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# Mixed Traffic in Chinese Cities: Bicycle and the Intersection Problems

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# Abstract

The mixed traffic (the traffic made up of bicycles and automobiles) is widely spread in Chinese cities. It is also greatly responsible for major traffic problems, such as the conflicts, low efficiency and safety problems. These problems are most evident at street intersections. However, they have never been investigated in Chinese cities. Therefore, it is the mixed traffic at intersections that requires detailed study. To predict types of transportation mode in Chinese cities, an investigation in Shanghai was performed. It is found that within a certain distance range, cycling is more efficient than other modes and it will still remain in future urban traffic system of China. Then, mixed traffic would require a new strategy of management. The mixed traffic conflict situation was studied in two major intersections of Chinese cities by analyzing digital video. The research showed that for constant number of automobile, the crossing time for mixed traffic increases with number of bicycles following a logarithmic equation. The crossing time of the mixed traffics with constant number of bicycle increases with number of automobiles following an exponential equation. The suggestions of traffic management strategies and intersection design are presented. It is anticipated that the new management strategies that consider severely the bicycle component can decrease the traffic impact on environment.

# Acknowledgment

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# Chapter 1
# Statement of the Problem

In a developing country like China, one of the concerns of the authorities is the explosion in traffic volume. To accommodate better service for the increasing number of vehicles in urban areas, there should be an expansion of the road network to meet heavy demand of the increasing urban traffic.

According to statistical data from 1994, the total road space in the 30 largest cities in China is 230 million $m^2$, which means 3.16 $m^2$. Per capita. Altogether, there are more than 30,000 public buses in the public transit service of these large cities. Their total service distance is more than 37 thousand kilometers. The 4 largest cities, Shanghai (14.6 million population), Beijing (12.5 million), Tianjin (9.6 million) and Guangzhou (7 million) are operating their metro systems as part of their public transit service, while several other cities including Changchun (4.5 million), Wuhan (7.3 million), Shenzhen (1.5 million) and Harbin (4 million), are planning to build up their metro systems. Another important way to accommodate increasing passenger traffic is to include the bicycle in city transportation systems. It is well known that China is a bicycle-oriented country. The total number of bicycles in the 30 biggest cities is 44 million, which shows that, generally, there is one bicycle for 1.58 persons. (Statistical year book of China, 1999)

In the 1990s, the spatial structure of big Chinese cites changed greatly because of the construction and displacement caused by the commercialization of real estate. Many automobiles joined the transportation system, which had formed over decades and mainly served bicycle traffic. In 1994, the national government pushed forward a policy to encourage the development of the automobile industry in support of the view that the automobile industry is one of the pillars of the state economy. The main reason for the government to carry out this policy is based on the consideration of the future development of the state economy of the next two decades. However, the largest potential market for the national and foreign automobile industry are the big cities in which the transportation systems are changing rapidly. So the transportation systems in big cities are very important to the billions of dollars of investment and the living style of hundreds of millions of Chinese people. Therefore, research on trends in development of the Chinese city transportation system along with the management strategy are of great importance.

The large cities played an important role in the states' economic strategy and have a trend to grow more rapidly than the country as a whole, which means an increased level of traffic.

The population and land area in large urban centers in China have shown a tendency for proportionally more rapid growth than the country as a whole for the last several decades because of immigration from the countryside.

The urbanization trend is, as well, one of the most important issues that affects the traffic environment. Generally speaking, the population in the big cities is the most productive group in the whole population. So, the passenger traffic condition, to some extent, played an important role in the state's economy.

In 1994, The populations of the 30 largest cities in China were already all over one million. The total non-agriculture population of these 30 cities is 59.6 million, which made up 42% of the total non-agriculture population of the whole state. Their Total GPD is 543 billion RMB Y, which is 35.6% of the Total (non-agriculture) GPD of the whole state. Their total urban area is nearly 4000 square kilometers; average population density is 150 thousand people per square kilometers. Thus, it is obvious that the large cities have become the most highly populated and developed area.

## 1.1 Transportation Problems in Developing Countries

Traffic jams, air pollution and traffic accidents are the universal key problems that all transportation systems face. However, compared with developed countries, the transportation problems in developing countries have their own characters.

The transportation problems of the developing country could be divided into the 9 aspects (Dimitrous, 1992):

1) Rapidly growing traffic flow;
2) The lack of well-maintained transportation equipment;
3) Low efficiency due to the contradiction of residential space and transportation system;
4) The inaccurate utilization of transportation technique;

5) An ineffective transportation administration system;
6) The insufficiency of public transit;
7) The special transportation problem caused by the low-income class in the city;
8) High traffic accident rates;
9) The weak transportation training system for system operators.

We can easily find examples for any of these nine problems in big Chinese cities. However, Chinese cities have their own characteristics. Every aspect of the traffic problem is connected with the existing and improved bicycle traffic system, which has existed for decades.

In the last ten years, many major cities in China have carried out surveys on residents daily trip modes. These data may well reflect the real situation of the proportion of residents' trip mode structure. Table 1.1 shows the result of the Transportation mode structure mode in large Chinese cities, which is mainly made up of public bus, pedestrian and bicycle.

The prominent role of the bicycle in city traffic is noted in most Chinese cities.

### 1.1.1 Public Transit System

The bus plays the main role in the public transit system and is also a major component of the traffic

The bus is usually the only choice in the public transit system in most of the largest cities. There are only 4 cities that have an underground metro system (Beijing, Tianjin, Shanghai and

Guangzhou), while four others (Dalian. Anshan, Changchun and Harbin) are operating 50-70 year old light rail systems left from the colonial era. Even in cities that have rail passenger traffic, the bus systems are still the largest part of the public passenger transit system, because the distance of existing railway traffic system service is very limited and has not yet formed a network. So it is understandable that the rail-based public transit system does not become the main role in the urban public transit system.

### 1.1.2 Non-automobile Traffic

Non-automobile traffic is always the largest part in the whole transportation system.

Pedestrian

Usually, pedestrians make up about one third of the passenger traffic. There are also some special cases, where the pedestrian traffic made up of 70% of the passenger traffic trips because of the natural geographic situation, (e.g.: the mountain cities like Chongqing (The Trip Generation Report of Chongqing, 1995)).

Bicycle

Bicycles form a large part of the passenger transportation. The proportion of the bicycle traffic in the 3 largest cities, Beijing, Tianjin and Shanghai, is about 50%. For other comparably smaller cities, the proportion can be even larger.

Table 1.1 The Proportion of Trip Modes in Major Chinese Cities (Yang Jun, 1990)

| City | Pop. of 1999 Million | Survey Date | Public Transit | Bicycle | Pedestrian | Employer Service | Motorcycle | Taxi | other |
|---|---|---|---|---|---|---|---|---|---|
| Beijing | 12 | 1986 | 27.71 | 54.28 | 13.79 | 4.35 |  | 0.3 | 3.25 |
| Shanghai | 15 | 1986 | 36.11 | 24.22 | 36.26 | 2.34 | 0.14 | 0.2 | 0.72 |
| Tianjin | 9 | 1990 | 8.32 | 74.63 | 10.58 | 3.98 |  | 0.1 | 2.49 |
| Nanjing | 4 | 1986 | 19.2 | 44.10 | 33.1 | 2.50 | 0.30 |  | 0.7 |
| Shijiazhuang | 2 | 1986 | 5.0 | 58.65 | 33.35 |  |  |  | 3.0 |
| Guangzhou | 7 | 1984 | 11.74 | 37.24 | 45.58 | 4.33 | 0.42 | 0.34 | 0.35 |
| Guiyang | 3 | 1984 | 11.57 | 12.96 | 69.74 |  |  |  | 5.73 |
| Zhengzhou | 3 | 1987 | 3.23 | 63.05 | 32.95 |  |  |  | 1.77 |
| Lanzhou | 3 | 1987 | 22.57 | 29.30 | 45.01 |  |  |  | 3.12 |
| Dalian | 4 | 1984 | 36.40 | 17.90 | 36.20 | 3.96 | 0.80 |  | 0.66 |
| Shenyang | 6 | 1990 | 10.10 | 29.00 | 29.00 | 6.50 |  |  | 2.20 |
| Fushun | 3 | 1985 | 22.10 | 40.42 | 40.42 |  |  |  | 2.25 |
| Chanqing | 11 | 1984 | 26.10 | 69.20 | 69.2 | 2.40 | 0.20 | 0.60 | 13.01 |
| Chengdu | 6 |  | 18.83 | 45.65 | 45.65 |  |  |  | 1.00 |
| Wuhan | 7 | 1987 | 20.12 | 35.23 | 39.41 |  |  |  | 3.20 |
| Harbin | 5 | 1985 | 17.70 | 39.41 | 41.66 |  |  |  | 7.26 |
| Changchun | 4 | 1984 | 37.03 | 41.66 | 33.74 |  |  |  | 14.41 |
| Anshan | 1.5 | 1987 | 16.35 | 33.74 | 27.65 |  |  |  | 2.91 |
| Hangzhou | 2 | 1986 | 12.96 | 56.29 | 39.21 |  |  |  | 3.10 |

The bicycle proportion in the public traffic has been increasing yearly to the detriment of the public transit system.

The utilization of bicycles is actually increasing in most cities. A survey in Shanghai shows that the proportion of the utilization of public transit and bicycle changed from 70:30 to 60:40 between 1990 and 1995

(Shanghai Comprehensive Transportation Research institute, 1996). In Tianjin, the trend is even more obvious. The proportion changed from 62:38 to 10:90 since the 1950s.

Table 1.2 The Proportion of Different Transportation mode in Tianjin:

| | Bicycle | Public Transit |
|---|---|---|
| 1950s | 38% | 62% |
| 1960s | 54% | 46% |
| 1970s | 77% | 23% |
| 1980s | 82% | 18% |
| 1990s | 90% | 10% |

(Source: Tianjin Transportation Planning Bureau, 1991)

This trend is still very obvious even in Shanghai, a city with the most complete transportation system in China. (Table 1.3)

Table 1.3. Trends in Transportation Modes Use Among Shanghai Urban District Residents

| Year | Public Transportation | Bicycle | Automobiles, Other |
|---|---|---|---|
| 1981 | 67.7% | 30.5% | 1.8% |
| 1986 | 58.2% | 40.3% | 1.5% |
| 1991 | 53.8% | 43.9% | 2.3% |

(Source: Shanghai City Comprehensive Transportation Planning Institute, 1992)

### 1.1.3 Traffic related to bicycle utilization

Bicycles are thought to be the biggest cause of traffic problems.

The new passenger traffic structure, especially the rapid growth of the amount of bicycles is widely considered to be the main reason that for the chaotic traffic situation. And generally speaking, many cities do believe the bicycle is responsible for the poor traffic situation, a conclusion from some research for the traffic situation of several cities:

- Shanghai: "The rapid growth rate of bicycle, which will also slow down the speed of the whole traffic system and increase the accidence rate, will lead to a worse traffic situation." (Shanghai Comprehensive Traffic Research Institute, 1990)
- Beijing: "The unreasonable traffic structure is the largest problem of the traffic situation." (Beijing Public Transit Research Institute, 1990)
- Guangzhou: "The Bicycle volume increased by 57% from 1982 to 1988... Because of the huge traffic volume, especially the heavy bicycle traffic, and limited traffic space, the peak hour traffic situation is very poor." (Liu Chuanyi, 1990)
- Shenyang: "The two key problems in Shenyang passenger traffic are: (i) The poor level of service of the two main highways that in the east-west direction and south-north direction. (ii) The problem of bicycle traffic.

(Shenyang Traffic Engineering Research Institute, 1990)

It can be seen that in large Chinese cities, the mixed traffic of bicycles and automobiles is usually considered a bottleneck for urban traffic. Therefore, is it possible to just get rid of the bicycle traffic? The answer is negative. The bicycle became a popular transportation mode, due to the following facts:

(i) Most of the urban residents' daily trip distances are within the accessibility range of bicycles.

(ii) Bicycles offer great flexibility in terms of destinations and stops en route.

(iii) In short daily trips, bicycles are actually faster than the bus system.

To make this clearer, we may do the following calculation to compare the efficiency of the two transportation modes (Public Bus System and Bicycle)

Table 1.4. Efficiency of Various Transportation Modes:

| Modes of Transpo-rtation | Time | Factors (min, km, km/h) | | | | | | | Time Consumed | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 5 km | | 6 km | |
| | | | | | | | | | Peak Hour | Reg. Hour | Peak Hour | Reg. Hour |
| Bus | Tb=2Lp/Vp+Tw+Lv/Vv | Tw | Lp | Lv | | Vp | Vv | | 28.6 | 24.2 | 32.6 | 27.2 |
| | | | | 5km | 6km | | Peak Hour | Reg. Hour | | | | |
| | | 2 | 0.3 | 4.4 | 5.4 | 4 | 15 | 20 | | | | |
| Bicycle | Tb=Lb/Vb+Tbp | Lb | | | | Vb | | Tp | 27 | | 32 | |
| | | 5km | | 6km | | | | | | | | |
| | | 5 | | 6 | | 12 | | 2 | | | | |

In order to calculate the actual time consumed time to travel by bicycle and bus, we can get the following equation:

$L_b = (T_b + T_{bp})\ V_b$ (1)

$L_v = (T_v - 2L_p/V_p - T_w)\ V_v + 2L_p$ (2)

$L_v = L_b$ (3)

$T_v = T_b$ (4)

in which,

$L_v$: Bus travel distance (km)

$L_p$: Pedestrian travel distance (km)

$L_b$: Bicycle travel distance (km)

$T_b$: Bicycle travel time (min)

$T_v$: Bus travel time (min)

$T_w$: Bus travel waiting time (min)

$V_v$: Bus travel speed (km/hour)

$V_p$: Pedestrian travel speed (km/hour)

$V_b$: Bicycle travel speed (km/hour)

$T_{bp}$: Bicycle parking and taking time (min)

Then, from (1), (2), (3), (4), the following conclusion can be made: When the trip time is below 5.6 km or 30 min, bicycles are more time efficient, compared with a well-operated bus system. In other words, within a certain travel distance or time (5.6 km or 30 min), bicycles are faster than buses.

To better understand the bicycle traffic situation which is an important component of the mixed traffic system of most Chinese cities, a questionnaire survey was carried out in the summer of 1999 at Shanghai, China, which will be further discussed in the Chapter 2.

# Chapter 2
# Cyclist Path Preferences in Shanghai

In order to increase the efficiency of traffic flow, it is necessary to investigate path and traffic mode preference under mixed traffic situations.

## 2.1 Methodology

A survey was carried out on people's behaviors and preference for using bicycles in Shanghai. Some useful information was collected, which helps to get a better understanding of the bicycle utilization situation in Shanghai.

The research was carried out in the biggest of Chinese cities: Shanghai, which is also the commercial center of China with a population of 15 million.

In the traffic planning strategy of the Greater Shanghai area, each municipality is supposed to set up their own bicycle traffic road system. However, this policy has not been thoroughly applied yet. So, although there are a few separate bicycle ways available in the urban area, they are a minor part of the whole system. Most of the bicycle traffic is mixed with automobiles, especially in intersections. The locations of the two case study areas are typical reflections of the general situation.

The survey was done by interviewing the passing cyclists intercepted randomly in two locations, Shanghai library and the Nanjing road area:

Case 1. Shanghai Library, the second largest library of China is located in an area in which 11 universities are also situated (Figure 2.5).

Consequently, interviewees mostly consist of highly educated people (university students, professor and other kinds of academic staff) (Figure 2.4).

Case 2. Nanjing Road, located in the downtown Shanghai, is in the center of the city commercial shopping area. In fact, it is one of the most famous commercial shopping areas in China. So the composition of interviewees here is much more complex and they belong to a generally less well educated group.

The questionnaires allowed us to collect parameters necessary to characterize bicycle traffic in Shanghai and predict its development in the future:

The questionnaires include the two following issues:

(i) Where is your starting point? Interviewees were expected to give a crossing of two streets that are closest to their starting or destination point.

(ii) How long does it take you to arrive here?

(iii) Why do you prefer to utilize the bicycle?

The interviewees were asked whether any of the following conditions would change their preference from riding the bicycle to take buses or metro. Those mitigating factors are:

- Not as crowded as now
- Ticket price is cheaper
- The bus speed is as fast as bicycle;
- The bus speed is faster than bicycle;
- The route is more direct than meanwhile;
- Necessity to bring some goods;
- Not Necessity to bring some goods;
- Bad weather;
- The start or destination is closer to the bus stop;
- The destination is not too far away;

The interviewees could make as many choices as they wanted.

Other information such as the maximum preferred time for a person to travel by bicycle was also collected in this part of survey. Also, the interviewees' personal information (gender, age) was recorded for the study purpose.

The first two questions permitted us to find out the typical speed and distance of the bicycle trips of the interviewees. The estimated time provided by the interviewees, or how long it would take to make the same trip by bus is also recorded here for the purposes of comparison.

Altogether, there were 148 questionnaires submitted in each location, with the subsequent analysis performed on more than 2000 data items.

## 2.2 The result of the investigation

The analysis data are presented in Table 2.1 to 2.6

The normal distribution of trip distances was recorded as Figure 2.1.

Table 2.1 The Trip Distance Distribution of the Nanjing Road Case

| | |
|---|---:|
| Below 1 km | 8 |
| 1-2 km | 27 |
| 2-3 km | 23 |
| 3-4 km | 18 |
| 4-5 km | 14 |
| 5-6 km | 11 |
| 6-7 km | 10 |
| 7-8 km | 2 |
| 8-9 km | 4 |
| 9-10 km | 8 |
| 10-15 km | 6 |
| More than 15 km | 0 |
| Mean (km) | 4.15 |
| Standard deviation | 2.81 |

Table 2.2 The Trip Distance Distribution of Shanghai Library Case

| | |
|---|---:|
| Below 1 km | 5 |
| 1-2 km | 28 |
| 2-3 km | 24 |
| 3-4 km | 21 |
| 4-5 km | 15 |
| 5-6 km | 7 |
| 6-7 km | 9 |
| 7-8 km | 3 |
| 8-9 km | 3 |
| 9-10 km | 3 |
| 10-15 km | 3 |
| More than 15 km | 2 |
| Mean (km) | 4.10 |
| Standard deviation | 3.45 |

Figure 2.1 compares the trip distance distribution in the two surveys. The result shoes that the trip distance for more than 70% of the trips is below 6 km (Nanjing Road case) and below 5 km (Shanghai Library case), which is in accordance with the result of many other studies.

The survey carried out in the Nanjing Rd area shows that the average trip distance of the interviewees is 4.14 Km. For male interviewees in this survey, the average travel distance is 5.46 km, while the average trip distance in the same survey for female interviewees is 4.04 km. Their average trip time is 26.1 minutes. For females the average is 25.6 minutes. For male interviewees the average trip time is 27.8 minutes.

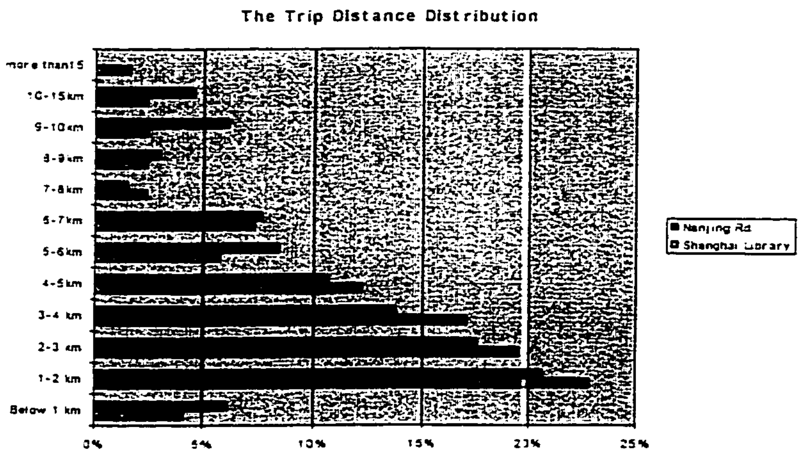


Figure 2.1 The trip distance distribution in Nanjing Road and Shanghai Library area

However, the estimated time for making the same trip by bus is 43.1 minutes (female 42.6 min, male 43.4 min), which is much slower than the bicycle (Table 2.3).

Table 2.3 Bicycle Trip Mode Characteristics in Nanjing Road Case

**Average trip time by bicycle (min)**

| | |
|---|---|
| Average trip time (general) | 26.1 |
| Average trip time (female) | 25.6 |
| Average trip time (male) | 27.8 |

**Average trip time by bus (min)**

| | |
|---|---|
| Average trip time by bus (general) | 43.1 |
| Average trip time by bus (female) | 42.6 |
| Average trip time by bus (male) | 43.4 |

**Average trip distance(km)**

| | |
|---|---|
| Average trip distance(general) | 4.14 |
| Average trip distance (female) | 4.04 |
| Average trip distance (male) | 5.46 |

**Average trip speed (km/h)**

| | |
|---|---|
| Average trip speed (general) | 9.52 |
| Average trip speed (female) | 9.47 |
| Average trip speed (male) | 11.78 |

The survey result at Shanghai library is quite similar (Table 2.4). The average trip distance is 4.13 km (female 3.17km, male 4.71km). The average trip time is 24.76 (female 22.04 min, male 25.32 min). The average trip speed is 10 km/h (female 8.63km/h, male 11.61 km/h). The average travel time for the same trip by bus is 37.93 min. (female 36.07 min, male 39.42 min).

Table 2.4. Bicycle Trip Mode Characterizes in Shanghai Library Case:

**Average trip time by bicycle (min)**

| | |
|---|---|
| Average trip time (general) | 24.76 |
| Average trip time (female) | 22.04 |
| Average trip time (male) | 25.32 |

**Average trip time by bus (min)**

| | |
|---|---|
| Average trip time by bus (general) | 37.93 |
| Average trip time by bus (female) | 36.07 |
| Average trip time by bus (male) | 39.42 |

**Average trip distance (km)**

| | |
|---|---|
| Average trip distance (general) | 4.13 |
| Average trip distance (female) | 3.17 |
| Average trip distance (male) | 4.71 |

**Average trip speed (km/h)**

| | |
|---|---|
| Average trip speed (general) | 10.01 |
| Average trip speed (female) | 8.63 |
| Average trip speed (male) | 11.16 |

In both surveys, it is shown that the utilization of bicycle travel mode in Shanghai largely depends on weather conditions, although the weather conditions in Shanghai are quite suitable for the bicycle riding due to the narrow temperature range and favorable climate.

