing or potential centers of development, eliminating opportunities to cluster more jobs and housing within walking distance of transit. Park-and-ride systems have stimulated peak-period, peak-direction ridership, worsening directional imbalances in ridership flows and reducing transit seat mile productivity, while driving up demands for costly peak transit capacity.

In recent decades, funding and institutional support for park-and-ride development has been far more readily available than support for bicycle and pedestrian enhancements. Indeed, the only transit-related expense eligible for U.S. highway trust funds when the modal allocation of this funding source began to weaken in the late 1960s and early 1970s was park-and-ride lots, on the condition that user fees would be set below the level needed to recover operating and maintenance costs (*11*). Park-and-ride construction was further encouraged as a quick and easy transportation control measure for air quality improvement in the mid-1970s. By the early 1980s, well over 1,000 park-and-ride lots had been created throughout the United States, with some having a capacity of more than 1,000 vehicles. By the late 1980s, park-and-ride strategies had become institutionalized and unquestioned as an asset to transit system development in America, where automobiles accounted for more than half of access trips to transit in many suburban communities and smaller cities.

Barriers to Bike-and-Ride in America

Although common in many American communities earlier in this century, bike-and-ride transit access declined sharply with the decline of transit in the 1950s and 1960s. Since that time, it has received only passing attention in most American communities and has frequently been addressed only as an afterthought, rather than being integrated into transportation and transit system planning and management. The result has often been the provision of a few bicycle racks, frequently subject to vandalism and without weather protection, accompanied by a few bicycle lockers, which have often been poorly marketed, managed, and maintained. A number of studies have found substantial latent demand for bicycle access and have called for new facilities, access improvements, and policy changes, but study recommendations have seldom been implemented (*12–15*). Funding and institutional support for creation of bicycle-friendly street networks and new bicycle parking concepts have simply not been made available in most communities. As a result, with a few exceptions, bicycles play only a marginal role in access to suburban American public transportation.

High rates of bicycle theft and vandalism pose a major barrier to bicycle-transit integration in the United States. This can be overcome only by providing secure bicycle parking at transit stops and stations—lockers, unguarded shared checkrooms, and guarded bicycle parking garages—as is found in Japan and much of Europe. Bicycle-hostile street environments near most U.S. transit stops and stations also pose a significant barrier to more widespread use of bicycles for transit access. The majority of U.S. cyclists are not comfortable riding in fast or heavy traffic unless offered separate paths or lanes. A large but not well-connected network of low-speed, low-volume, relatively bicycle-friendly streets exists in most U.S. suburbs. However, without penetrator bicycle paths to connect them to major transit stops, employment, and shopping centers, only a minority of cyclists will consider it attractive to bicycle to transit. Marketing, education, and promotion programs will also be needed to encourage greater and safer use of bicycles for short utilitarian trips, including transit access. Such programs are needed in conjunction with initiatives that reduce the current barriers of theft, security, safety, and legitimacy that impede nonrecreational bicycle use in America.

Ensuring Appropriate Air Quality and Congestion Management Strategies

Many American state and local governments plan major expansions of park-and-ride systems in the 1990s to meet air quality and congestion management goals. However, bike-and-ride appears to offer far greater cost-effectiveness and long-term potential for strengthening alternatives to the automobile. One study found that the installation of secure bicycle parking at rail stations would reduce hydrocarbon emissions at a public cost of $311 per ton, compared with $96,415 per ton for an express park-and-ride service, $214,950 per ton for a feeder bus service, and $3,937 per ton for a commuter rail carpool matching service. Similar differentials were found for CO reduction costs (*16*). Automobile park-and-ride trips involve cold start vehicle operation, with associated pollution emission and fuel use rates several times higher than the average for all automobile travel, resulting in almost negligible emissions reductions from park-and-ride, when all factors are considered (*4*). In contrast, bicycle and pedestrian access to transit has no emissions. Switching short automobile access trips to bicycles can free park-and-ride spaces for travelers living more than 2 mi from the lot, improving the cost-effectiveness of the overall transit access system.

Access for All

About 100 million Americans own bicycles, and many of these people live 1/4 to 2 mi from express transit stops. Few of these people now use transit to get to work, in part because of the lack of an inexpensive, convenient, safe, and fast transit access system suited to trips of this distance.

With more than three-fourths of employment growth in U.S. metropolitan areas in the suburbs over the past several decades, new strategies are needed to adapt transit to access suburban jobs. Bike-and-ride can play a major role in this. In the Silicon Valley of California, 40 percent of those using bicycle lockers at rail stations leave bicycles in them overnight and use them to get from the station each morning to their nearby schools and employment, just as in the Netherlands. This strategy is far cheaper than provision of dedicated van and bus feeder services and can provide inner city residents with an inexpensive way to reach suburban employment opportunities, while boosting reverse direction transit patronage, transit agency revenues, and transit system capacity utilization factors. As employer trip reduction programs are more widely implemented, it is important to develop a wider array of transportation choices for suburb-to-suburb commuters as well. Bicycle access and egress strategies are vital to expanding the freedom of Americans to choose alternatives to automobile travel at a low cost.

The U.S. Intermodal Surface Transportation Efficiency Act of 1991 has set in motion significant reforms in U.S. transportation planning, funding, and decision making. It provides opportunities to allocate substantial resources to improve alternatives to the automobile, including bicycle-transit integration. Successful implementation of this law, however, will require new multimodal thinking at the state and local level and the testing of new strategies.

Bike-and-ride is not a panacea for the problems faced by transit agencies seeking to adapt to new markets. However, by learning from Europe and Japan and adapting ideas that have enhanced their transportation system efficiency, America can restore its economic competitiveness while meeting clean air requirements, managing traffic congestion, and developing more livable communities.

ACKNOWLEDGMENTS

The author wishes to acknowledge FHWA, which supported a recent research effort by Michael Replogle and Harriet Parcells from which much of this paper is drawn. Thanks also to Robert Patten, who served as a research assistant in that effort, and to Andre Pettinga, the Japan Bicycle Promotion Institute and its staff in Tokyo, the Dutch National Railways, and the Bicycle Federation of America for providing research materials.

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