Another factor that influences people's transportation mode choice is the trip distance. Generally, from the survey results, it can be seen that the maximum trip distance in the people's conception is about one hour riding. If the distance is higher, the people's preference for use of the bicycle will be greatly influenced and it could turn to the automobile traffic mode.

Whether the bus route leads directly to the destination or it is necessary to change buses is also a very important factor in moving people from the use of bicycle to public transit. In the latter condition, people are much less willing to take a bus.

On the other hand, many other factors, such as the price of the bus ticket, the location of the bus stop, the speed of buses and whether it is crowded or not also played important roles in some individual choices.

The table 2.5 and table 2.6 show detailed results of two surveys.

Table 2.5 Factors That Influence Respondents' Preference for Public Transport in Shanghai Library Case

| Item | Respondent Number |
|---|---|
| The destination is too far away | 57 |
| Bad weather | 49 |
| Ticket price is cheaper | 46 |
| The route is more direct | 37 |
| Bringing some goods | 32 |
| Not so crowded | 30 |
| The bus speed is faster than bicycle | 28 |
| Never change | 28 |
| The bus speed is as fast as bicycle | 23 |
| The starting or destination is closer to the bus stop | 19 |
| Not bringing goods | 2 |
| Total | 131 |

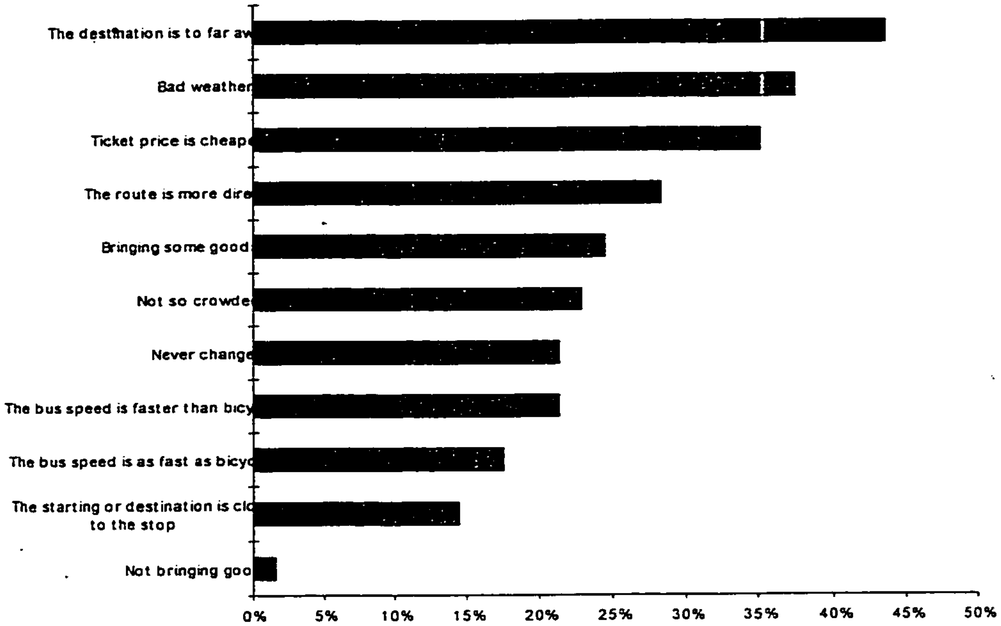


Figure 2.2 The respondents' preference of Shanghai Library case

Table 2.6 Factors that influence respondents preference for public transport

| .Item | Respondents Number |
|---|---|
| Bad weather | 111 |
| The destination is to far away | 100 |
| The route is more direct | 89 |
| The starting or destination is closer to the bus stop | 52 |
| Not so crowded | 49 |
| Bringing some goods | 43 |
| The bus speed is faster than bicycle | 39 |
| Ticket price is cheaper | 34 |
| The bus speed is as fast as bicycle | 21 |
| Not bringing some goods | 7 |
| Never change | 7 |
| Total | 123 |

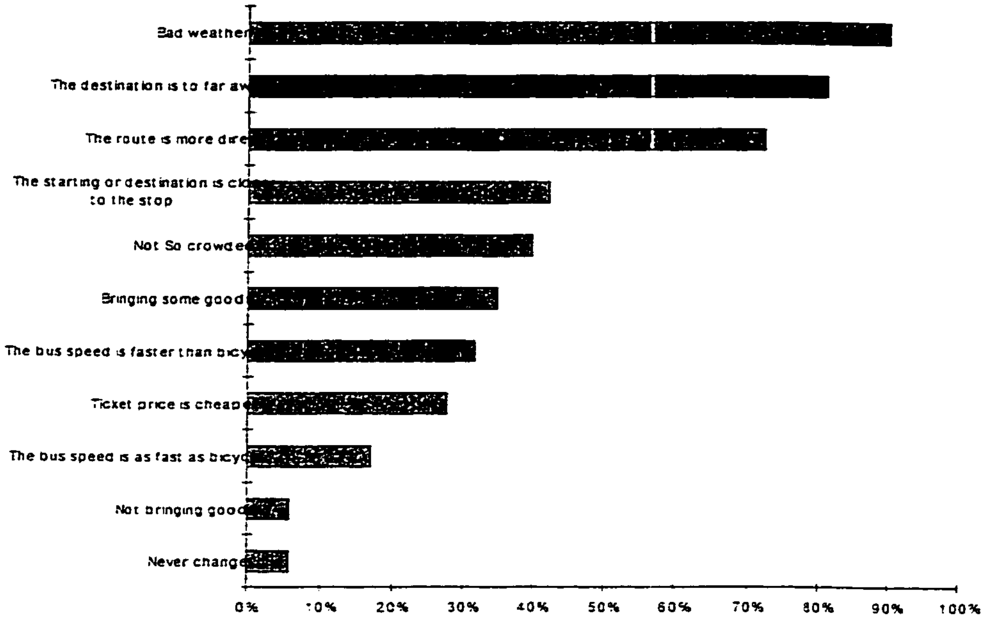


Figure 2.3 The respondents' preference of Nanjing road case

Among the 51 respondents who cared about the speed of bus systems in the Shanghai Library case, there were 18 (35%) also indicating ticket price as an important factor. In the Nanjing case, there were 24 out of 60 respondents who cared about the speed who also indicated bus ticket price as an important factor that might influence their trip generation mode choice.

Other studies have also provided information about Chinese cyclists' preferences. For example, it was found that people feel uncomfortable during the bicycle ride when there are many pedestrians in narrow roads, when there are many automobiles in narrow roads and when the road is congested by bicycles (Hisashi and Teysuo, 1994). It can be concluded that the general problem with the bicycle traffic trip is related to mixed traffic.

Results of other research also showed that the bicycle is the preferred traffic mode for the trips shorter than 30 minutes or for distance up to 7 km (Traffic Engineering Research Institute of South-East University, 1990).

Some surveys reveal that the average trip distance of a resident of different Chinese large cities is between 3 and 5 km (table 2.7). So, most of the daily trip distances of Chinese residents are within the accessibility range of bicycles, a situation which encourages the utilization of bicycles.

Table 2.7 The Average Daily Trip of Residents of Major Chinese Cities

| City | Average Trip Distance of All Modes (km) |
|---|---|
| Shanghai | 3.99 |
| Beijing | 5.20 |
| Tianjin | 3.70 |
| Shenyang | 3.40 |
| Wuhan | 3.58 |
| Guangzhou | 3.84 |
| Chengdu | 3.45 |
| Fushun | 4.65 |
| Zhengzhou | 2.54 |
| Hangzhou | 3.36 |

(Source City Construction Research Institute, 1996)

Another reason that leads to this situation is the low-income and low consumption policy in force before 1978. A special urban space structure was designed especially for the traveling patterns of bicycles in Chinese cities. For example, the daily service necessities of urban residential neighborhoods are within the 10 minutes bicycle travelling distance.

Another part of the present survey finds the starting point and the trip routes of the respondents. From the result we can easily tell that the bicycle travel mode is, generally speaking, accessible to any place, which implies that it is almost impossible to set up a bicycle traffic network obliging the bicycle to follow a dedicated route, sure to make the trip significantly longer (Figure 2.4, 2.5)

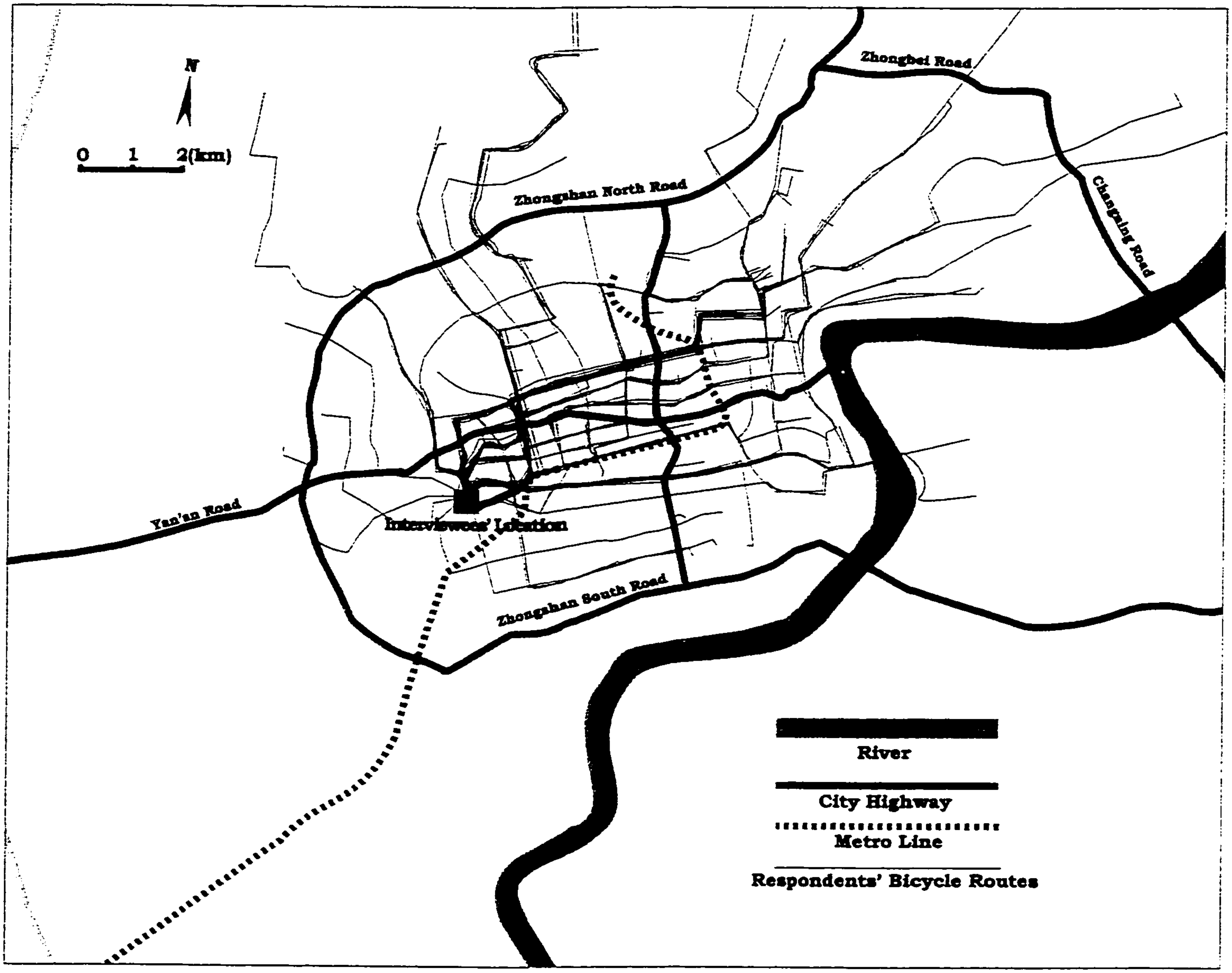


Figure 2.5 The repondents' routes (Shanghai Library case)

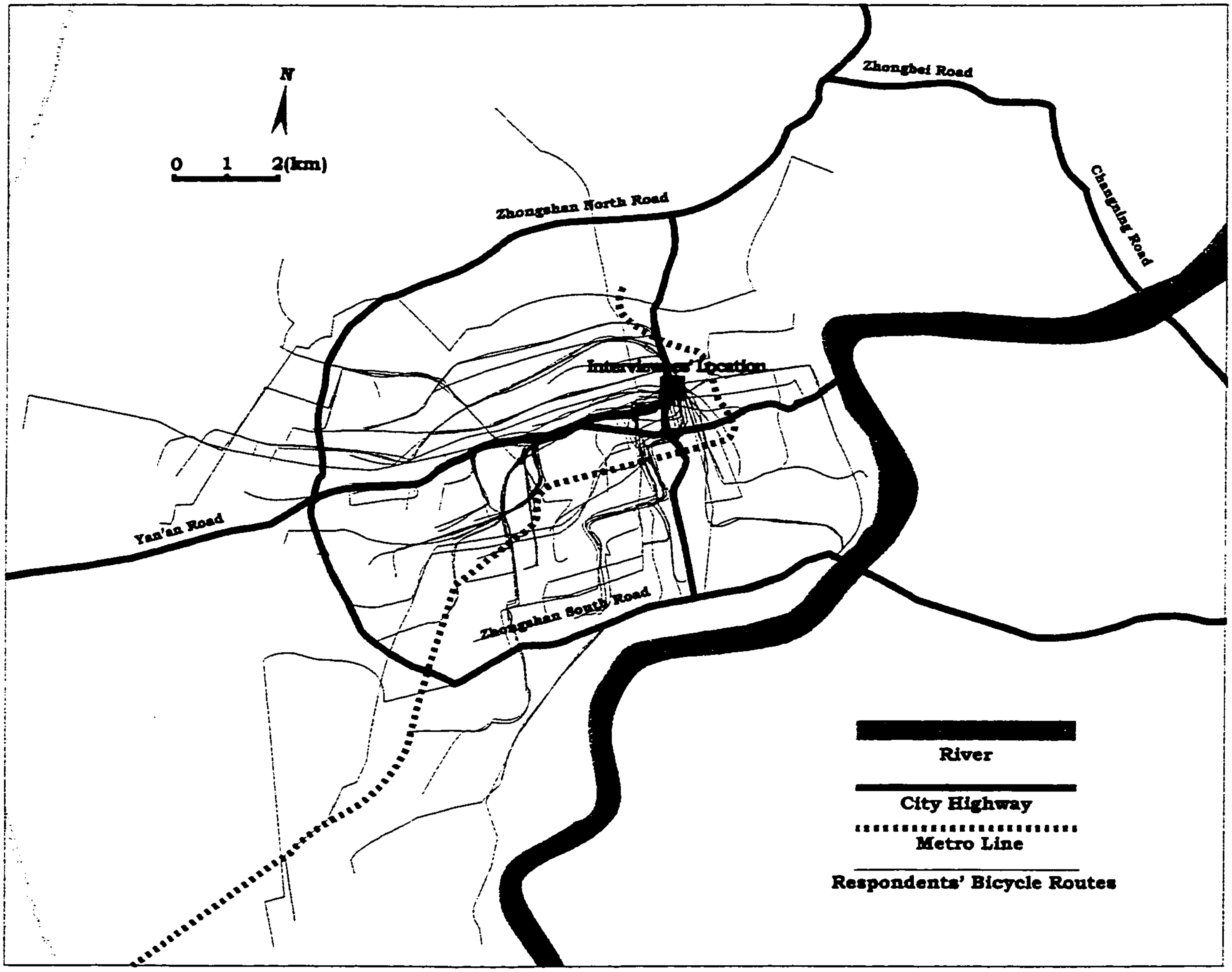


Figure 2.4 The repondents' routes (Nanjing Road case)

Survey results could also show that bicycle trip demand would keep increasing in the next decades, while public transit service level remains comparatively low and not growing as quickly as bicycle traffic. Also, It is widely recognized that it is impossible to solve the traffic problem by the popularization of private automobiles.

The bus system meanwhile in major Chinese cities is not really satisfactory. The buses' speed is very low and, because of the population density, Chinese buses are usually very crowded even under the comparatively high frequency schedule of one bus for each 10 to 30 seconds. These facts limit people's utilization of the bus systems. Therefore, it is reasonable to encourage the utilization of bicycle in a developing country like China.

However, some problems in this existing urban space structure were raised when the Chinese economy began to experience rapid growth and migration to urban areas in the middle of the 1980s. In 1990s, this problem became even more obvious.

## 2.3 Social factors in the generation of demand for bicycle mode

In addition to above-mentioned factors, Some social factors would also influence the demand for bicycle mode.

Government policy encourages the utilization of bicycle. There is for example financial compensation for the cyclists' cost in maintaining the bicycle. Also, the bicycle utilization tax was abandoned in 1978 (2 RMB Yuan per year, 5.6 RMB Yuan = 1 CND). Furthermore, the maintenance subsidy that was paid to the bicycle commuters, the amount of which is the same as that of the subsidies that used to be given to bus commuters (5 Yuan). Therefore, it is always possible for bicycle commuters to save the subsidies and purchase a new bicycle after a few years (Hisashi and Teysuo 1994).

1. The emergence of the labor market and the disappearance of enterprise-based housing provision.

   Before the reform of the economic system, urban housing in China was spatially tied to urban employment. So it was reasonable that jobs were located adjacent to the residential area. However, due to economic reforms liberalizing land management and responding to market demands where the commercial sector was concerned, employment less related to housing either institutionally or spatially. This trend will increase the length of working commuting trip.

2. Economy and income growth.

   Possessing a higher income, more people will be able to travel longer to access more preferred (better and more expensive) daily needed goods and services.

3. The private automobile is regarded as the modern mode of transportation. This issue demonstrates an important difference between big Chinese cities and their counterparts in Europe and North America due to the following facts:

(i) Before the rapid growth of automobiles in Chinese cities, the city developed a high density urban structure. For example, the percentage of land area devoted to streets in Shanghai is only 8%. (25% New York City and 32% London UK.)

(ii)After the Chinese economy becomes a part of the world economy, China faces a mature international automobile industry. With the strategy of flexible production, the industry can quickly make large amounts of locally produced automobiles, which are cheaper and easier to sell. If the Chinese economy keeps growing in the future, automobiles, locally-made and imported, will take over Chinese cities with in a few years. In other words, once the city gives up controlling the number of automobiles, a huge number of automobiles provided by the industry will fill the traffic space in a very short period of time.

The above factors imply that Chinese cities do not have a certain slow process of development that would allow the urban transportation system to adjust itself to meet the demands of the development of automobile industry, as happened in London, Boston and New York City. It is impossible for a city like Los Angeles, which was built from the beginning for automobile users, to exist in China.

Based on the above discussion and the experience of other countries, it can be concluded that Chinese metropolises need to apply not only the restrictions on the development of small cars, but also set up a traffic system development strategy. These strategies should be based on the utilization of public transit and bicycles, and should be executed as soon as possible. It is thought that the metro system, together with other ground traffic patterns (e.g. buses, mini buses, etc.) as a supplementary system, is an ideal transportation system. However, the development of city traffic systems is obstructed due to the following facts:

(i) The huge investment in the subway system is usually beyond the financial capability of Chinese metropolises.

(ii) Even though the public transit corporation tries its best to improve its management and administration, the bus component faces traffic jams caused by bicycles and rapidly increasing numbers of cars. It is almost impossible for them to improve their service level, especially in the two most important issues: speed and reliability.

(iii) For some reason, none of the major cities has applied any regulation to restrict the automobiles, which leads to taking over increased road space through an increase in the number of cars. As a matter of fact, the last 5 years have seen the increase of private automobiles by 80% (Beijing Morning Press, May 21, 1998).

The increase in working trip distance of the general public has brought more problems for the bicycle riders. The owning of a private car or taking taxi daily is still beyond the income of most of the working class, so the travel pattern of most of them remains a combination of public transport and bicycles.

Consequently, it is important for Chinese cities to find a solution for a new strategy for the management of streets with large capacity and mixed traffic, especially where intersections are concerned.

Therefore, we should try to solve the problem of the bicycle creatively by trying to solve the mixed traffic problem effectively. It is necessary to give more consideration to the contribution of bicycles to urban transportation. In big Chinese cities, where every family owns 2 bicycles on average, it is required to combine this traffic pattern with the widely adapted public passenger transportation model, in which the public transit and bicycle traffic play the major role.

However, there are both advantages and demerits in the wide usage of bicycles. While enjoying the benefit of saving energy and reducing green house and toxic gases, people are paying the price in the increase of the traffic accidents and decline of the efficiency of the entire urban traffic system. The proportion of bicycle-related accidents reached 30% to 50% of the traffic accident in urban areas and 40% to 70% of the fatal accidents in China. In 1989, for instance, bicycles in Shanghai were involved in about 32% of the traffic accidents and 37% of the fatal traffic accidents out of the total of 7527 traffic accidents. Moreover, the number of car-bicycle collisions in Shanghai was 2254, which was almost twice of the number of car-pedestrian collisions 1272 in 1988. The Figure also shows that the number of car-bicycle collisions was 1087 and the number of bicycle–pedestrian collisions was 686 from January to

September in 1989. (Shanghai Police Bureau, 1991) However, these Figures should be understood in the context of an explosion in the number of bicycles.

Therefore, as we've mentioned before, the motorized and non-motorized mixed traffic situation does lead to the chaotic traffic situation. The intersection traffic is always considered to be a bottleneck in the whole traffic system. Especially under the mixed traffic situation, the traffic of the intersection plays a key role in the efficiency of the whole traffic system. Traffic engineers are eager to increase the flow. But, as it has been discovered before, public transport, in the form of light rail lines or underground trains, requires a huge investment of public money. Thus, a far cheaper alternative, at least in the short run, is considered to be converting stop-and-go intersections into roundabouts. To apply this strategy, we need a much better understanding of the current traffic situation of the intersections. The following chapter reports on a field study of two types of typical high-volume mixed mode intersection. In this study, we examine the intersection effects of cyclists and drivers in relation to efficiency. The intersections are in Shanghai and Beijing.

# Chapter 3 Literature Review

Studies of the interactions in crossing traffic are important in evaluating the safety and efficiency of urban traffic. Previous research on intersections is concentrated in conflict and delay studies.

## 3.1 Study of traffic

### 3.1.1 Traffic Conflict Studies

One of the most important issues that previous research has emphasized is traffic conflict. A conflict was defined as "an event involving two or more road users, in which the action of one user causes the other user to make an evasive maneuver to avoid a collision" (Park and Zegeer 1998). In this definition, an evasive maneuver is considered to have occurred when the second road user showed an obvious braking or swerving. Also, another related conflict concept is secondary effects of a primary conflict. It is possible that when conflicting vehicles make an evasive maneuver, a third road user may be placed in jeopardy of collision. A secondary conflict was defined as a conflict that takes place as the result of another conflict that has already taken place. This secondary conflict is recorded when the vehicles involved showed an obvious breaking or swerving to avoid a collision.

Traffic conflicts can be used as good surrogates when sufficient accident data are not available to evaluate safety problems at urban intersections (Hummer et al. 1994). These studies supplement traffic accident studies in several ways. The magnitude of the traffic safety problem at a particular location can be estimated from traffic conflicts.

The research of Perkins and Harris (1968) can be regarded as pioneering work in this particular field, since they introduced the concept of using traffic conflict data as a surrogate measure of accidents. Spicer (1971) developed a technology to conduct a pilot study of traffic conflicts at a rural dual carriageway. Williams (1972) evaluated the traffic conflict technique developed by General Motor research laboratories in cooperation with the state highway departments of Washington, Ohio and Virginia. Further research reported vehicle conflicts at six intersections, showing that serious conflict and the frequency of accidents involving injury at different junctions were positively related (Spicer, 1972). The reported accidents involving injury with observed serious conflicts at 50 intersections were compared and it was found that conflicts and speed were positively related. (Hyden, 1975).

In order to reduce the conflict rate, various conflict reduction techniques have been developed. The utility of conventional traffic conflict reduction techniques has included an evaluation of earlier studies (Gelennon et al. 1974). Malarterre and Muhlrad (1979) observed a substantial measure of agreement in identifying conflicts using studies in five different countries. However, this comparative research did not produce agreement on the definition of severity classes.

Another topic that Figures in several studies is whether there is a significant correlation between traffic volume and conflict rate. On the specific question of a correlation between volume and conflicts rate at intersections, varied results were obtained from different research studies. Some research showed a lack of significant correlation (Spicer 1973) and existence of poor correlation between volume and conflicts rate (Russam and Sabey 1972, Zegeer and Deen 1978, Spicer et al. 1980).

Other estimation techniques for accidents have been derived from conflict data. Glauz and Migletz (1980) carried out extensive research on conflicts, providing standard definitions and refined data collection procedures as well as the application of this technique to estimating the number of accidents at an intersection. Darzentas et al. (1980) developed an event-stepping discrete simulation model of a nonurban T-junction, intended to investigate the risk of traffic accidents. Using empirical data, this model predicted the number and severity of conflicts as a function of various traffic and behavioral parameters.

Most studies have been carried out in an ordered traffic situation with saturated volumes. Among the few studies of traffic behavior that have been carried out under the heterogeneous environment of an uncontrolled urban intersection, the study of V. Trinadha Rao and V.R. Rengaraju (1998) describes the method of simulating the traffic flow and thereby estimating the number of conflicts in varying traffic flow conditions. The model was validated externally, using field observed data, and was found to predict the number of conflicts. As an illustration of usefulness of the model, variation of conflict rate (the probability of a vehicle's getting involved in conflict) due to variation in traffic volume and the proportion of right-turning traffic has been quantified. Generally speaking, very few such studies have been carried out and no standard modeling procedures have emerged yet.

Overall, we can conclude that traffic volume is weakly related to conflict. Conflict is rather the product of particular field conditions, arrangements of traffic and the behavior of individuals in intersections.

### 3.1.2 Delay studies

Another major research area is traffic delay and relates directly to the question of the Chinese urban intersection. Measuring delay in the field accurately is important for the design and operation of traffic control systems. As a performance measure delay plays a critical role in the evaluation of the delay levels of different kinds of intersections (signalized and unsignalized). Delay is also included in the calculation of the average speed, which always used to determine levels of service on arterial streets.

Since bicycles are blamed for delay at intersections, we need to examine how studies of delay may help in analyzing the Chinese intersection. As a performance measure, delay plays a critical role in evaluating levels of service at signalized and unsignalized intersections. Delay is also included in the calculation of average speeds used to determine levels of service on arterial streets.

Measurements related to efficiency and capacity have used "delay" as a significant variable in order to set up a method to calculate the crossing time of different traffic modes. There are actually two kinds of traffic delay considered.

(i) Crossing (approach) delay.

Crossing delay is defined as the difference between the time used by any vehicle to travel a fixed distance from a pre-specified point upstream of an intersection to the intersection stop bar and the free-flow time associated with that distance (Reilly et al. 1976). Examples of application of the approach delay concept include those of Reilly et al. (1976) and Olszewski (1993).

(ii) Stop delay

Stop delay is defined as the time during which a vehicle is stopped at an intersection.

(iii) Control delay

Another concept must be included here, known as control delay. Control delay is defined as the total delay due to the signalized intersection, which includes decelerating delay, stopped delay and accelerating delay.

From these definitions, it could be that using a fixed reference distance for measuring delay is a direct response to the difficulties mentioned above concerning the trace of individual vehicle trajectories.

In the studies of the relationship of stop delay and control delay, further research also found that the relationship between stop delay and control delay was linear (Quiroga, et al. 1999). Furthermore, it was found that such a relationship did not pass through the origin and that a deceleration-acceleration delay value had to be added to the stopped delay term to obtain control delay. It was also found that the percentage of the control delay that takes place after the signalized intersection stop bar is not negligible (Quiroga, et al. 1999).

The delay model developed by Webster (1958) is the basis for most delay models developed subsequently. It is based on deterministic queuing theory and is given as:

$$d=C(1-\lambda)^2/2(1-\lambda X)+X^2/[2v(1-X)]-0.65(c/v^2)^{1/3}[X^{2+5\lambda}] \quad (1)$$

where d = average overall delay per vehicle on the subject approach or movement(s); $\lambda$= proportion of the cycle that is effectively green for the approach or movement(g/C); C = cycle time(s); g=effective green time(s); X=degree of saturation (ratio of volume to capacity(v/c)); v=flow rate (average number of vehicles passing a given point on the road in the same direction per second).

This formulation uses the average overall delay per vehicle on the subject approach by considering the cycle time, effective green time, degree of saturation (ratio of volume to capacity) and the flow rate, which is the average number of vehicles passing a given point on the road in the same direction per second.

Box and Alroth (1967) recommend a practical procedure for measuring delay at unsignalized intersections. The method involves counting the number of standing vehicles (queue length) at 15-second intervals, which yields the total delay in the terms of vehicle-hours using the parameters of total delay and queue length.

Kyte et al. (1996) took into consideration capacity on a given approach or lane, average service time or service delay on the approach or lane and average move-up time, so as to estimate approach capacity at unsignalized intersections. While the above research methods are useful in standard traffic situations where vehicles occupy a standard amount of roadspace, this is not the case with bicycles which expand and contract on the road surface depending on conditions.

Other research proposed a delay model for signalized intersections, which is suitable for variable demand conditions. This model is applicable to the entire range of expected operations, including highly oversaturated conditions with initial queues at the beginning of the analysis period. The model clarified several issues related to the determination of the peak flow period, as well as the periods immediately preceding and following the peak (Akcelik and Nagui, 1993).

Lin (1989) evaluated the reliability of the Highway Capacity Manual (HCM) procedure on the estimation of delay, based on field data, and discussed the need for modifications. The evaluation revealed that the HCM procedure tends to overestimate stop delay at reasonably well-timed signal operations. The discrepancies between the HCM estimates and observed delays were very large even when correct cycle lengths and green duration were used, and these discrepancies were attributed to the progression adjustments recommended in the HCM procedure.

The 1994 HCM provided a method for comparing intersection control types for two-way stop-control (TWSC), all-way stop-control (AWSC) and signalized intersections using a delay-based approach. The HCM (1994) also provides a way to calculate delay for the TWSC intersections, by considering the average total delay, volume for movement and capacity of movement and analysis period (HCM, 1994).

Another model (Mareck et al. 1997) shows that the total average approach delay is a function of the volume on the approach and the capacity estimated for the approach. Volume for subject approach and capacity of subject approach are included in the model.

Cronje (1983) analyzed existing formulations for delay, Webster's (1958) and Miller's (1963) equations for average delay, overflow, and average number of stops for under-saturated conditions. These formulas were examined over a large variation of flows and cycle lengths. He concluded that the Miller formula (1963) gave most accurate results. Hagen et al. (1989) compared the HCM (1985) delay model with the models used in the Australian Signal Operations Analysis package (SOAP 1985) and the TRANSIT-7F Release 5. They focused on the effect of the degree of saturation, the peak hour factor, the length of period of flow observation on delay computations, and the effect of straight-ahead traffic on right-turning vehicles. The result of all these models agreed closely at volume levels below saturation point. When conditions became over-saturated, the models diverged. We can note that while these models for delay work well under under-saturated or saturated conditions, they do not work well in over-saturated situations this research is considering. On the other side, research also shows that there hasn't been any model that is suitable for all timing conditions. Teply (1989) studied two approaches to measure delay in the field and explained various problems related to each. He concluded that delay cannot be precisely measured and that a perfect match between the results of an analytical delay formula and measured delay values cannot be expected. Teply also concluded that the ratio between overall delay and stop delay was not a constant and depended mostly on the duration of the red interval. As a result, a fixed coefficient for all timing conditions was not found appropriate.

However, certain delay models applicable to situations under fixed-time traffic signals have been developed. Brilon and Ning (1990) used a new approach, based on Markov, to calculate delays on a numerically exact basis. The computations enable the evaluation of average delays of vehicles at fixed-time traffic signals under time-dependent input volumes and under Poisson or non-Poisson model assumptions. A new approximate set of formulas was developed, which describes the exact average delays. The results obtained by these formulas proved to be in good agreement with empirically based data. This approach provided a sound evaluation of the distribution of queue length and their profile over time. A similar result was also obtained by Olszewski, who further studied the relationship between overall delay and stop delay. It was demonstrated that for the uniform delay component, the delay ratio is a function of red period and deceleration- acceleration delay, and not a constant (Olszewski, 1993). From his finding, it can be seen that for bicycle traffic, the length of red light period will have effects on stop delay and the reason why this is likely to be the case with bicycles is that, with longer red light time, the bicycles are backed up behind the stop line and do not move immediately when the light goes green. Thus, in order to find out the optimal management strategy, it is necessary to find out the clear time and the waiting time of the bicycle and automobile.

Easa (1993) used a probability approach to design the intergreen interval. In this study, the intergreen interval was estimated for a specified probability. In this method the approach speed, reaction time, deceleration rate, and vehicle length were random variable.

However, most of these formal researches were based on the situation of automobile-only traffic and under-saturated or saturated traffic system. Few studies on the over-saturated and mixed traffic situation of non-motorized and motorized transportation can be found.

### 3.2 Research method utilized

Different research methodologies and measuring instruments have been applied by various researchers. Generally speaking, field surveys are widely used and various models are derived from the data. Alternatively, theoretical models have been developed and field data used to find out if they are accurate. Normally, solutions to traffic issues are developed through empirical or analytical approaches using data from field surveys.

McDowell et al. (1983) introduced a new method of measuring gap-acceptance behavior of drivers in traffic conflict simulation as a measure of risk. The data thus obtained were used in a simulation model to predict conflict rates in turning maneuvers. Migletz et al. (1985) demonstrated the application of traffic conflict data to predicting future traffic accidents. Parker and Zegger (1988, 1989) studied mean, variance and abnormally high (90th and 95th percentile) conflict counts for four-leg intersections, with and without traffic. Crowe (1990) determined the average and abnormally high conflict counts for a three-leg intersection with no signal. The results Crowe obtained are based on data collected in Houston, Texas, during daylight hours on weekdays and with dry pavement conditions. It may be used as a guideline for evaluating other three-leg intersections without signals using the traffic conflict technique. Rahime (1991) suggested methodology for validation of microscopic traffic simulation models. Hummer et al. (1994) presented a detailed description of traffic conflict studies, tracing developments in the use of traffic conflict data-developments in training observers, sample size determination, survey methodology, and data analysis technology. Most of these studies are of homogeneous traffic conditions.

Heterogeneous traffic flow is creating problems in developing countries because different types of traffic with different characteristics use the same road. In addition, the phenomenal growth of traffic has resulted in low speed, excessive travel time, delays, and other safety-related traffic problems in urban areas. Traffic conflicts must be considered to assess the quality of traffic flow at uncontrolled intersections. In practice, this assessment is made to suggest appropriate traffic control measures at an intersection.

Until recently, methods based on mathematical and statistical theories have been used. These methods are founded on simplified assumptions such as Poisson distribution of traffic streams, fixed critical gaps and move-up times, and constant traffic volumes. These assumptions appear unrealistic for mixed traffic conditions. Furthermore, the exact consideration of the degrees of priority of different traffic streams at an intersection is still an unsolved problem. These difficulties can be alleviated with the help of simulation. Much recent research using simulation models has proven its usefulness in the analysis of intersection operation.

Delay at signalized intersections is defined and used in many different ways. To trace individual vehicle trajectories, researchers have experimented with a variety of devices and procedures including ground-based time-lapse photography (Buehler et al. 1976), aerial time-lapse photography (Benekohal, 1991), and video photography (Benekohal et al., 1992). Unfortunately, these techniques tend to be very laborious, time-consuming (Olszewski 1993), and expensive. For these reasons, control delay is rarely measured.

On research of stop delay, there are also several measurement techniques, including the "stopped-vehicle count" technique, the "arrival and departure volume" technique, and the "test car" technique (TRB

1994). With these methods, the stopped-vehicle count technique is the most common approach to measure stop delay (TRB 1994). With this technique, stop delay is measured indirectly based on the number of stopped vehicles recorded at specific time intervals and the volume of vehicles crossing the stop bar during the total duration of the survey. This technique is relatively simple to execute, although it may be quite labor intensive if long queues are present (Hummer 1994). In addition to this, questions remain with respect to the accuracy of the technique, particularly in situations of low volumes and short red intervals (Teply, 1989).

From the discussion above, it can be seen that existing research has made a lot of achievements in recent years. The influence of different kinds of conflicts (primary conflicts or secondary conflicts) under various environments have been evaluated. The relationship of conflict rate, speed and volume was also studied. There are, as well, results in the study of delay. Several models have been set up for both stop delay and passing (crossing) delay (including decelerating delay and accelerating delay). The relationships between control delay (total delay due to the signalized intersection, which includes decelerating delay, stop delay and accelerating delay) and stopped delay was also studied.

A lot of research has been devoted to the relationship of overall delay and stop delay. Until now, except certain models developed for the fixed signal time situation, there haven't been any all-timing models developed.

Also, we can see the major progress that has been made based on the situation of automobile-only traffic and under-saturated or saturated traffic system. Few studies can be found under the over-saturated and mixed traffic situation of non-motorized and motorized transportation can be found.

We are able to derive some important definitions and measurement principles from the above studies. However, for the following reasons we are not actually able to use any of these models directly:

(i) Most of these studies were carried out in motorized countries of North America and Europe. The transportation situation in these countries is rarely mixed as can be observed in China.

To study and evaluate the traffic situation in the developing countries, we must be able to understand the traffic situation in those countries.

The following table gave some comparisons between developed and developing countries.

Table 3.1 The Comparison of Developed and Developing Country

| | Developed Countries | Developing countries |
|---|---|---|
| Existing Transport System | Highly developed & diversified; using modern technology; relatively good service; fairly ubiquitous networks; heavier emphasis on urban & passenger transportation | Undeveloped with poor service & network coverage; greater reliance on animal and human motive power and on inland waterways; heavier emphasis on commodity movements to ports; greater use of simpler technology and order equipment |
| Transportation Concerns | Efficiency and equity mobility; service quality; negative impacts (safety, environment, community) serving the disadvantaged, preserving the viability(Physical and financial) of the existing infrastructure | Basic accessibility, connectivity, coverage; employment and economic development; national security and prestige; transportation for improved health and education |
| Transportation Planning Problems | Multiplicity of jurisdictions, as lawyers hinder positive action | Inadequate data; scarcity of planners and data processing equipment |
| Applicable transportation Solutions | infrastructure preservation; some rationalization or abandonment; system management, fine tuning, optimization, more capitalization solutions, more advanced technology | New construction offend to reduced standards to save capital costs; more labor intensive solutions; simpler technology, longer equipment life |

|  | Developed Countries | Developing countries |
|---|---|---|
| Transportation Planning Practices | Relatively decentralized; more complex models requiring more data, computations and skills; more continuity and model integration | Relatively Centralized; relatively simple planning tools; more qualitative evaluations |
| Applicable Transportation Planning Solutions | more flexible shorter term planning with more fine tuning and fewer major new projects; more sophisticated techniques as data collection and processing advance; less regulation, more emphasis on pricing and other incentives | Simpler methods, e.g., sketch planning models; selective adaptation of techniques from developed countries; more coordinated and continuous multimode transportation plans integrated with overall national plans. |

(ii) Even among those few studies of mixed traffic carried out in developing countries, most of them are based upon the traffic background of India, which is always considered to be a typical example of a developing country, where there are existing mixed traffic situations. However, the mixed traffic situation in India case can hardly be considered as mixed systems of non-motorized and motorized transportation. Compared to the non-motorized transportation in the countries like China, the Indian situation is more likely to be a mixed traffic situation of all kinds of motorized traffic.

Generally, this literature has helped to define the factors for the delay study. From empirical studies, we have learnt that there are 3 important components of delay: crossing, stop delay and control delay. So, it is necessary to include these facts in further research.

Also, most of the research is under motorized and well-controlled situations, for which the model is well developed. However, they are hardly applicable under the mixed traffic situation, especially the non-motorized part of the mixed traffic. The non-motorized is very different from automobile traffic, for non-motorized vehicles adapt easily to diferent traffic situations. In other words, the conjunction in the intersection produces little delay for the bicycles but significant and predominant delay for automobiles.

On the other hand, the preformed reasearch is concentrated in under-saturated situations. Mixed traffic studies under this situation are hardly of interest because of the free flow of both vehicles. Non-motorized traffic delay is not linearly co-related with non-motorized traffic as a function of saturation. In fact, the relationship is likely to be more complex and require more empirical studies.

## 3.3 Objective

The results from Chapter 2 shows the necessity of the study of mixed traffic in Chinese cities. However, the literature review does not demonstrate significant information about this issue. Therefore, the main objective of this thesis is the investigation of delay in the context of interactive components of mixed traffic at urban intersections of Chinese cities.

# Chapter 4
# The Studies of Intersection Traffic

Characteristics of traffic are the result of many varied and complex interactions among road users, transportation mode, the design of roadways, and the control system. Altogether, they generate traffic conditions that may broadly be separated into two principal categories:

(i) Uninterrupted flow that suffers most by approach delay, and

(ii) Interrupted flow that suffers most by stop delay.

It would be a mistake to interpret the effects of rapid motorization just in terms of congestion, delays, accidents and environmental problems, especially in urban centers. If it was the case, developing countries would just be experiencing the problems faced by developed countries 20 or 30 years ago, which is highly misleading; the problems are different in nature and context in the developing world.

In developing countries' street intersections, complexity increases because the traffic flow is a combination of motorized and non-motorized traffic, together with the pedestrians using the same facilities.

Several typical problems are essentially the same in all developing countries, already discussed in Chapter 1. To solve these problems, one must have an understanding of certain traffic situations. To gain a better understanding of the traffic situation in China, two case studies were done in two intersections of two major mainland cities in the summer of 1999.

The intersections are located in the two largest Chinese cities, Shanghai and Beijing. The two intersections are important nodes traffic points of Shanghai and Beijing.

The intersection of Pingliang road and Dalian road, which is the location of the Shanghai case study, is a very busy traffic point in the western townships of Shanghai. It is located between the downtown business area and one of the major city residential areas. Therefore, the intersection sees a huge work trip flow in the peak hour on working days. The video sample for the following case study was taken during the peak hour.

The location of the Beijing case study is an intersection of one of the major city highways, Fuxin Road, which connects the eastern and western parts of the city, and a minor street. There is very heavy automobile traffic on Fuxin road. Also, there is a separated bicycle path incorporated in the Fuxin Road, which has a large bicycle flow.

Compared to Fuxin road, the minor street crossing it, Yandaixie Road, has a larger proportion of bicycle traffic, because it passes through a large residential district. However, the total mixed traffic flow in the minor road is smaller.

The size of the intersections where the studies were carried out is intersections of two 30-40 meters wide major road. This is a typical size for the intersections of the major streets in Chinese cities.

These two intersections stand for two typical mixed traffic controlling situations:

(1) Mixed traffic situation controlled by automated intersection lights for each movement and mode (the Shanghai case); (2) Mixed traffic situation with automated control only for one movement in each direction:

## 4.1 Case 1: Fuxin Road and Yandaixie Road intersection study, Beijing

For the intersection in the Beijing case (Figure 4.1), the mixed traffic is without direction control. It is the relationship between the two that is the object of the research of this section.

### 4.1.1 The Intersection layout

Following are the plans of the intersection. The plans are covered with a 2 meters grid.

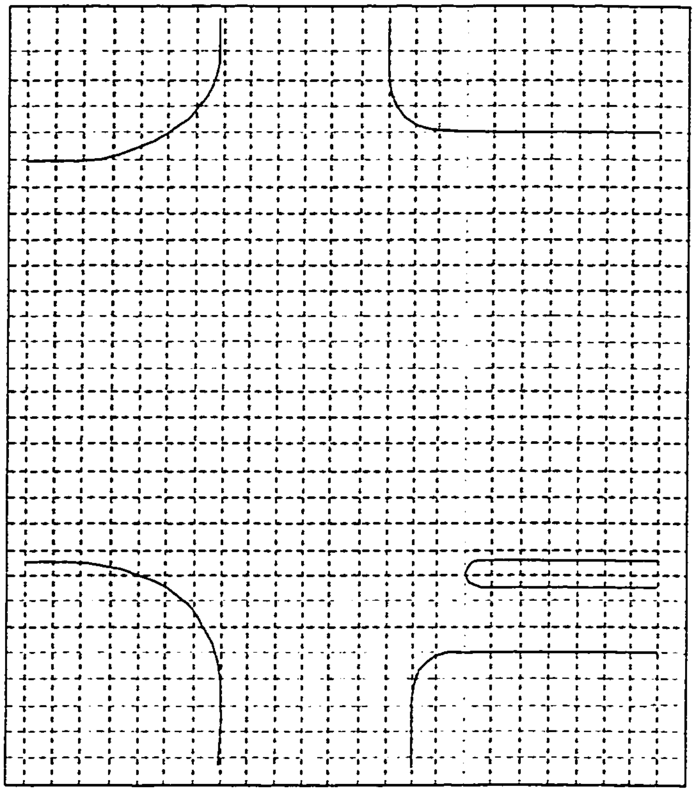


Figure 4.2 Intersection plan of Beijing case

### 4.1.2 Methodology

The following research was done:

First of all, a 2-meter grid was applied to a measured drawing of the intersection. The next step was to transform the plan to fit the computer screen image of the street, with corrected perspective. The digital video was displayed using the Adobe Premiere software package. The angle of view was 60 degrees and the frame rate was ten frames per second. The resolution was clear enough for the researcher to distinguish the movement of bicycles, automobiles and pedestrians (Figure 4.1). Eight minutes of video was used in the following analysis.

The videotape from the digital video camera was imported into a Macintosh computer and displayed by the Adobe Premiere software package in real time. There are two main reasons for doing the transferring of the format of the file: (i) Single frames of the entire video can be kept and studied. (ii) It is possible to keep track of time and the precise time of a frame to an accuracy of one-hundredth of a second also recorded.

The videos were sampled to ensure accurate representation of the trajectories. This amounted to a 5-second interval. The five-second distribution of the automobiles and bicycles in each frame was marked down on the plan. Altogether, more than 30 pictures were created from the available frames (e.g. Figure 4.3). Moving vehicles were then identified and their occupancy of the space, as represented in the converted grid entered in one set of data.

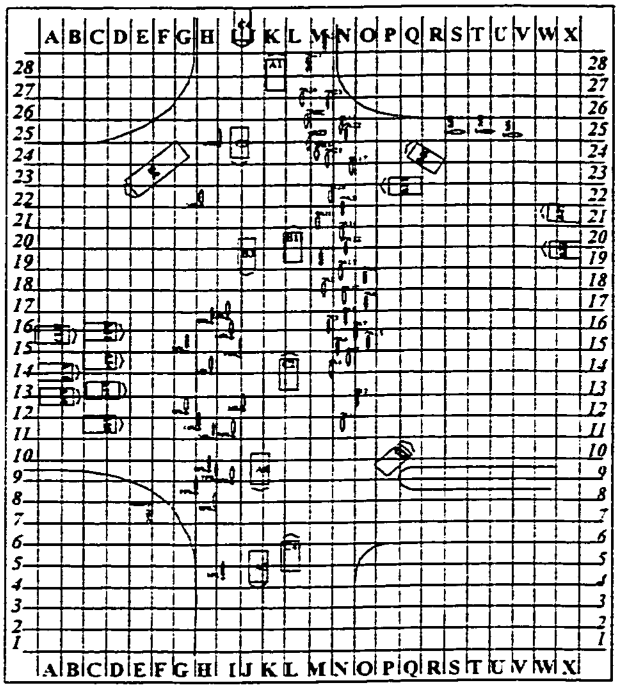
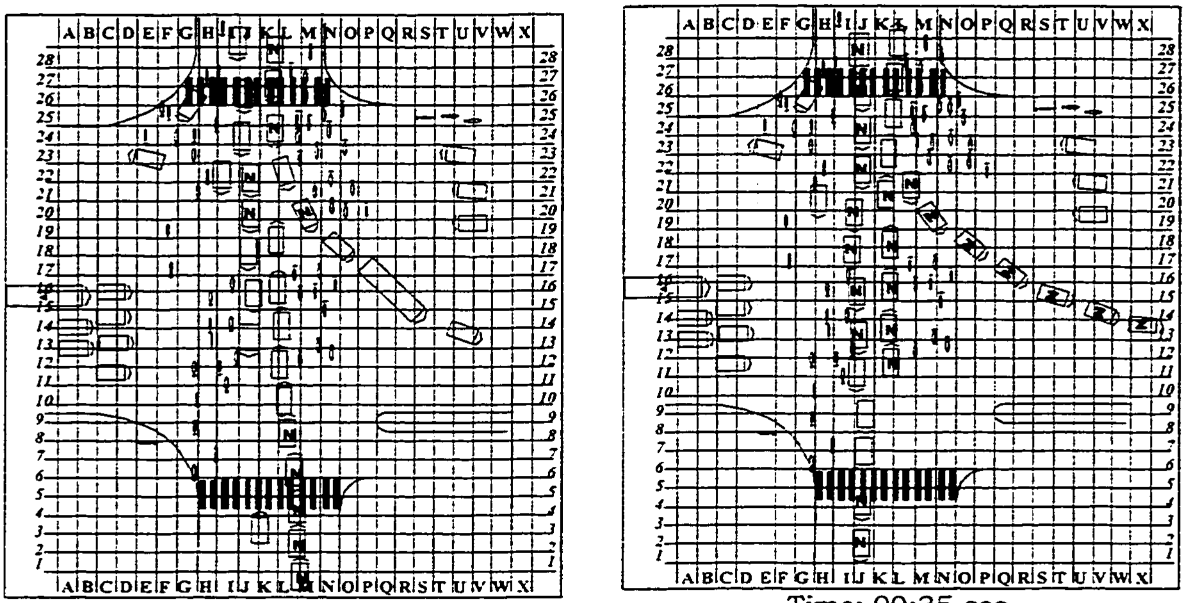


Figure 4.3 Actual samples from the Beijing case

In the following (Figure 4.4), vehicles (bicycle and cars) were added heuristically, following the patterns already identified in the original rides. For automobiles, this means simply adding more units to the line-up. For bicycles, the size of the cohort but also the density was increased in the same way as it occurs presently (Figure 4.3).



Time: 00:25 sec.

Time: 00:35 sec.

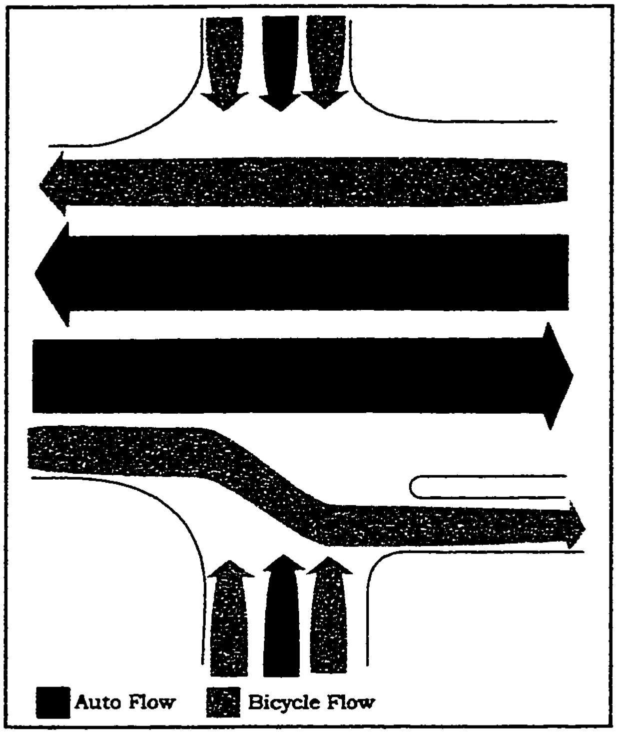
Figure 4.4 Intersection with simulated increased traffic in Beijing case

### 4.1.3 Intersection traffic flow

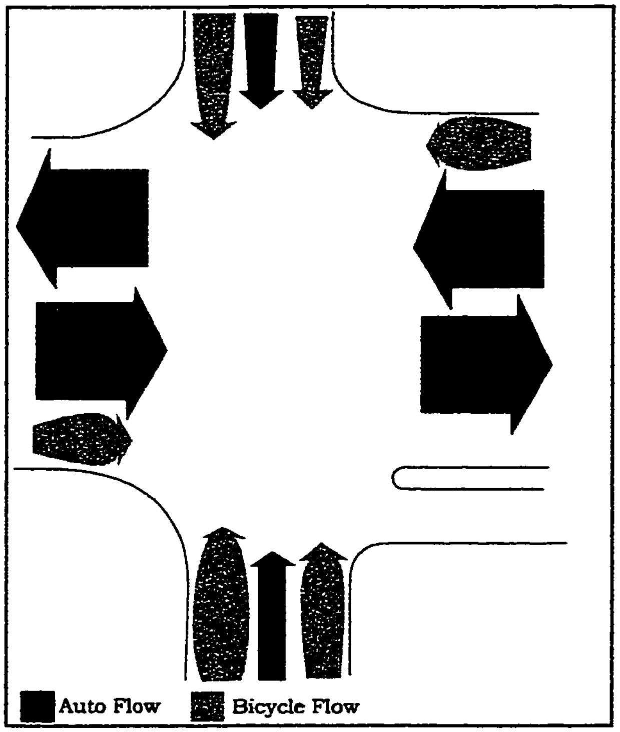
Diagram (Figure 4.5) showed the traffic flow situation for a red light period of the intersection

The traffic sequence follows the light sequence, but involves some intermediate stages.

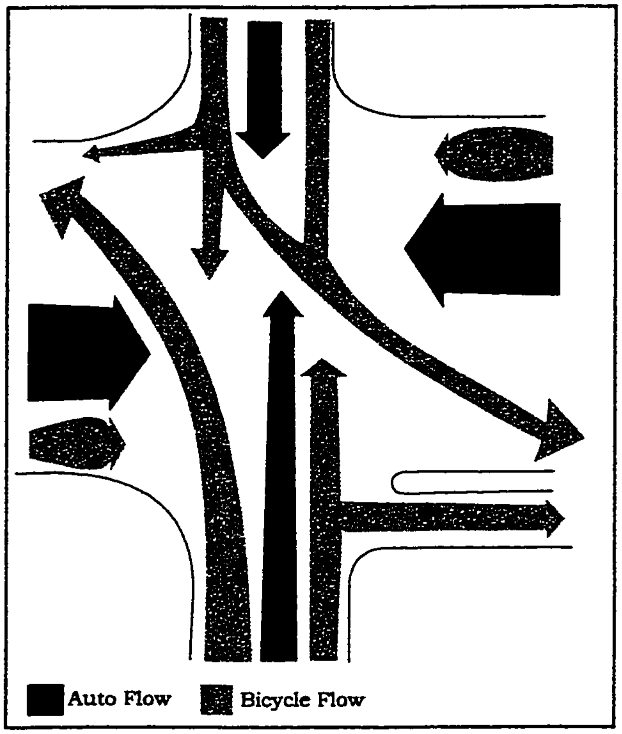
1. When the light changes, it is the left-turning bicycles that begin their movement first. They occupy the road space immediately. Therefore, the straight-going bicycle has to wait until they are cleared up.



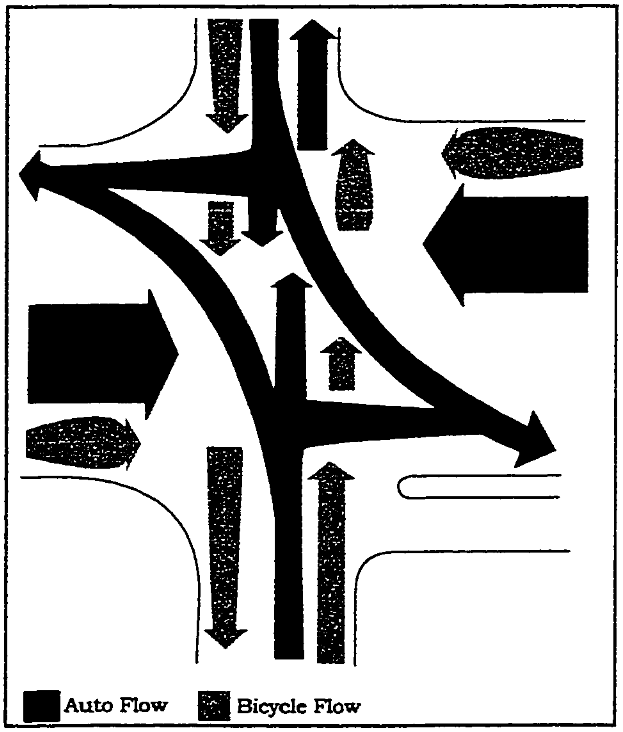
00:00 sec from the starting of green light



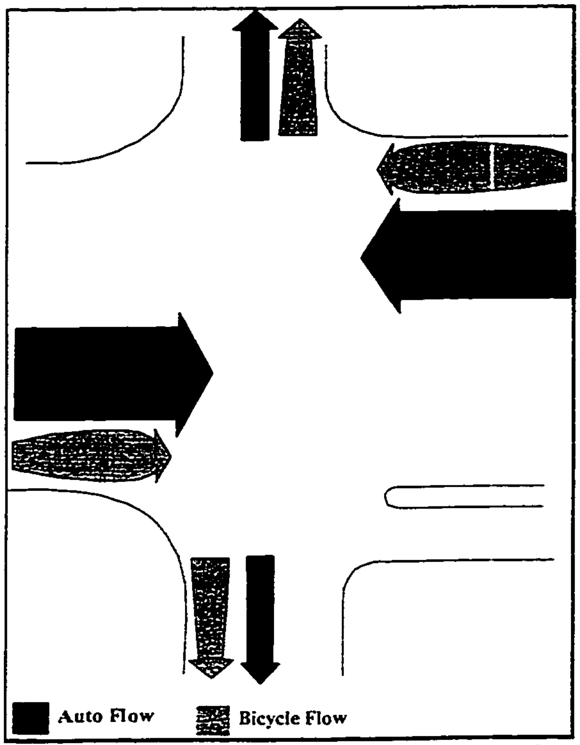
00:00 sec-00:05 sec from the starting of green light



00:05 sec-00:30 sec from the starting of green light



00:30 sec-00:55 sec from the starting of green light



00:55 sec.- 00:60 sec. from starting of green light

Figure 4.5 Intersection mixed traffic flow situation of Beijing case (Related to crossing time)

2. After the cleanup of the left-turning bicycles, the straight-going and left-turning automobiles take the road space.

3. The bicycles that did not get the chance to pass the crossing before the left-turning auto stream have to wait until the left-turning automobiles clear up.

Furthermore, from this crossing procedure we can easily see in the intersection situation, that the passing priority sequence in chronological order is: (i) Part of straight-going bicycles, all left-turning bicycles, right-turning automobiles. (ii) Straight-going automobiles and left turning automobile (iii) other straight-going bicycles.

From these pictures we can clearly see how the road space is utilized by different traffic modes, which provided the necessary information for the proposed solution for this situation that will be discussed in the next chapter.

### 4.1.4 Intersection crossing time study

The data for crossing time for the automobiles and bicycles crossing without and with delay were recorded. The crossing time for each individual bicycle and vehicle was recorded and input into Excel Software. The average crossing time from start of green sequence until they clear the intersection was also calculated.

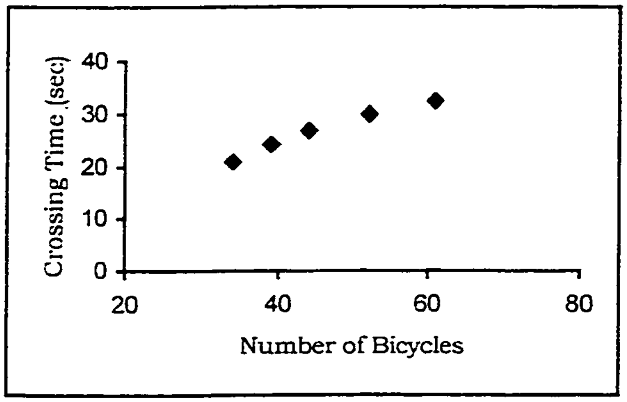
Visual data analysis stopped when the 95% confidence limits on the mean allow us to distinguish between the 5 levels of delay time shown in the following Figures (Figures 4.6 (a)-(e) and 4.7 (a)-(e)). The mean value of the data points was taken as the average time bicycle crossing.

Because the flows are distinct and sequential, the following research can be done: (i) Analysis of the delay caused by each straight-going bicycle to all the automobiles and bicycles. (ii) Analysis of the delay caused by each straight-going automobile for all autos and bicycles. (iii) Analysis of the delay caused by each left-turning bicycle to all the autos and bicycles. (iv) Analysis of the delay caused by each left-turning automobile to all the automobiles and bicycles.

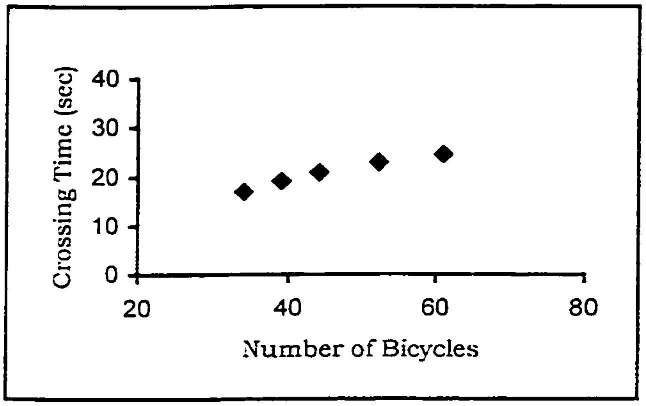
Diagrams (e.g. Figure 4.3) of the traffic situation of the crossing served to find out what is the maximum volume (automobiles and bicycles) that the intersection can accommodate by representing more vehicles in the diagrams, and calculate the crossing time according to delay time caused by each vehicle. The number of left-turning and straight-going automobiles were added and related crossing time was also calculated.

From the analysis of case study, it is concluded that each combination of mixed traffic components give a different delay sequence. Total delay of mixed traffic was considered that permit the researcher to incorporate the relationship between components of mixed traffic. These conditions are visualized in Figures 4.6 (a)-(e) and 4.7 (a)-(e).

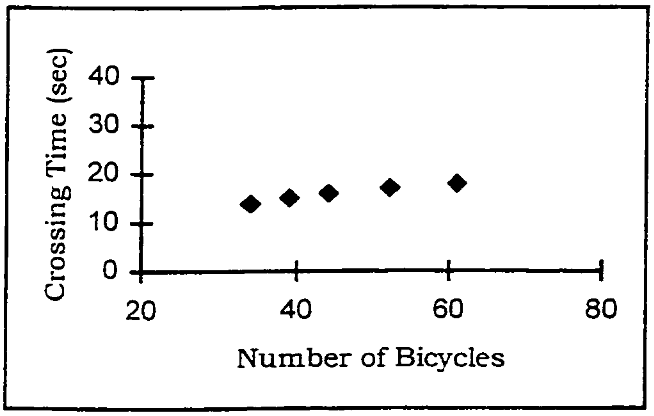
These Figures show the relation between intersection crossing time and different proportion of volumes of automobiles and bicycles number:



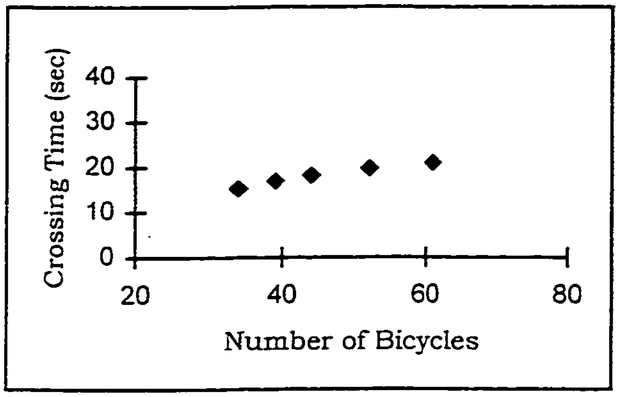
y=-0.998+3.726×ln(x)
(a) 25 left turn and 11 straight-going automobiles



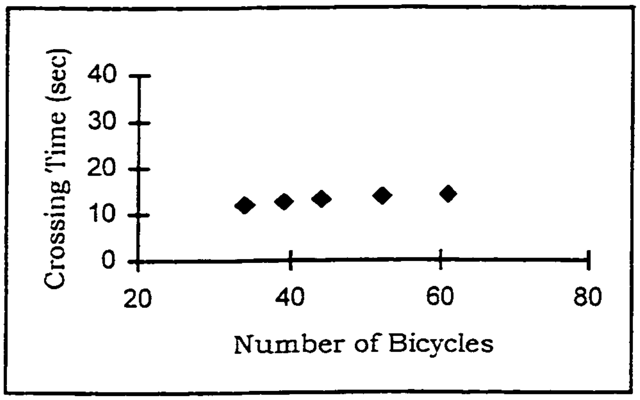
y=-10.411+6.917×ln(x)
(b) 17 left-turning and 11 straight-going automobiles



y=-18.267+9.579×ln(x)
(c) 12 left-turning and 11 straight-going automobiles



y=-27.691+12.772xln(x)
(d) 7 left-turning and 8 straight-going automobiles

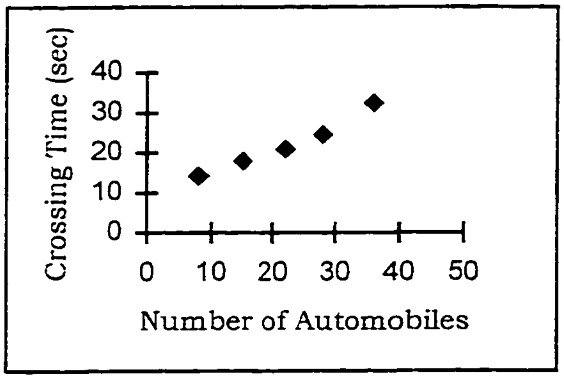


y=-48.102+19.689xln(x)
(e) 4 left-turning and 4 straight-going automobiles

(In the equations y is the crossing time and x is the number of automobiles)
Figure 4.6 (a)-(e) Mixed traffic crossing time for variable number of bicycles

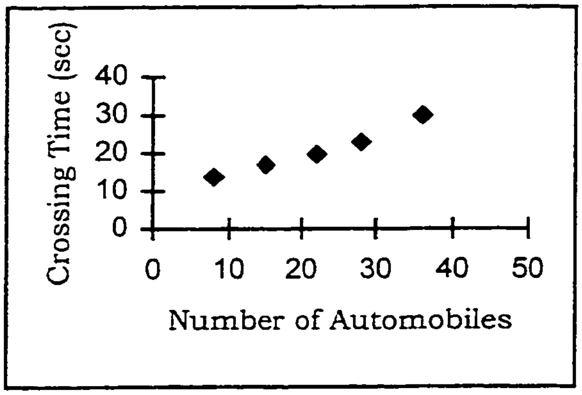
Different models have been fitted to the data and, for constant number of left-turning and straight-going automobile, the crossing time for mixed traffic increase with number of bicycles following a logarithmic equation.

It is estimated that it costs less time for an automobile to cross the intersection than the bicycle. Therefore in the initial situation, when few vehicles are in the traffic, the increase of the proportion of automobile traffic in the traffic system is actually reducing the passing time of the whole mixed traffic. However, as their number keeps growing, their disadvantage becomes more obvious, as will be discussed later. On the other hand, it is found that with the increase of the number of bicycles, there is a falling rate of increase in the crossing time.



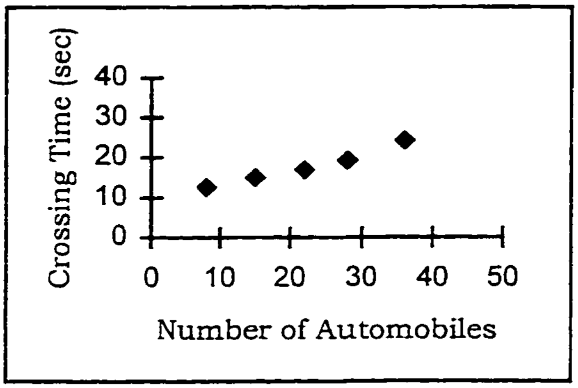
$y=10.27\times e^{0.019X}$

(a) The crossing time for the automobiles with 61 bicycles



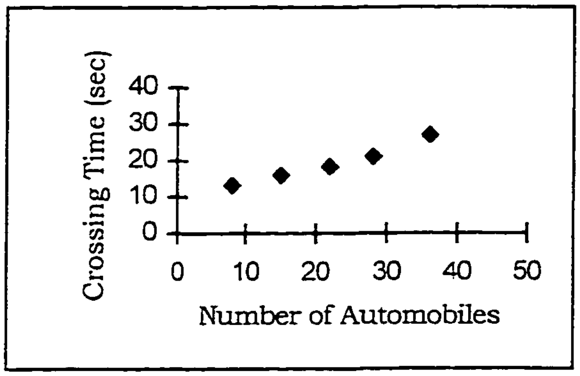
$y=10.549\times e^{0.022X}$

(b) The crossing time for the automobiles with 52 bicycles



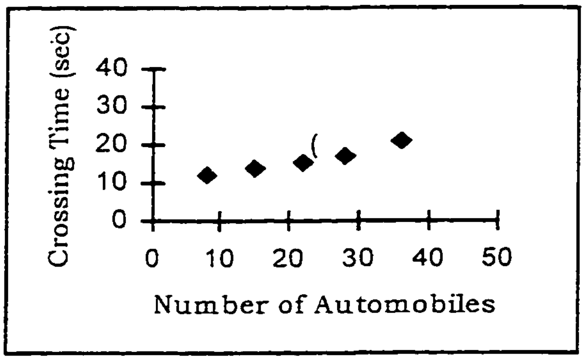
$y=10.79\times e^{0.025X}$

(c) The crossing time for the automobiles with 44 bicycles



$y=11.102\times e^{0.027X}$

(d) The crossing time for the automobiles with 39 bicycles



$y=11.549\times e^{0.029X}$

(e) The crossing time for the automobiles with 34 bicycles

In the equations y is the crossing time and x is the number of bicycles)

Figure 4.7(a)-(e) Mixed traffic crossing time for variable number of automobiles

Similarly, the crossing time of the mixed traffics with constant number of bicycle increase with number of automobiles following an exponential equation

In these models, we can see with an increase of the number of automobiles showing a rising rate of increase, which means that with the increase number of automobiles. There will be more delay in a crowded intersection than in a less crowded one.

In general, a decline in the result of intersection delay can be seen as bicycle increase and automobiles are kept constant. On the other hand the rate of increase actually grows when bicycles are kept constant and automobiles increase.

### 4.1.5 Intersection traffic space occupation situation

The following studies were also carried out to gain an understanding of the use of the road in Beijing case. This could be useful in solutions that involve channeling of traffic.

1. The proportion of the vehicle and bicycle's utilization of the road. The study was carried out in the following way: 1) The times of each grid having been passed by a vehicle were recorded. 2) From this kind of study, the frequency of use of the surface area is found out.

A full cycle is represented in the following, which does not represent the flows but the intensity of use. Clearly, there is already a separation of the mode by use of area.

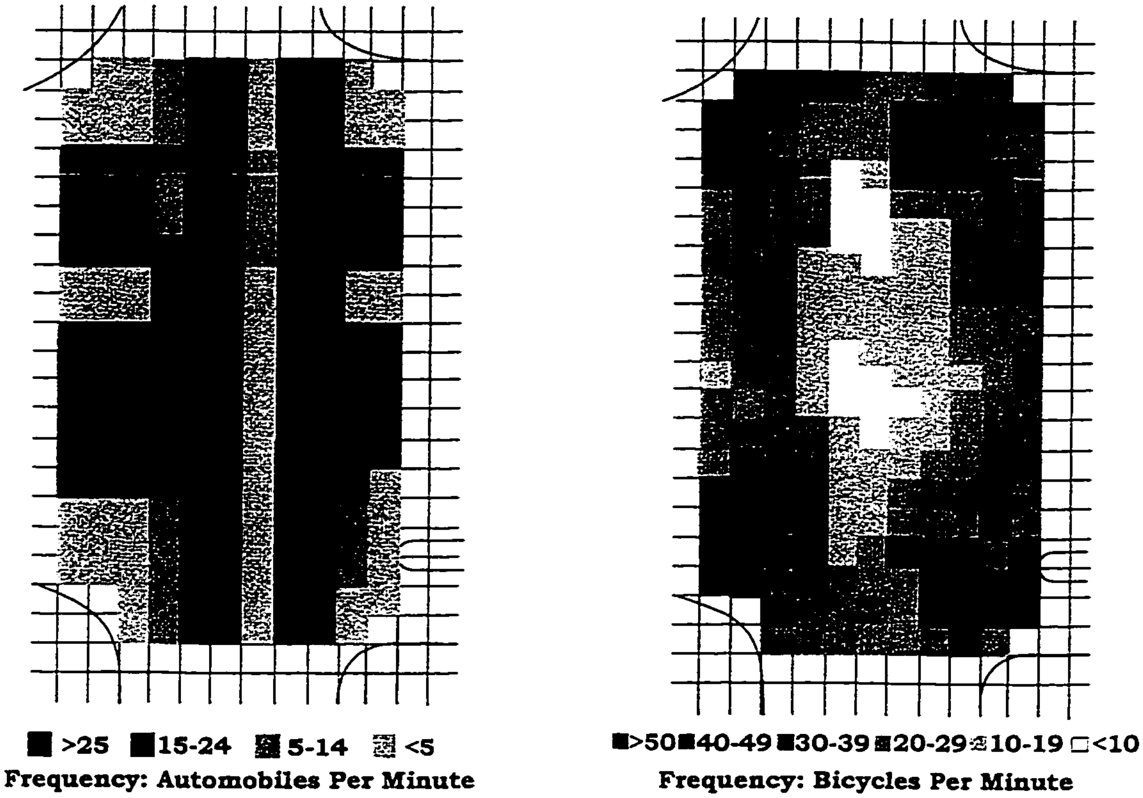


Figure 4.8 Intersection traffic space occupation of Beijing case

## 4.2 Case 2: Pingliang Road and Dalian Road Intersection, Shanghai

In the case study carried out at the intersection of Pingliang Road and Dalian Road, Shanghai, the situation is considered to be a controlled mixed traffic situation. The mixed traffic are separated and organized in the intersection by different light signals. During each green-red light period, a 20 seconds period is given to the left-turning traffic at the very beginning of the period followed by the signal period for the straight-moving traffic later. Therefore, the straight traffic and left turning traffic were separated to avoid possible traffic conflicts, which leads to more waiting time.

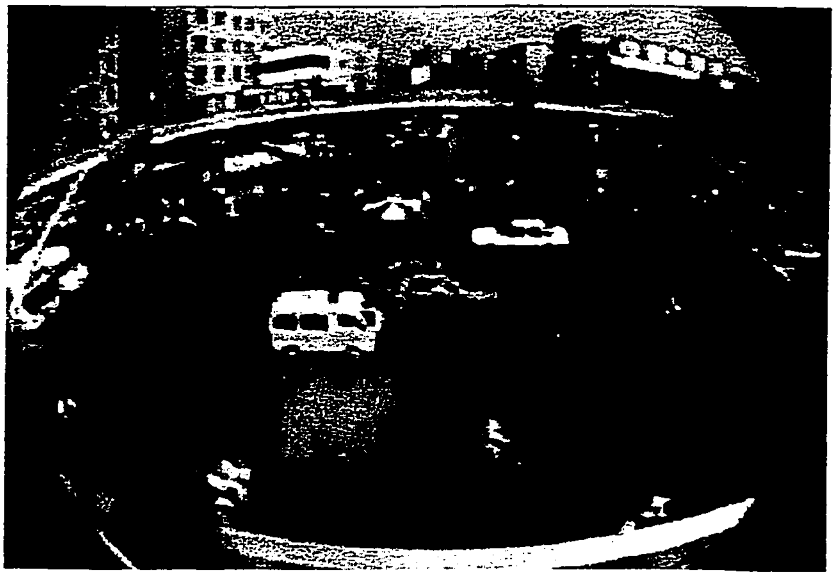


Figure 4.9 Intersection of Pingliang Road and Dalian Road (Shanghai case)

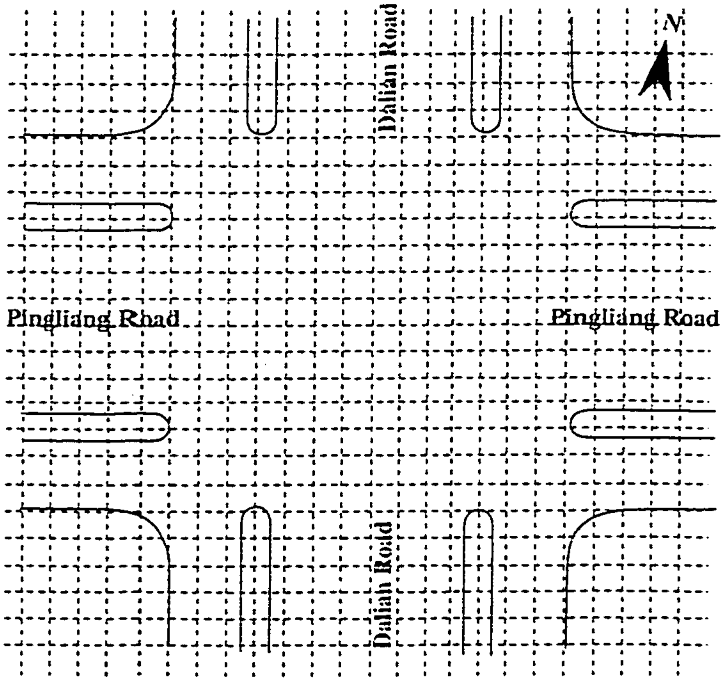


Figure 4.10 Plan of Shanghai case intersection with a 2-m grid

### 4.2.1 Intersection traffic flow

Vehicles move in the following way through the intersection (Figure 4.11).

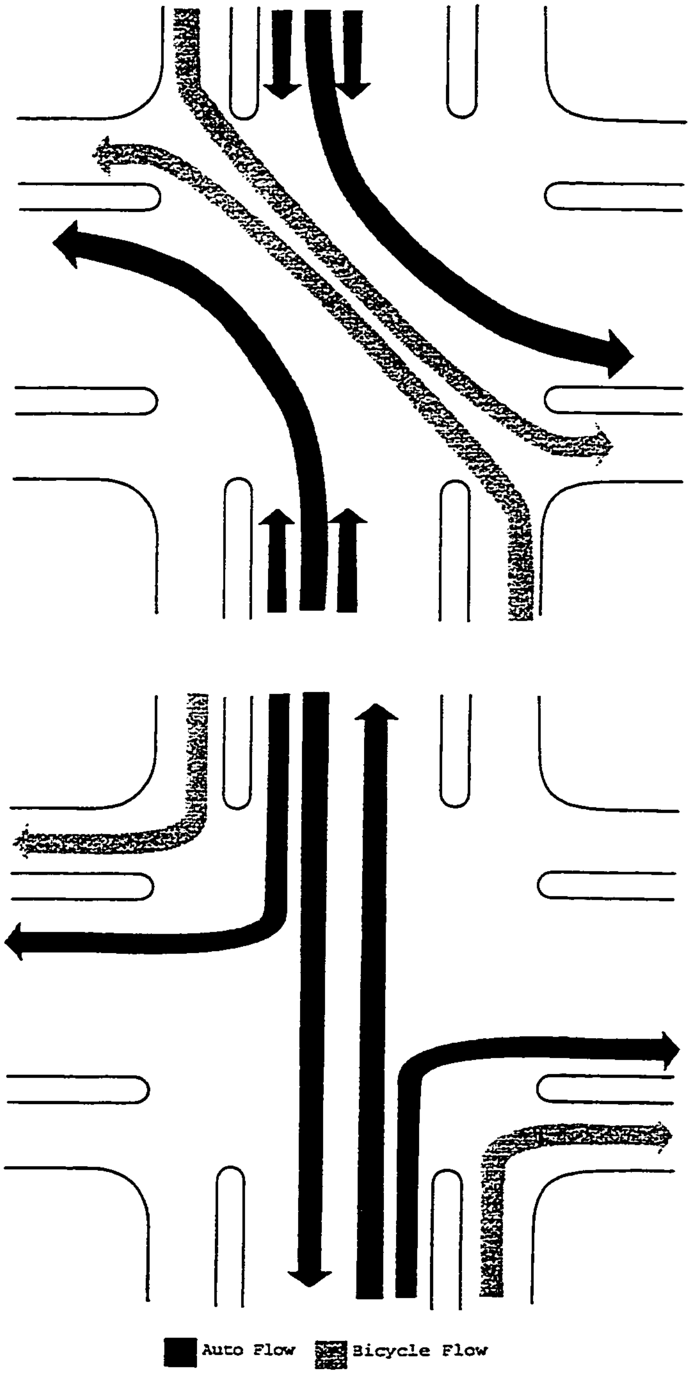


Figure 4.11 Traffic flow of Shanghai intersection

### 4.2.2 Intersection crossing time study

Similar research on crossing time was also carried out in the Shanghai case, which is also a well-controlled situation. In this intersection, during each inter-green period, there is a 20-second period that only allows the left-turning automobiles and bicycles to pass, followed by a one-minute period from the straight-going traffic. Therefore the straight-going traffic can pass without the influence of the left-turning traffic. However, they will have to spend another 20 seconds for the left-turning traffic.

The average passing time for motorized traffic is 9 seconds. The average passing time for non-motorized traffic is 14 seconds, which is very similar to the Beijing case. Thus, the crossing time of the automobiles in the Shanghai case is actually 20+9=29 seconds and for the bicycle is 14+20=34 seconds. This compares with 12-33 seconds for the automobiles and 11-34 seconds for bicycles in Beijing. As will be clear the additional delay is not due to a difference in traffic volume, but a different control regime.

### 4.2.3 Intersection traffic space occupation situation

The occupancy of the road space is as follows also showing a natural separation of traffic.

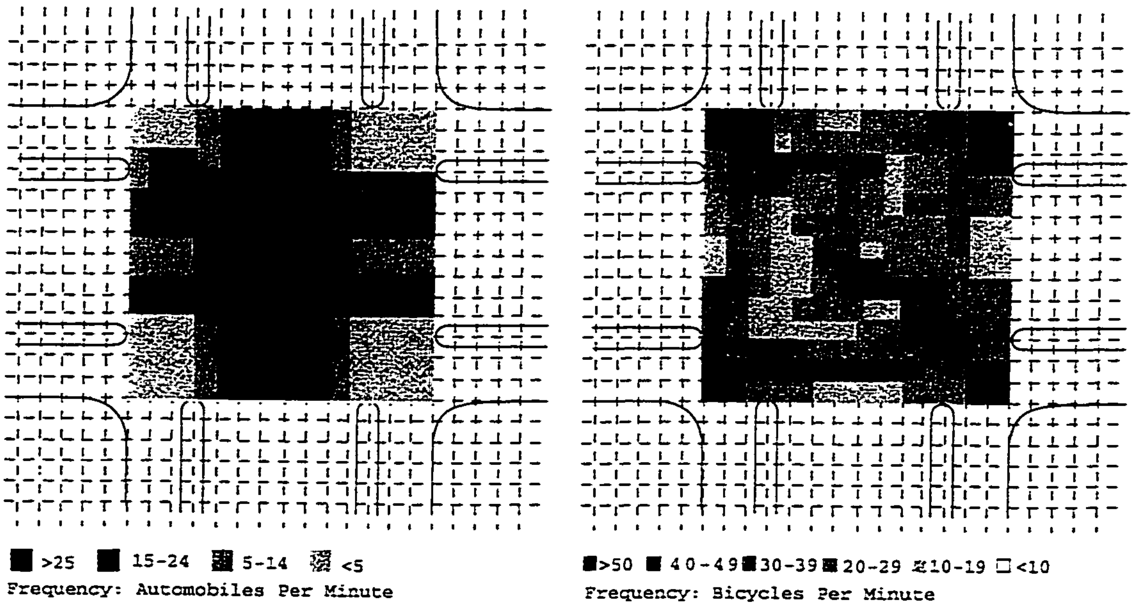


Figure 4.12 Intersection traffic space occupation situation of Shanghai case

## 4.3 Conclusion of the Research

The result of the study shows:

(i) For constant number of left-turning and straight-going automobile, the crossing time for mixed traffic increases with the number of bicycles following a logarithmic equation and The crossing time of the mixed traffics with constant number of bicycle increases with the number of automobiles following an exponential equation.

(ii) The delay time was actually caused by the left-turning automobiles and bicycles.

(iii) The left-turning automobiles wouldn't be delayed during the left-turning process by the straight-going automobiles.

(iv) The straight-going automobiles do not affect the straight-going bicycles.

(v) The maximum bicycle volume that can pass before the left-turning autos is constant level depending on the size of the intersection (In Beijing Case, this number is 24). So, if the total number of bicycles is more than this level, the rest of the bicycles would have to wait until the left-turning automobiles cleared up, which significantly increased the total delay time of mixed traffic.

(vi) In the current situation, there are certain spaces in the roads that are utilized by both automobiles and bicycles, which generates the conflict of the two traffic modes in the intersection.

(vii) Whether under control or not, a natural separation of traffic can be observed in the mixed traffic flow. In other words, intersection space utilized by different kinds traffic mode in the mixed traffic is, to some extent, constant. This information could be very useful in future strategies for intersection management.

(viii) In general, added control reduces the conflict time by 5%-66%, but increase the total delay by 5%-60%.

# Chapter 5
# Alternative Intersection Management Strategies

Analysis of the case study performed in Chapter 4 permitted to find out, in the Shanghai case (which is considered to be a controlled traffic), the traffic situation is better organized and costs less delay time for cyclists and automobiles to cross the intersection. However, the waiting time for passing through the intersection is longer. Thus, it costs more time for the vehicles and cyclists to cross the intersection overall. In the comparatively less controlled case of Beijing, the passing time is shorter. The delay time crossing the intersection increased greatly, which implies a decrease the safety level of the traffic in the intersection.

Thus, the problem is finding ways to make maximum utilization of bicycle and motorized transit system, which seems to be the optimal transportation situation for the Chinese public passenger transportation. The size of the volume makes alternative designs desirable, due to the large number of conflicts existing in the Chinese intersection.

In order to get maximum benefit from the existing road system, some re-configuration strategies can be applied. Since it has already been noticed that most of the delay is due to various kinds of conflicts. On the other hand, conflicts arise because of the configuration of road space. In other words, most of the intersection problem is not one of control but of configuration.

The following chapter will discuss certain strategies that might be taken as alternative to optimize the intersection design strategies under different traffic situations.

These design strategies of two main types:

## 5.1 Separating no-motorized traffic and motorized traffic completely

For this strategy, the following steps have been taken,

### 5.1.1 The elevated bicycle way

Generally speaking, the elevated bicycle-only way was set up with the separated bicycle-only lane above the pedestrian path (about 5-6 meters high). The width of the lane is about 5-7 meters. The slope leading to and from the elevated way is 1:3 to 1:4.

The elevated bicycle-only way can separate bicycles, pedestrians and automobiles. It can also increase the speed of bicycles by 20%-30% by eliminating waiting time (Su Chundong, 1992).

However, no city in China has applied this strategy. The main problems existing here are:

(i) The elevated bicycle way adds a slope leading up to and way from the elevated highway, increasing the length and difficulty of the bicycle trip;

(ii) The elevated bicycle way creates another problem of bicycle parking and traffic connection with other roads, which would be an additional problem for the whole city's traffic configuration;

(iii) The whole city's planning and underground sewer, including underground pipeline and roadside green space will also be influenced by the elevated bicycle high way.

(iv) The elevated way requires a huge investment. The cost for one kilometer's highway will be around 8 million RMB Y (1.5 Million CAN$). So, a 50 km bicycle elevated way network system is about 400 million RMB Y (75 million CAN$), which would be a heavy financial burden on the city.

In summary, the elevated bicycle system does not seem to be a very promising solution to most of the Chinese cities.

### 5.1.2. The elevated highway for the automobiles

Generally, it is more feasible but more costly to set up an evaluated automobile highway in the city to separate bicycle and automobile traffic. The following facts here have to be considered:

(i) It can be set up just above existed urban avenue, so as to minimize the influence on existing urban infrastructure.

(ii) Slopes are not so critical to automobiles as they are to bicycles, so that it is easier for automobiles to adapt to steeper slopes. This makes the connection of elevated roads and the existing traffic system easier.

Meanwhile, the three largest major cities in China (Beijing, Shanghai and Guangzhou) have developed their own elevated automobile highway systems, which are, to some extend, successful in increasing the traffic efficiency. However, there are still lot of traffic bottlenecks existing at the connection points of the elevated highway system and ground-level system. Also, it is very expensive to set up the elevated highway system.

### 5.1.3 Three-lane road

Three-lane road is the most popular type of roads in Chinese cities. The regulations submitted by the national traffic community board 1980 were regarded as the national standard for the new traffic engineering projects (Table 5.1).

Table 5.1 The Road Standard Proposed in 1980

| Grade | Speed (km/hr) | Auto lanes | | Separation (m) | Width (m) | Total Width (m) | Crossing |
|---|---|---|---|---|---|---|---|
| | | No | Width(m) | | | | |
| 1 | 60-80 | ≥4 | 3.75 | Required | ≥6-7 | 40-70 | Elevated Crossing |
| 2 | 40-60 | ≥4 | 3.5 | Required | ≥5 | 30-60 | Surface Crossing |
| 3 | 30-40 | ≥2 | 3.5 | Not Required | ≥3 | 20-40 | Surface Crossing |
| 4 | <30 | ≥2 | 3.5 | Not Required | ≥3 | 16-30 | Surface Crossing |

*(Source: Chinese National Construction Board, 1980)*

The Three-lane road is very effective in solving problem of modal conflict. However, the problem in the intersection is really not solved by this traffic strategy at all. During peak hours, when traffic becomes really heavy, the contradiction of the different traffic streams generates dozens of “conflict points” in the intersection area. Especially the left-turning traffic stream makes a significant contribution to the mass situation. This could be considered to be the key bottleneck of the traffic system.

### 5.1.4 The bicycle-separated traffic network

The bicycle separated traffic network has major potential in China.

A bicycle-separated traffic network is different from the bicycle-only lane. The policy of the bicycle-only lane is that automobiles are generally forbidden to enter the traffic system. However, in a bicycle-separated traffic network system, things are much more flexible. The traffic flow of the bicycle-separated traffic network is mainly made up of bicycles. The automobiles are not really forbidden to utilize the system. In some cases, they are also allowed to enter the system in case of emergency.

It is possible to apply this strategy to Chinese cities, for the following reasons:

(i) It is preferable that cyclists take minor roads in big Chinese cities.

In the downtown area of Chinese cities, it is usually very difficult to go through the intersections by bicycle, because the red light period will usually consume a lot of time. So, cyclists always wish to avoid these major roads with busy intersections, preferring minor roads, in which they will come across fewer red lights and crossings. This condition can already be regarded as a prototype or the internal dynamic of the bicycle-separated network.

(ii) There are huge numbers of minor roads and alleys, which are very suitable for bicycle traffic, but too narrow to accommodate automobile traffic in large Chinese, which, though has not form a traffic network yet, can be taken as a potential bicycle-separated traffic network.

The traffic space in central Shanghai is only 2 square meters per person. However, road density, which is 6~7 km per square kilometer, is comparatively high (Comprehensive Transportation Institute of Shanghai, 1992). The total traffic road length in Beijing today is 2500 km. More than 70 percent of these roads are narrower than 7 meters. About half of the 434 roads in Guangzhou are narrower than 7 meters (Su Chundong, 1992). These numbers shows the obvious fact that narrow streets or alleys make a big proportion of the whole traffic road network system of large Chinese cities.

However, narrow streets themselves are still not a complete bicycle-separated traffic network. A large proportion of these narrow alleys and streets are too narrow even for bicycles, which in turn influences people's choice of bicycle path.

In order to make a perfect bicycle traveling environment, there are still something need improving:

The following improvements were supposed;

(i) The road should be made wider so as to make more streets accessible to cyclists and the surface of roads needs to be improved to make it better to ride bicycles on.

(ii) Because of the complexity of the road configuration, some direction signs will be needed to show directions to confused cyclists.

(iii) Road planning should be improved, with the whole traffic network better organized to make a complete traffic system which can access varied destinations of the city.

### 5.1 5 One-way bicycle way

One-way bicycle streets are also considered to be an effective way to provide better service for the increasing bicycle traffic. It is a traffic planning strategy that requires all the bicycles in certain bicycle path to travel in only one direction.

The main advantages for the bicycle are as follows:

(i) It is an effective way to accommodate heavy bicycle flow at comparatively low cost. The one-way bicycle traffic system is actually based on the utilization of the existing bicycle system. So, there is no need for setting up new paths, which could be very expensive.

(ii) It is a good way to make full use of the old narrow paths and alleys, which are no longer suitable for the heavy traffic today. The old alleys and small streets are actually very old and narrow, which were initially set up for pedestrian traffic. They are too narrow to accommodate two-way bicycle traffic but they are still ideal for one-way bicycle traffic.

(iii) It helps to improve the traffic organization in the road crossing by reducing the numbers of conflict points.

The one-way bicycle-only lane is most applicable to the following situations:

(i) Urban areas with a heavy bicycle traffic: It is very understandable that the traffic mode will need a certain level of traffic to support.

(ii) Two close parallel small streets are available. Generally speaking, the distance between the two streets should be no more than 150 meters. If the distance in between of the two parallel streets is too long, the bicycle riders will ignore the regulation by making two-way traffic on the one-way bicycle path.

(iii) Another important fact that might determine the success of the strategy is that there should be a reasonable connection between the two parallel streets. It helps people make the transfer from one direction to another when necessary; otherwise, the bicycle riders are still going to ignore the "one-way" policy.

In China many cities, including Beijing and Shanghai, applied this strategy in 1990s. The result seems to be successful. For example, the speed of the bicycle was increased by 20~25% when the one-way strategy was applied in Beijing (Su Chundong, 1992).

However, we can see it is not really possible and economical to apply this strategy everywhere. From the former results, bicycles actually access everywhere. It made impossible to separate the mixed traffic everywhere. Therefore, It is important to find an alternative strategy.

## 5.2 Improvement of the intersection situation

### 5.2.1 The organization of bicycle movement in intersections.

According to the tape and the author's observation, there are normally two traces for left-turning traffic. These two situations are showed on Figure 5.1. Two main traces utilized by the bicycles are as follows:

Stream 1: Cyclists try to cross the automobile stream ahead of the on-coming case and make the left turn;

Stream 2: Cyclists follow the automobiles a little distance and cross the automobile streams to make the left turn.

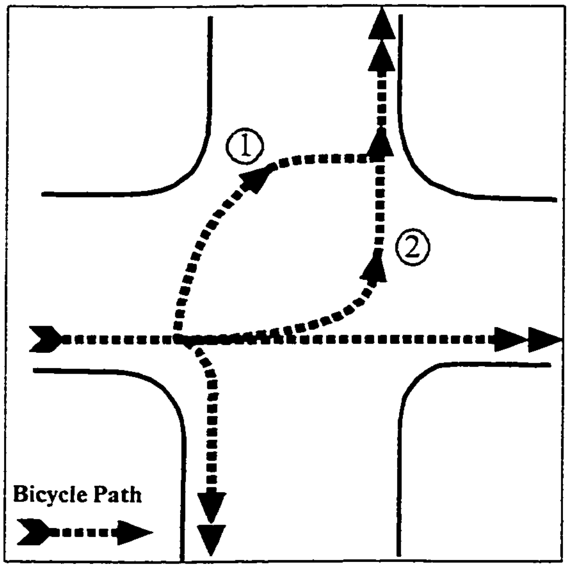
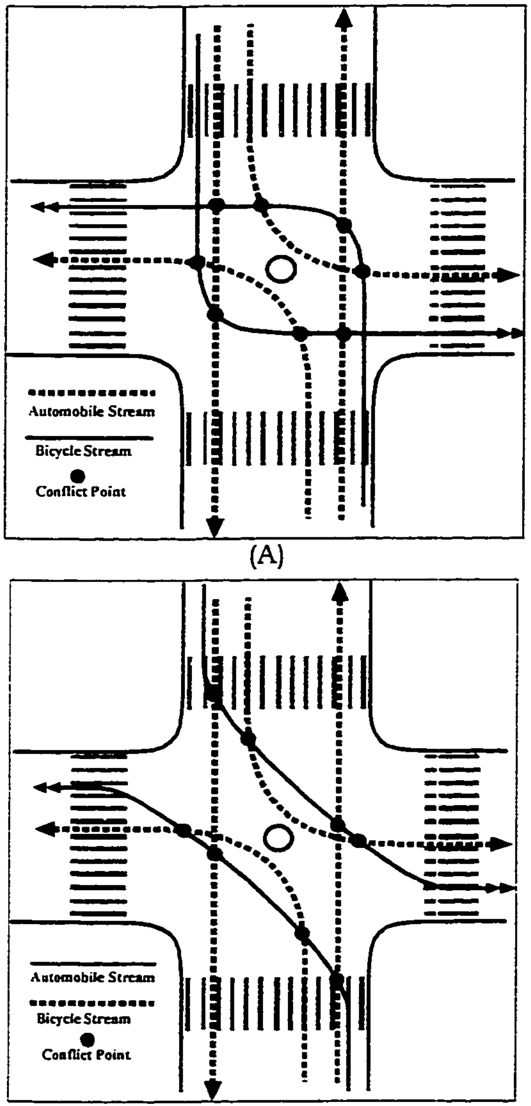


Figure 5.1 Bicycle traffic path at the intersection

Thus, the organization of the left-turning cyclists should also respect these two major traffic streams. There are several designs that can be applied in this situation.

#### 5.2.1.1 The Bicycle Restriction Areas

At a mixed traffic intersection under the control of one signal light, there are theoretical 16 conflict points. (Figure 5.2a and Figure 5.2b). However because bicycles actually move in-groups, the larger number of conflict points in the real world would be expected.



(A)

(B)

Figure 5.2 The conflict points at intersection

Setting up the bicycle holding area can be considered as an effective way to reduce the conflict points.

As what is shown in the Figure 5-3, the bicycle holding area (the shaded area) can not be accessed by the bicycles. Therefore, the bicycles have to travel along certain traffic channel around the holding area, which greatly reduces the number conflict points of two traffic flows.

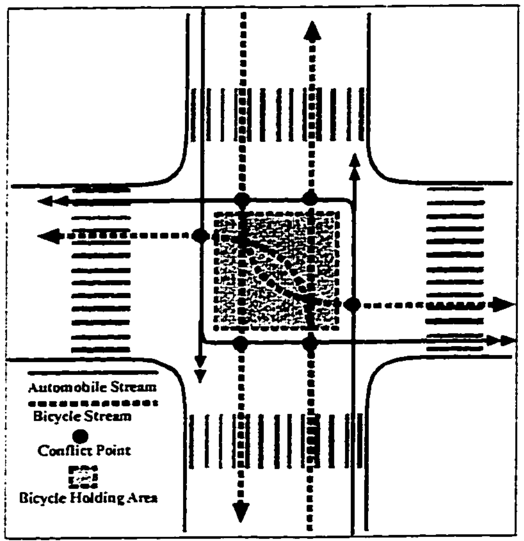


Figure 5.3 Conflict points at intersection with bicycle holding area

In case the bicycle traffic needs to make a left turn, they will have to stop at the turning point to wait for the gap of the straight through automobile traffic in order to cross (Figure 5.4).

This method helps to organize the traffic environment in an orderly way.

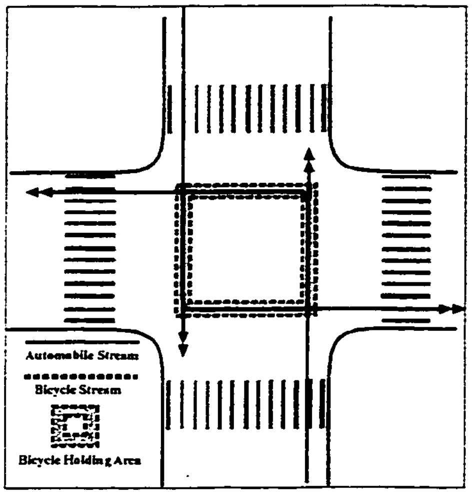


Figure 5.4 Bicycle flow channel at intersection with bicycle holding area

This strategy has been already applied to certain intersections of Beijing; (e.g. the intersection of Xingdong Rd and Lunan Rd). The following traffic survey shows that the traffic situation was improved after the application of the strategy. The peak hour automobile flow is 3720 vehicle/hour, bicycle flow is 10840 Bicycles/hour and the left turning rate is 0.15 in this intersection (Beijing Comprehensive Transportation Research Institute, 1992).

Table 5.2 Average passing time of different vehicles at the intersection of Xingdong Rd and Lunan Rd, Beijing, China before and after the bicycle holding area applied

| | Before | After |
|---|---|---|
| The average passing time of straight going automobiles | 13.42 s/v | 13.35 s/v |
| The average passing time of left turning automobiles | 21.79 s/v | 19.99 s/v |
| The average passing time of left turning bicycles | 40.30 s/v | 34.05 s/v |

(Source: Beijing Comprehensive Transportation Research Institute, 1992)

This method regularized the bicycle traffic at the intersection area. Generally speaking, if the conflict space is too large, traffic is usually very difficult to control. In traffic intersections, by restricting the bicycle traffic in a certain area, the conflict area and points are considered to be reduced.

### 5.2.1.2 Bicycle priority path

Another similar method is to set up a bicycle priority path. Instead of setting up of the bicycle restriction area, a bicycle safe path can also be set up at the edge of the bicycle holding area. Bicycles can enjoy traffic priority only in the bicycle safe path, which may lead cyclists to obey the rules and ride along the path (Figure 5.5).

In certain conditions, this strategy can be very successful in increasing the efficiency of the traffic. In the following " T " crossing, the bicycle traffic can be organized very well with this strategy.

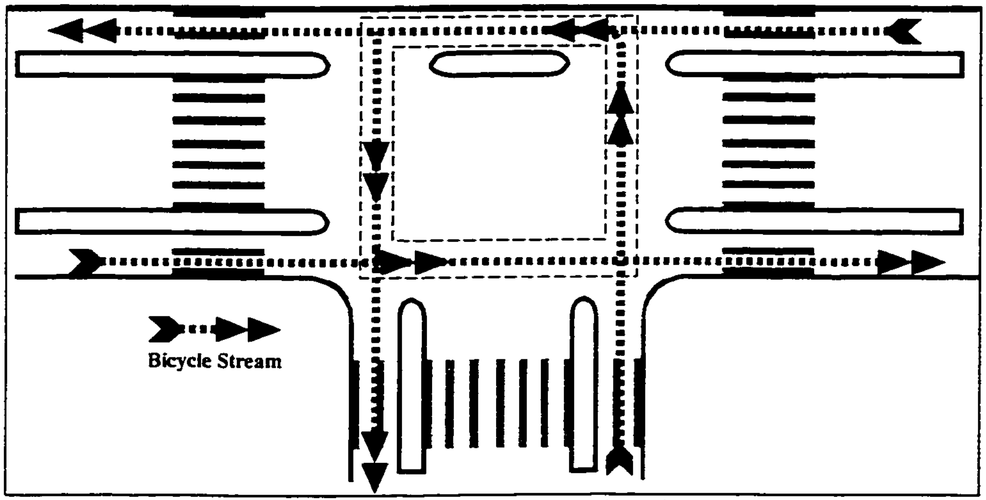


Figure 5.5 Bicycle holding area in the T intersection

### 5.2.2. The left-turning bicycle priority waiting area

Generally speaking, the strategy of setting up bicycle intersection area is most applicable to large intersections without much left-turning bicycles traffic. However, according to the study of last chapter, the left-turning traffic starts up and crosses the intersection faster in comparatively smaller intersections where left-turning bicycles can start and pass the intersection more quickly than the straight-going traffic. Also, in intersections with huge left-turning bicycle traffic where a huge number of bicycles have to wait, left-turning priority is not a really ideal strategy.

A better alternative strategy is setting up the bicycle waiting area after the intersection stop line and in front of the vehicle stop line so that bicycles can wait in this area. In the green light period, the bicycle traffic can start up and pass the intersections quickly so as not to lead to any problem in the automobile traffic behind them. (Figure 5.6)

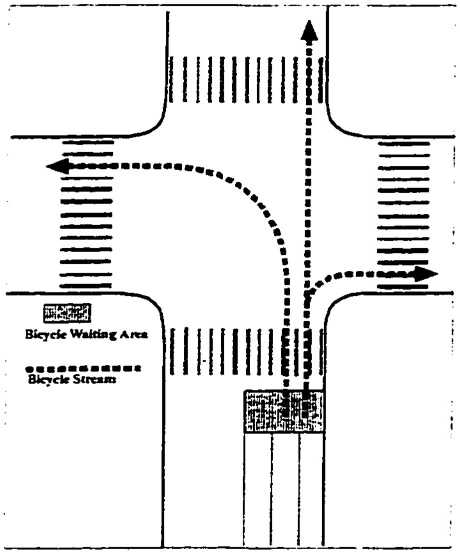


Figure 5.6 Regular bicycle waiting area arrangement

If the bicycle waiting area can be located in front of the pedestrian crossing path, the result could be even better, because there is more road space between the bicycles and the automobiles. The bicycle traffic can clear up even more quickly. (Figure 5.7)

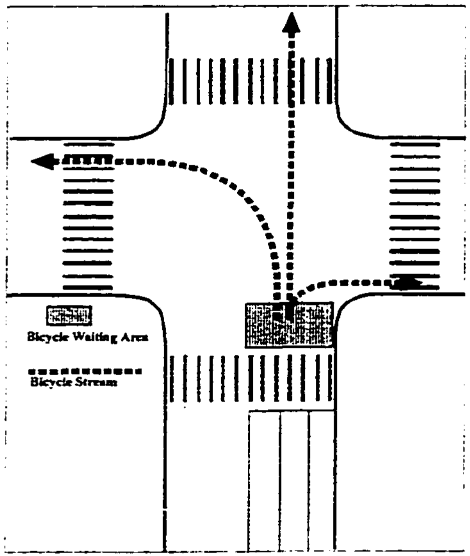


Figure 5.7 Bicycle waiting area in front of pedestrian crossing path

In the research performed that bicycles waiting in front of the vehicle can always pass the intersection quickly without creating traffic conflict. Therefore, what is applied here is to find a better way accommodate more bicycles in front of automobile traffic.

The size of the bicycle waiting area is suggested to be about 3.5-4.0 meters wide and about 10.0 meters long, which is big enough to accommodate 25-40 bicycles.

Since this is a traffic strategy that provides the priority to bicycle traffic, it is most applicable to the intersection with a comparatively high left-turning bicycle traffic (more than 30 bicycles in one red light period).

Actually, certain laws that have been applied in Eindhoven, Netherlands, which give the priority to the bicycle traffic in the intersections, can be also considered based on the same idea.

Another kind of bicycle waiting areas is organized in the following way. At the green light, the left-turning bicycles are supposed to travel together with the straight-going bicycle flow. However, left-turning bicycles are made to stop at the left-turning waiting area. Then, they will wait there until another green light sign is given, which allows them to cross the intersection before the straight-moving traffic in another direction. This strategy has been applied in Nanjing and was observed to avoid obvious conflicts (Figure 5.8).

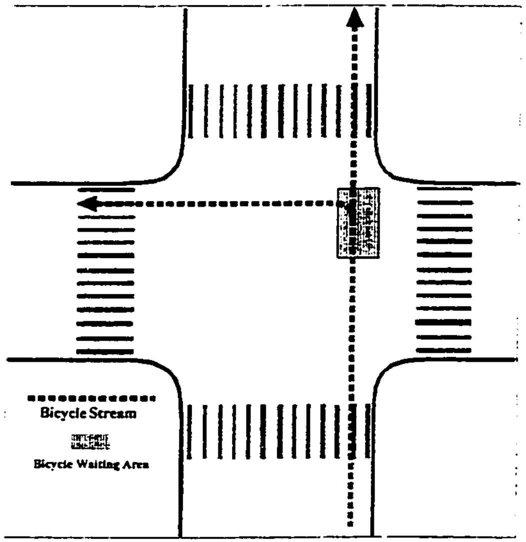


Figure 5.8 Bicycle left-turning waiting area

### 5.2.3 The restriction on left-turning bicycles

In certain intersections, where there is less left-turning bicycle traffic, it is also a possible strategy to prevent left-turning bicycle from making the left turn directly. However, this strategy would cause inconvenience to the cyclist. Thus, whether the cyclists would follow these rules depends on the convenience of the alternative path provided to the left-turning bicycle traffic.

#### 5.2.3.1 The utilization of the neighboring block

This strategy requires the left-turning bicycle traffic to go straight at the intersection and utilize the neighboring block to change the travel direction. (Figure 5-9) Generally speaking, this strategy will cost the cyclists a much longer travel distance, which makes cyclists in turn not follow the rules.

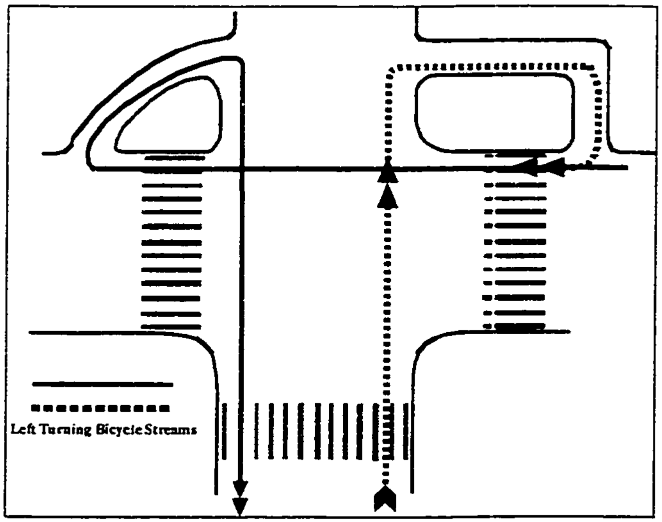


Figure 5.9 Left-turning by the utilization of neighboring block

### 5.2.3.2 Left-turning — cross the street — straight going

This strategy requires the left-turning bicycle traffic flow to make a right turn first, travel straight to the back of the pedestrian path, cross the street there and finally go straight to cross the intersection to finish the whole left turning procedure. (Figure 5.9)

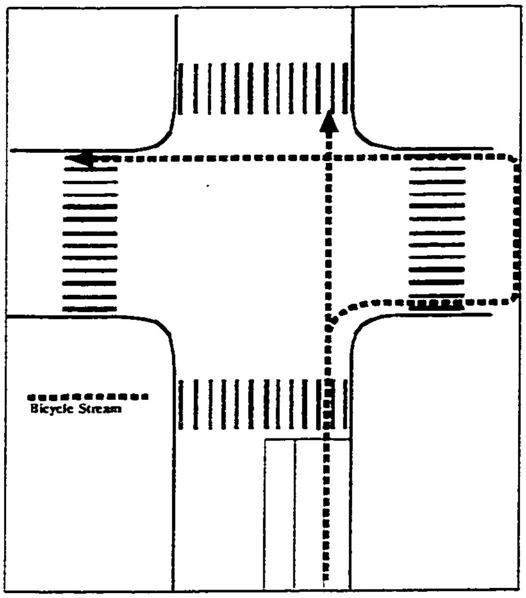


Figure 5.9 Left-Turning — Cross the Street — Straight Going Path strategy

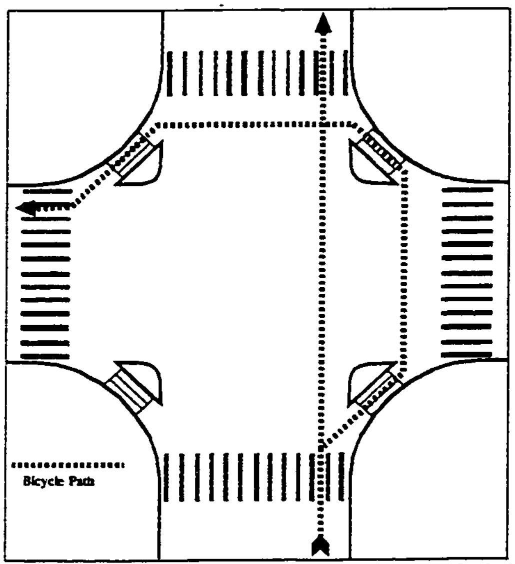


Figure 5.10 Make left turning by a series of right-turning

An alternative method can be taken for this strategy is setting up the right turning path to transfer the left turning into a series of right turning movements (Figure 5.10). This strategy is most applicable to the narrow minor mixed traffic road.

#### 5.2.3.3 Push the Bicycle to Cross the Intersection.

This strategy requires the straight-going and left-turning cyclists to get off their bicycles and push their bicycle to cross the intersections along the pedestrian crosswalk. This strategy can separate the bicycle traffic from the vehicle traffic and be most applicable to the mixed traffic situation with large volume fast-motorized traffic and comparatively small bicycle traffic. For example, this strategy would be very applicable to a newly developed Chinese city like Shenzhen.

### 5.2.3 3-dimensional traffic crossing

In the case the bicycle traffic is very heavy, the surface separation strategy would not be very efficient. Then a grade-separated strategy should be considered. Usually, when the bicycle traffic system come across the motorized-traffic, it is considered to be most applicable to set up double level intersections. Bicycle path with a slight slope, providing easy accessibility to cyclists, is usually built under the motorized-traffic path (Figure 5.11).

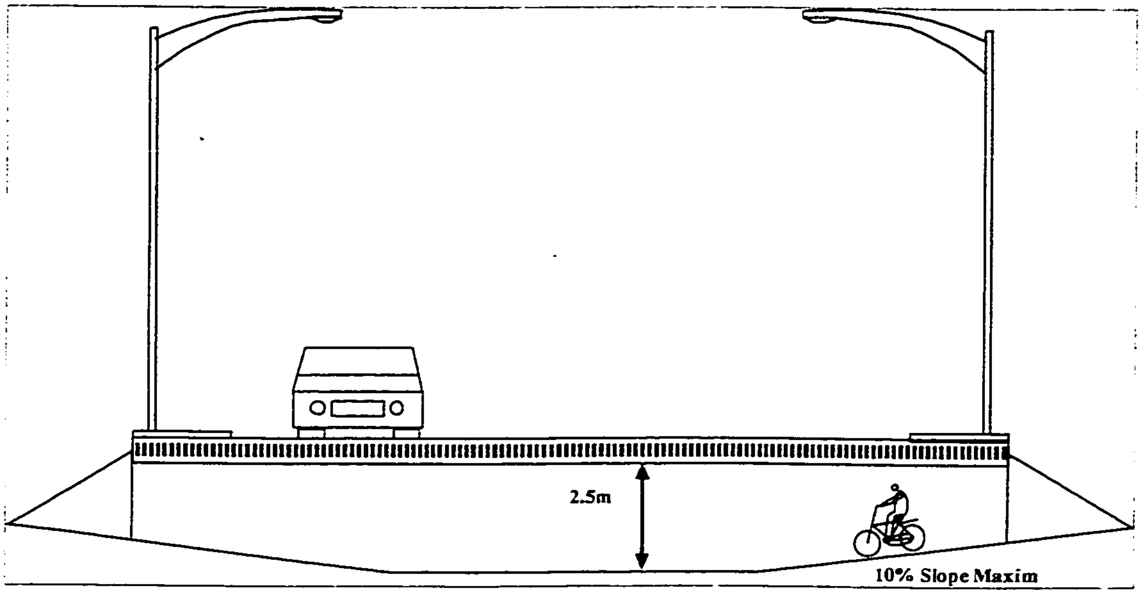


Figure 5.11 The section of 3-dimensional traffic intersection

The following Figure shows a 3 level intersections having been set up at Fuxingmeng intersection in Beijing (Figure 5.12a).

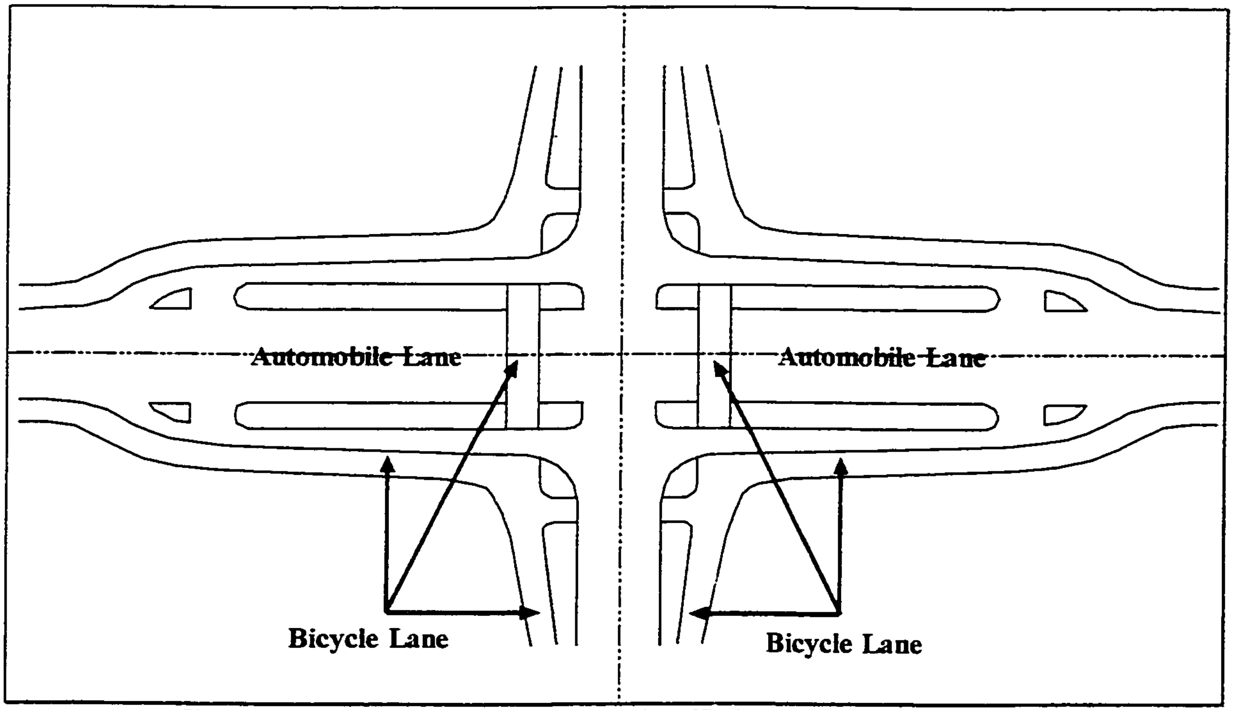


Figure 5.12a: Jianguomen 3-dimensional traffic intersection, Beijing, China

In intersections near the river, the difference of height between bridges crossing the river and road by the river can be utilized to apply a simple 2-level intersection. (Figure 5-12b)

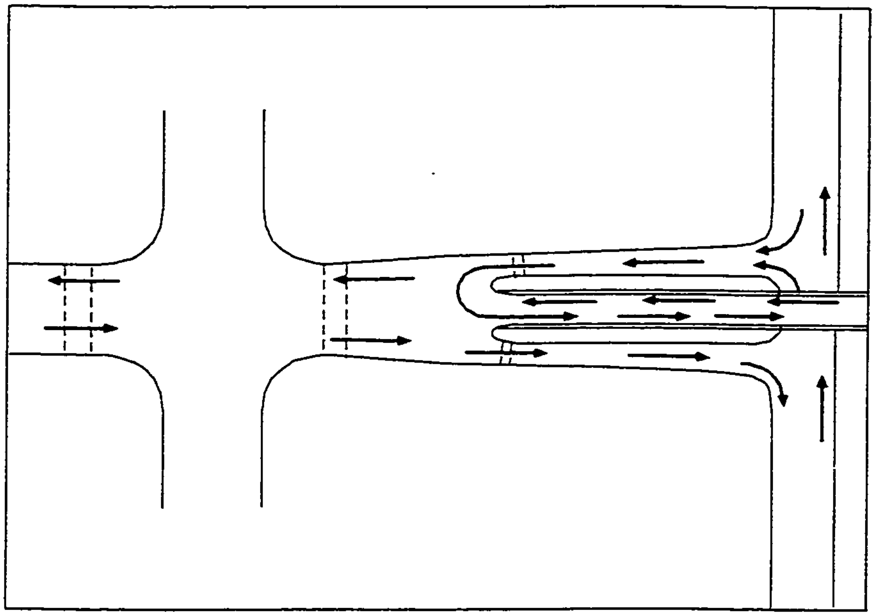


Figure 5-12(b) Simple 2-level intersection by the river, Yancheng, China

Generally, all these intersections can be considered as alternative strategies that meet different traffic flow level and various ratio of different traffic mode. Some of have already been applied in certain cities of China. However, further studies are still expected in the service level of these variable intersection management strategies.

## 5.3 Proposed traffic management strategy of the two case stdy intersections

It is from the traffic management strategy given above. The bicycle restricted path and the bicycle waiting area would be considered as two proposed management strategies for the intersection of the two case study examples.

In the Beijing case, where there is a comparatively low bicycle flow. The bicycle waiting area can be considered as the strategy to improve the intersection traffic management strategy. Bicycle waiting area can be arranged from the automobile stopping line. (Figure 5-13)

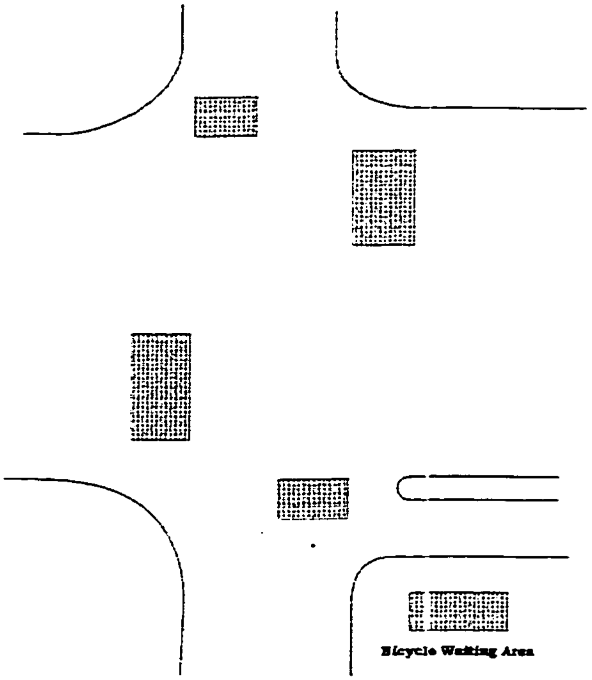


Figure 5-13: The proposed bicycle waiting area for intersection of Beijing Case

For the Shangahi case, the bicycle restriction area is a sound management strategy to apply, which would be a better alternative to increase the efficiency of the traffic (Figure 5-14).

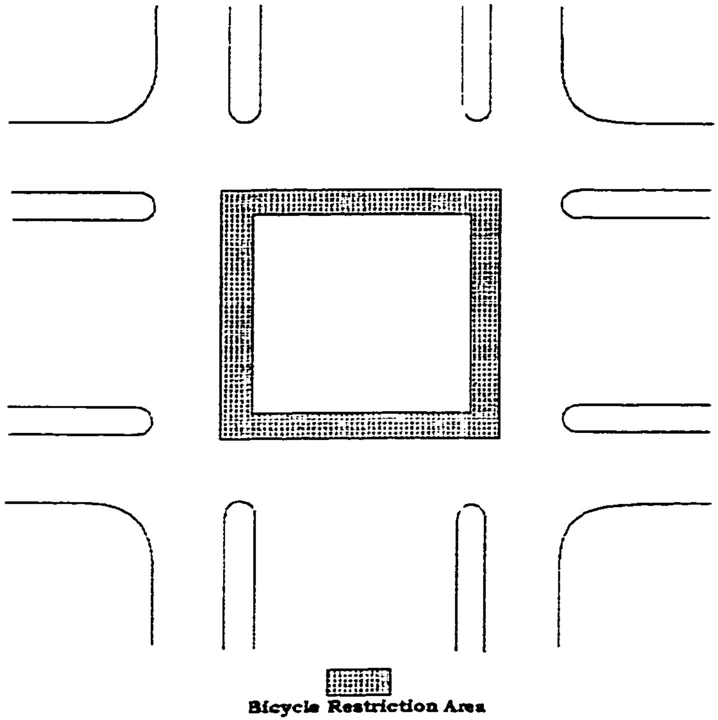


Figure 5-14: The proposed bicycle waiting area for intersection of Shanghai Case

# Chapter 6 Conclusion

## 6.1 Conclusion of primary research

The questionnaire survey carried out in Shanghai revealed that the average trip distance of the interviewees by bicycles is approximately 4 Km, their average trip time around 26 minutes. However, their estimated time for making the same trip by bus is almost 40 minutes, which is significantly slower than by bicycle (Table 2.3). From the research, it is also found that In short daily trips, bicycles are faster than the bus system when the distance is shorter than 5.6 Km or 30 min (Table 1.4). Also, most of the urban residents' daily trip distances are within accessibility of the bicycles (Table 2.7), which encourages the utilization of bicycles.

The literature review reflects the lack of studies in mixed traffic and the necessity of investigation of new strategies for traffic management in a highly populated country.

Traffic efficiency is related to intersection traffic, where most of the conflict area exists. It is observed that the conflicts between different traffic modes played a major role in reducing the speed and the safety level of both traffic modes. The primary case studies and literature review also shows that efficiency of traffic is associated with how intersections are managed.

Research also shows that the management of traffic in the intersection includes interactions of all traffic components in the traffic. Therefore, the study of the maximum capacity of intersection with mixed traffic must take into consideration the interaction of automobiles and bicycles. For a constant number of left-turning and straight-going automobiles, the crossing time for mixed traffic increases with the number of bicycles following a logarithmic equation. On the other hand, the crossing time of mixed traffics with a constant number of bicycles increases with the number of automobiles following an exponential equation.

Traffic left turning control system does reduce the crossing time of the mixed traffic. It costs a certain period of waiting time for the vehicles it start their crossing movement, although it is anticipated that this traffic management strategy increases the safety level of traffic by reducing the traffic conflicts.

Many alternative management strategies were proposed to solve the problem. Some of the management strategies call for a major reconfiguration of intersections and streets, which leads to larger financial investment. Some others do not require a major financial investment. Therefore, it is possible to find a balanced solution for the intersection traffic management strategy in populated countries with low as well as high revenues.

The method and analysis based on video study and image analysis proved to be quite successful in deriving clear patterns related to the traffic control system.

## 6.2 Conditions for various traffic management strategies

Research described in Chapter 4 and proposals presented in Chapter 5 showed that the application of various traffic management strategies involve many factors including, conflicts and safety level. Results from Chapter 4 lead to suggestions for the appropriate range of volumes for different types of control of mixed traffic.

Since the investigated cases are representative of major cities of China, the results of this research are likely to be widely applicable to most of the Chinese cities.

The investigation concerned two types of regular intersections, the intersection with a simple two-signal direction control and the intersection with left-turning control. However, beyond these two types, there are two other types of regular intersections that are often applied: (i) a free-passing intersection can be considered when traffic flow is so low that no control is necessary, which allows the vehicles (automobiles and bicycles) to pass freely. By convention, the first vehicle to arrive at the conflict point passes first. A group of bicycles or cars maintains the right-of-way until a gap. (ii) an intersection with controls for each movement needed when the traffic is too high even for the left-turning controlled intersections.

Research showed for the data range involved in the research, the one signal controlling system is more efficient than the left-turning controlled intersection. However, considering the safety factors, the range of conditions for applying controlled intersections should be reduced. In other words, under a certain level of traffic flow, even if the one-signal controlling system is more efficient for the traffic, it might still be less applicable for safety reasons, for example.

Table 6.1 presented suggestion of different control regimes of mixed traffic components:

Table 6.1 Suggested Applicable Range for Different Control Regimes

| **Intersection Type** | **Bicycle volume range (bicycle/min)** | | | **Automobile volume range (autos/min)** | | | **Suggested improvement strategy** |
|---|---|---|---|---|---|---|---|
| | With 10 Autos | With 20 Autos | With 40 Autos | With 30 Bikes | With 45 Bikes | With 60 Bikes | |
| Without controlling | <20 | NA | NA | <5 | NA | NA | |
| One signal controlling intersection | <40 & >20 | <20 | NA | >5 & <15 | <10 | <5 | **The left turning bicycle priority waiting area**<br>**Bicycle restriction area,** |
| Left turning controlling Intersection | >40 | >20 | <60 | >15 & <45 | >10 & <30 | >5 & <20 | |
| All movement controlling Intersection | NA | NA | >60 | >45 | >30 | >20 | **3-dimensional traffic intersection.** |

This table shows that the suggested bicycle restriction area (Chapter 5) might be applied to bicycle volume range below 40 (bicycle/min) and automobiles below 15 (automobiles/min). In addition 3-dimensional traffic intersections are supposed accommodate high volume of bicycle and automobiles. In the complex real world, some flexibility in the applicable range for the different traffic situations will be necessary. Also, with the variability of the intersection size there might be different applicable ranges because the conflict space will be smaller or larger. However, generally speaking, the case study intersection represents a typical size in Chinese cities and can stand for approximately 45%-50% of the intersections on arterial roads in Chinese cities.

## 6.3 Trend forecasting for different traffic modes

As has been discussed in Chapter 1, the traffic volumes in large Chinese cities are due to increase because of the increase in individual trip generation rate, trip distance and the urban population. In other words, the traffic systems in Chinese city today are actually going to face an increase in traffic volume tomorrow. This growth is much faster than the growth in the population. Thus, it is very important that the traffic management applied today meets the future demand.

From the studies that have been carried out, the following facts can be clearly detected:

(i) When the number of automobiles increases, it is at a rising rate of increase delay. On the other hand, when the number of bicycles is increased, there is a falling rate of crossing time increase. This fact means that with the increase of numbers, the bicycle traffic causes less delay overall to the whole traffic system. Furthermore, this trend is continuous as the traffic numbers increase. This phenomenon may reason be explained through the easier adjustment of cyclist behavior than automobiles and adaptation to the busier traffic situation.

(ii) The bicycle mode of traffic is a pollution-free traffic mode, unlike automobiles that generate green house effects and gas during their utilization. The bicycles can be considered as a green traffic facility.

(iii) Also, certain poisonous waste will be generated during the utilization of automobiles, which will finally stay in the soil. From the soil, they can enter people's food, which leads to a health problem for people.

(iv) Noise, which is already a serious problem in Chinese cities, is getting much worse with increasing traffic levels. The utilization of bicycle traffic mode decreases the noise level in cities.

Therefore, encouraging bicycle utilization in the mixed traffic can be considered as an optimal solution for the future Chinese urban traffic and for the environment.

## 6.4 Suggesting further research

Further research can be done on one of the following aspects:

Similar research can be carried out in intersections with different size and configurations. Although, the case study in the Chapter 4 stands for typical intersection situations of Chinese cities. Yet, there are still many other types of intersections that have not been investigated. For example: the traffic of T-intersections under a mixed traffic situation is still waiting for future study.

Another field that is calling for future study is concentrated in the relationship between the pollution level and the rate of bicycle traffic components in the mixed traffic, which will help to gain a better understanding of the relationship of the traffic system an environment.

Also, for many of the intersection management strategies, although there has been some research carried out, further investigation is needed in order to find out the optimal situation for the utilization of these strategies.

The research applied, using the digital video and image analysis, has proved to be an ideal research method in the study of traffic movement and can also be applied to study the channeling of vehicle movement in intersections where signals are not necessary but where volume generate low level of conflict. While such design studies are beyond the scope of this thesis, it has already been shown in the thesis how the research could be conducted.

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# Appendix A

# Intersection Crossing Time Analysis Data Sets

Crossing Time with Fixed Number of Bicycles

| Number of Bicycles | 25 left turn and 11 straight move Automobile | 17 left turn and 11 straight move Automobile | 12 left turn and 11 straight move Automobile | 7 left turn and 8 straight move Automobile | 4 left turn and 4 straight move Automobile |
|---|---|---|---|---|---|
| Number of Autos | Crossing Time | Crossing Time | Crossing Time | Crossing Time | Crossing Time |
| 30 | | | | | |
| 31 | | | | | |
| 32 | | | | | |
| 33 | | | | | |
| 34 | 20.9 | 17.1 | 15.3 | 13.8 | 12.1 |
| 35 | | | | | |
| 36 | | | | | |
| 37 | | | | | |
| 38 | | | | | |
| 39 | 24.2 | 19.2 | 16.9 | 15.0 | 12.7 |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | 26.8 | 20.9 | 18.2 | 15.9 | 13.2 |
| 45 | | | | | |
| 46 | | | | | |
| 47 | | | | | |
| 48 | | | | | |
| 49 | | | | | |
| 50 | | | | | |
| 51 | | | | | |
| 52 | 29.9 | 22.9 | 19.7 | 17.0 | 13.8 |
| 53 | | | | | |
| 54 | | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | | | | | |
| 58 | | | | | |
| 59 | | | | | |
| 60 | | | | | |
| 61 | 32.4 | 24.6 | 20.9 | 17.9 | 14.2 |
| 62 | | | | | |
| 63 | | | | | |
| 64 | | | | | |
| 65 | | | | | |
| 66 | | | | | |
| 67 | | | | | |
| 68 | | | | | |
| 69 | | | | | |
| 70 | | | | | |

## Crossing Time with Fixed Number of Automobiles

| Number of Autos | 61 | 52 | 44 | 39 | 34 |
|---|---|---|---|---|---|
| Number of Bicycles | Crossing Time | Crossing Time | Crossing Time | Crossing Time | Crossing Time |
| 0 | | | | | |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | 14.2 | 13.8 | 13.2 | 12.7 | 12.1 |
| 9 | | | | | |
| 10 | | | | | |
| 11 | | | | | |
| 12 | | | | | |
| 13 | | | | | |
| 14 | | | | | |
| 15 | 17.9 | 17.0 | 15.9 | 15.0 | 13.8 |
| 16 | | | | | |
| 17 | | | | | |
| 18 | | | | | |
| 19 | | | | | |
| 20 | | | | | |
| 21 | | | | | |
| 22 | 20.9 | 19.7 | 18.2 | 16.9 | 15.3 |
| 23 | | | | | |
| 24 | | | | | |
| 25 | | | | | |
| 26 | | | | | |
| 27 | | | | | |
| 28 | 24.6 | 22.9 | 20.9 | 19.2 | 17.1 |
| 29 | | | | | |
| 30 | | | | | |
| 31 | | | | | |
| 32 | | | | | |
| 33 | | | | | |
| 34 | | | | | |
| 35 | | | | | |
| 36 | 32.4 | 29.9 | 26.8 | 24.2 | 20.9 |
| 37 | | | | | |
| 38 | | | | | |
| 39 | | | | | |
| 40 | | | | | |

# Appendix B

# Statistical Tests

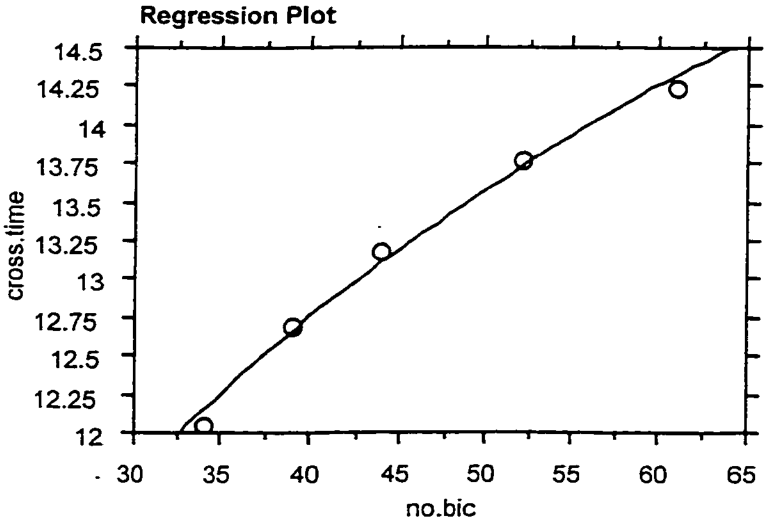
## Statistical analysis for increase number of bicycles with 4 left-turn and 4 straight-going automobiles

**Regression Summary**
**cross.time vs. no.bic**
**Y = b0 + b1 * ln(X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | .996 |
| R Squared | .993 |
| Adjusted R Squared | .990 |
| RMS Residual | .086 |

**Regression Coefficients**
**cross.time vs. no.bic**
**Y = b0 + b1 * ln(X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 | -.998 | .711 | -.998 | -1.403 | .2553 |
| b1 | 3.726 | .187 | .996 | 19.975 | .0003 |



Y = -.998 + 3.726 * ln(X)

## Statistical analysis for increase number of bicycles with 7 left-turn and 8 straight-going Automobiles

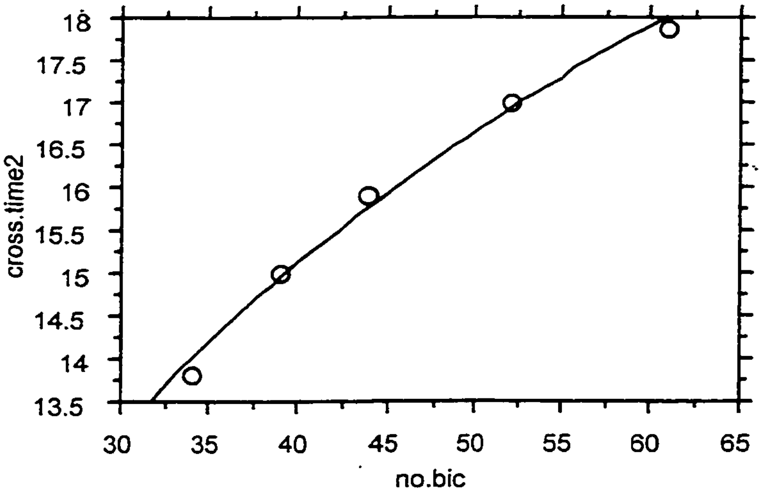
**Regression Summary**
**cross.time2 vs. no.bic**
$Y = b0 + b1 * \ln(X)$

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | .996 |
| R Squared | .993 |
| Adjusted R Squared | .990 |
| RMS Residual | .160 |

**Regression Coefficients**
**cross.time2 vs. no.bic**
$Y = b0 + b1 * \ln(X)$

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 | -10.411 | 1.319 | -10.411 | -7.891 | .0042 |
| b1 | 6.917 | .346 | .996 | 19.991 | .0003 |

**Regression Plot**



$Y = -10.411 + 6.917 * \ln(X)$

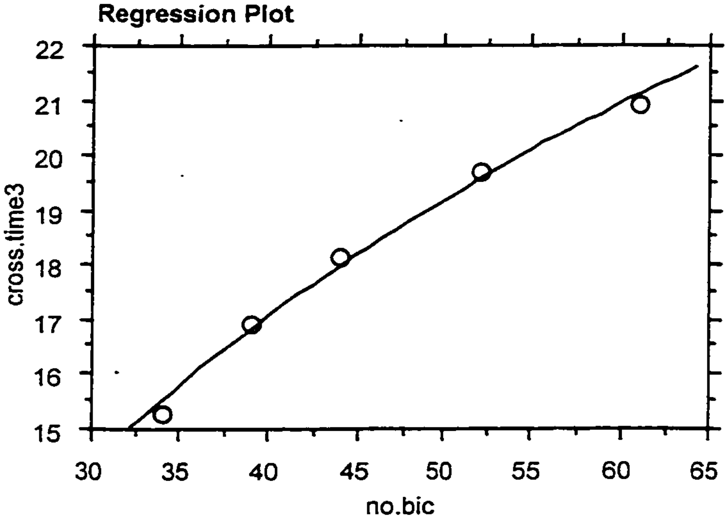
## Statistical analysis for increase number of bicycles with 12 left-turn and 11 straight-going automobiles

**Regression Summary**
**cross.time3 vs. no.bic**
**Y = b0 + b1 * ln(X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | .996 |
| R Squared | .993 |
| Adjusted R Squared | .990 |
| RMS Residual | .221 |

**Regression Coefficients**
**cross.time3 vs. no.bic**
**Y = b0 + b1 * ln(X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 | -18.267 | 1.822 | -18.267 | -10.024 | .0021 |
| b1 | 9.579 | .478 | .996 | 20.042 | .0003 |



Y = -18.267 + 9.579 * ln(X)

## Statistical analysis for increase number of bicycles with 17 left-turn and 11 straight-going automobiles

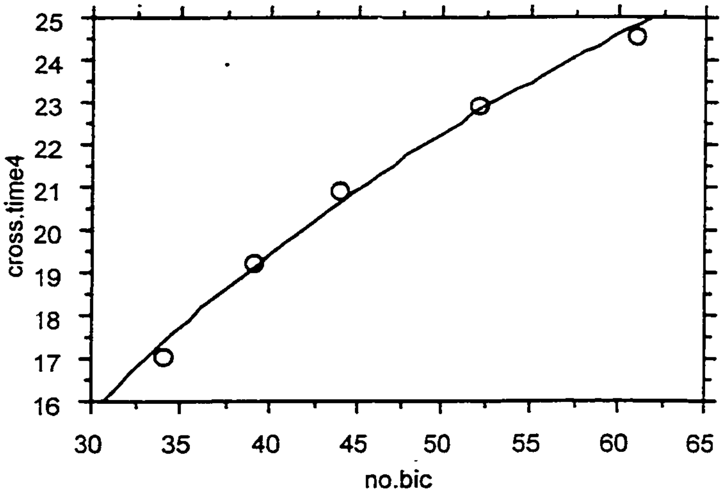
**Regression Summary**
**cross.time4 vs. no.bic**
**Y = b0 + b1 * ln(X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | .996 |
| R Squared | .993 |
| Adjusted R Squared | .990 |
| RMS Residual | .295 |

**Regression Coefficients**
**cross.time4 vs. no.bic**
**Y = b0 + b1 * ln(X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 | -27.691 | 2.436 | -27.691 | -11.369 | .0015 |
| b1 | 12.772 | .639 | .996 | 19.993 | .0003 |

**Regression Plot**



Y = -27.691 + 12.772 * ln(X)

## Statistical analysis for increase number of bicycles with 25 left-turn and 11 straight-going automobiles

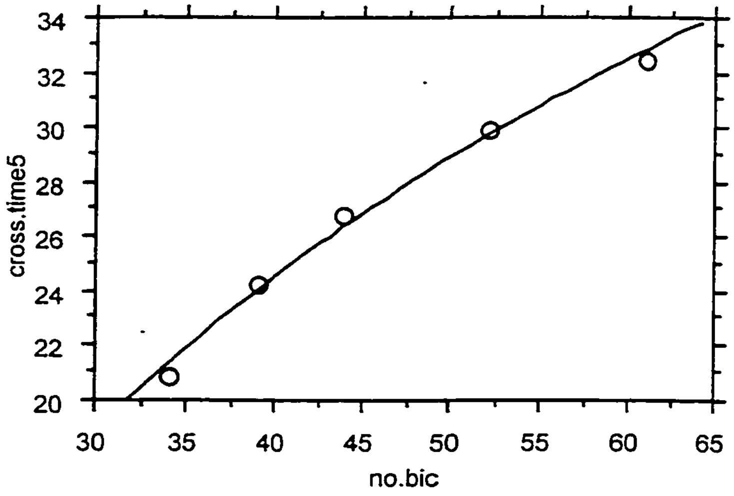
**Regression Summary**
**cross.time5 vs. no.bic**
**Y = b0 + b1 * ln(X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | .996 |
| R Squared | .993 |
| Adjusted R Squared | .990 |
| RMS Residual | .454 |

**Regression Coefficients**
**cross.time5 vs. no.bic**
**Y = b0 + b1 * ln(X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 | -48.102 | 3.752 | -48.102 | -12.819 | .0010 |
| b1 | 19.689 | .984 | .996 | 20.006 | .0003 |

**Regression Plot**



Y = -48.102 + 19.689 * ln(X)

## Statistical analysis for increasing number of automobiles with 61 bicycles

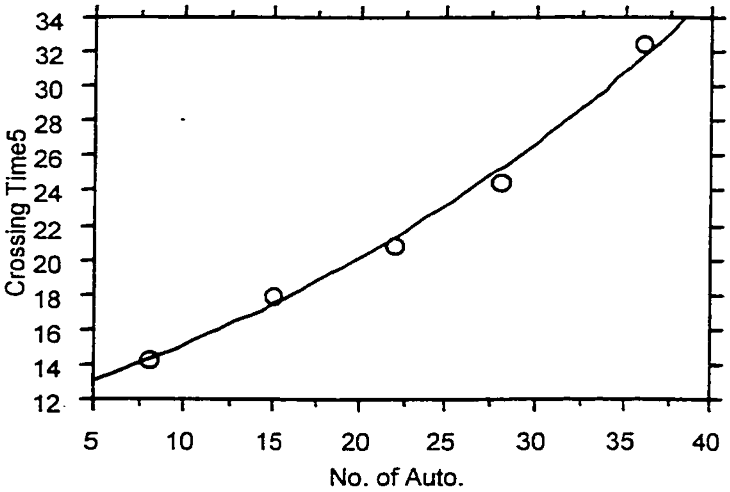
**Regression Summary**
**Crossing Time5 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | |
| R Squared | |
| Adjusted R Squared | |
| RMS Residual | |

**Regression Coefficients**
**Crossing Time5 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 (from ln(b0)) | 11.368 | | | | |
| ln(b0) | 2.431 | .030 | 2.431 | 81.213 | <.0001 |
| b1 | .029 | .001 | .997 | 22.753 | .0002 |

**Regression Plot**



Y = 11.368 * e^(.029 * X)

**Statistical analysis for increasing number of automobiles with 52 bicycles**

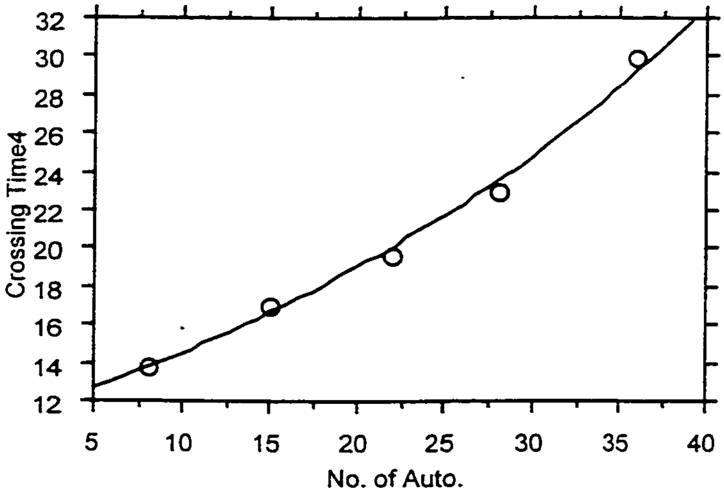
**Regression Summary**
**Crossing Time4 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | |
| R Squared | |
| Adjusted R Squared | |
| RMS Residual | |

**Regression Coefficients**
**Crossing Time4 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 (from ln(b0)) | 11.102 | | | | |
| ln(b0) | 2.407 | .030 | 2.407 | 81.475 | <.0001 |
| b1 | .027 | .001 | .997 | 21.740 | .0002 |

**Regression Plot**



Y = 11.102 * e^(.027 * X)

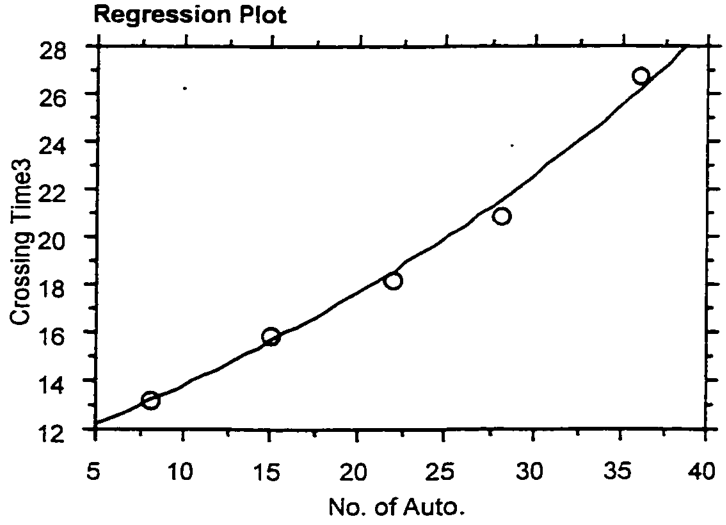
## Statistical analysis for increasing number of automobiles with 44 bicycles

**Regression Summary**
**Crossing Time3 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | |
| R Squared | |
| Adjusted R Squared | |
| RMS Residual | |

**Regression Coefficients**
**Crossing Time3 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 (from ln(b0)) | 10.790 | | | | |
| ln(b0) | 2.379 | .029 | 2.379 | 81.760 | <.0001 |
| b1 | .025 | .001 | .996 | 20.205 | .0003 |



Y = 10.79 * e^(.025 * X)

## Statistical analysis for increasing number of automobiles with 39 bicycles

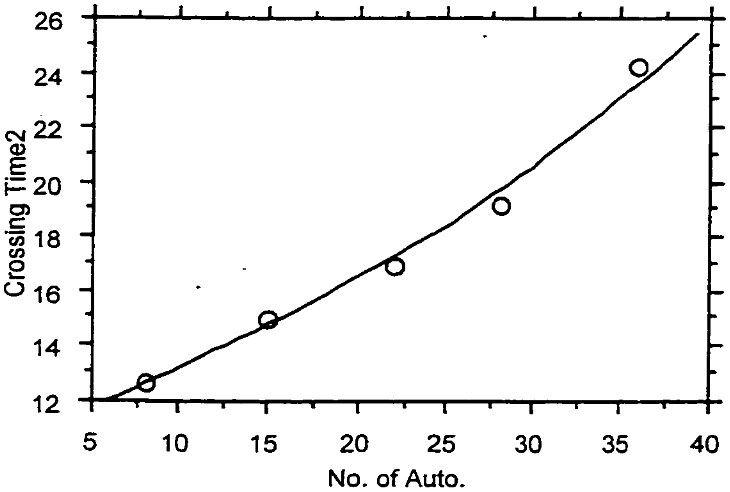
**Regression Summary**
**Crossing Time2 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | |
| R Squared | |
| Adjusted R Squared | |
| RMS Residual | |

**Regression Coefficients**
**Crossing Time2 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 (from ln(b0)) | 10.549 | | | | |
| ln(b0) | 2.356 | .029 | 2.356 | 82.345 | <.0001 |
| b1 | .022 | .001 | .996 | 18.700 | .0003 |

**Regression Plot**



Y = 10.549 * e^(.022 * X)

## Statistical analysis for increasing number of automobiles with 34 bicycles

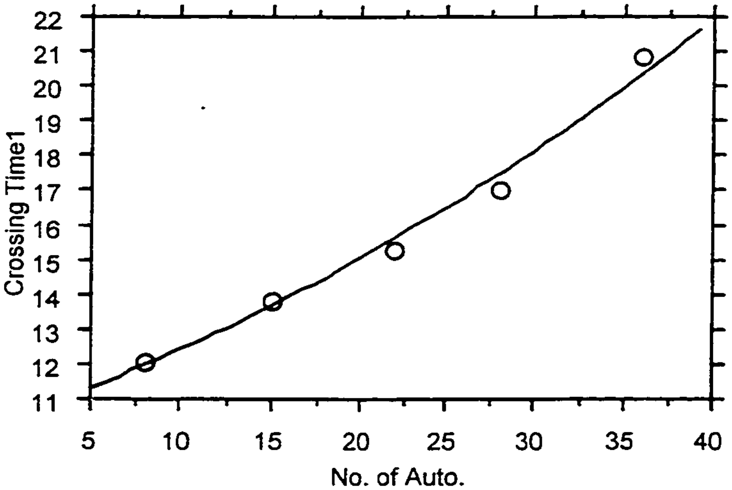
**Regression Summary**
**Crossing Time1 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | |
|---|---|
| Count | 5 |
| Num. Missing | 0 |
| R | |
| R Squared | |
| Adjusted R Squared | |
| RMS Residual | |

**Regression Coefficients**
**Crossing Time1 vs. No. of Auto.**
**Y = b0 * e^(b1*X)**

| | Coefficient | Std. Error | Std. Coeff. | t-Value | P-Value |
|---|---|---|---|---|---|
| b0 (from ln(b0)) | 10.270 | | | | |
| ln(b0) | 2.329 | .028 | 2.329 | 84.560 | <.0001 |
| b1 | .019 | .001 | .995 | 16.484 | .0005 |

**Regression Plot**



Y = 10.27 * e^(.019 * X)

# Appendix C
# Questionnaire

QUESTIONNAIRE for Shanghai study (translated from Chinese)

Interviewee Personal Information

No.: _____

Sex: _____

Age: _____

Date: _____

Time: _____

Temperature: _____

Weather: _____

Bicycle flow: _____ No./Min./M

1. Estimate the number of times/week you use bicycle to:

A. Go to work (or school) _____

B. shopping _____

C. Doing exercise _____

D. Other (please specify) _____

2. Are there roads you avoid because of the surface condition? If yes, Give the name of the road.

___________________________

3. In a day like today, do you think the shadow is important to bicycle riders?

A . Yes _____ B. No _____

4. Please give two examples of acceptable and unacceptable slopes.

_______________________________________________

5. which of the following routes would you prefer to take?

A. 1 KM acceptable slope. _____ B 2 KM flat Road _____

6. What would change you from bicycle to bus or metro?

| | |
|---|---|
| 1.Less crowed bus | |
| 2.Cheaper ticket.(half price) | |
| 3.Faster bus (as fast as bicycle) | |
| 4.Faster bus (faster than bicycle) | |
| 5.More direct route | |
| 6.Carrying things | |
| 7.Not Carrying thing | |
| 8.Worse weather condition | |

Or you will not change at all. _____

8. Could you please evaluate the bicycle route to this point?

A. Much too narrow _ B. Too narrow C. A bit narrow D. Perfect

9. If an alternate wider path were provided on ________ road, would you take it instead?

10. What other trips do you make regularly?

______________________________________________

11. If an alternate shaded path were provided on ________ road, would you take it instead

12. It takes you _______ minutes to reach your destination by bicycle. It would take you _______ minutes to reach your destination by bus.

# Sample of the Questionnaire

## 上海市自行车使用情况调查问卷

受访情况

| | | | |
|---|---|---|---|
| 序号: 97 | 性别: a | 年龄: 20 | 日期: 0.22 |
| 时间: 5:10PM | 温度: 27 | 天气: 阴[illegible] | ~~自行车流量:~~ |
| 交通方式: [illegible] | 出发地: [illegible] | 目的地: 上海图书馆 | 调查地(上海) |

备注:
45分钟

1. 请估计您每周将自行车用于下列用途的次数:

| | | | |
|---|---|---|---|
| A. 上班(或上学) | 10 | B. 购物 | 2 |
| C. 锻炼 | 0 | D. 其他(请指明) | 不常骑 |

2. 您是否会因为路面情况不佳而特意回避这条路? 如果有, 请指出路名.

3. 在今天的天气情况下, 对于骑车人而言, 树荫是否很重要?
[✓ A. 是]　B. 否

4. 什么样的坡是可以骑的, 请举个例子(路名). 什么样的坡是不能骑的, 请举个例子(指明路名).

5. 您愿意选择以下那一种路线.
[✓ A. 1公里骑得上去的坡]　B. 2公里平路

6. 在什么状况下您愿意坐公共汽车或地铁而不是骑自行车.

| | |
|---|---|
| 1. 公共汽车不拥挤 | ✓ |
| 2. 票价便宜一些(现在的一半) | |
| 3. 公共汽车车速更快(与自行车车速相同) | |
| 4. 公共汽车车速更快(超过自行车车速) | ✓ |
| 5. 路线更直接 | |
| 6. 携带着东西 | |
| 7. 未携带东西 | ✓ |
| 8. 天气太坏 | ✓ |
| 9. 住处或目的地离地铁或公共汽车站更近 | |
| 10 路途较长 | ✓ |
| 11 从不改变 | |

7. 您认为此处的道路情况如何?
A. 极窄　B. 很窄　C. 较窄　[✓ D. 正合适]

8. 如果在________路的自行车道被拓宽, 您是否会转而选择这条路线?
[✓ A. 是]　B. 否

9. 您还经常走另外那些路? ______________________

10. 如果在________路的自行车道有树荫, 您会选择这条路线么?
A. 是　B. 否

11. 到您的目的地骑车要 50 分钟, 坐公共汽车要 60 分钟.