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Research on bicycle conversion factors

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ABSTRACT

In developing countries, bicyclists have heavy occupation in all travelers. The safety and efficiency are reduced because of the motor vehicle–bicycle conflict under mixed traffic condition that motor vehicles and bicycles use the same road simultaneously. In order to solve the problem, it is necessary to separate motor vehicles from bicycles and to distribute the road resource reasonably between motor vehicles and bicycles. In order to conduct the above work, it is necessary to work on the bicycle conversion factors. The factors are researched under various traffic conditions in the paper. According to traffic characteristics of motor vehicles and bicycles, the conversion factor models are set up for bicycle relevant to pcu (passenger car unit). The bicycle conversion factors are calculated under four situations based on the field data collected in Shenyang, Tianjin and Shijiazhuang in China. The through bicycle conversion factor is 0.28 and the left-turn 0.33 at mixed intersections. The bicycle conversion factor in road section is 0.22 with physical separations and 0.24 without physical separations.

1. Introduction

China is a developing country with large population over 1.3 billion by the end of 2005. National economy and per capita GDP are still lower than the developed countries. Motor vehicles are costly merchandise for common people; therefore, many people select bicycle as travel tools. This tendency may last for a long time. Among all travel modes, cycling is still one of the more sustainable modes than motor vehicle travel (Krizek, 2004; US Department Transportation, 2000). Even in the developed countries, bicycle travel is recognized as low energy consumption, healthy to the users and do not damage the health of others. Furthermore, encouraging bicycle traffic can reduce the use of motor vehicles. It is relatively fast over short distances, and provides a reliable and affordable form of transport for most sectors of the population (Gatersleben and Appleton, 2007). At present, cycling still has heavy proportion among all travel modes in China, and in Tianjin, as large as over 60% (Quan and Liu, 2002).

It is incontestable that economy has been developing in the past 30 years in China. Especially in the last decade, motor vehicle amount rose rapidly. Thus urban road facilities cannot meet the traffic demand, so the roads become seriously congested. Meanwhile, because of the huge number of bicycles in existence, the motor vehicle–bicycle conflict becomes severe in mixed traffic (Gu, 1998). In order to make good use of the road resource for bicycles and motor vehicles, the latter should be converted into pcu, so that the road capacity can be easily analyzed. In this paper, the conversion of 1 bicycle into 1 pcu is the focus for discussion.

On the mixed traffic, scholars have done much research work. Wang and Nihan (2004) studied the characteristics of motor vehicle–bicycle conflict at signal intersection. Taylor (1998) gave a review of the bicycle traffic science, traffic operations, and facility design. Allen et al. (1998) found the relationship between bicycle flow and the percent of the green phase

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between bicycles and right-turn motor vehicles. The result showed that motor vehicle saturation flow decreased with increasing of bicycle flow. Wardman et al. (2007) described the development of a mode choice model for the journey to work with special emphasis on the propensity to cycle. Rose and Marfurt (2007) found that over 80% of first-timers indicated that 'Ride to Work Day' event had a positive impact on their readiness to ride to work. Forester (1994) found that the bicycle traffic can not decrease road capacity, but increases the capacity to some degree resulting from adequate usage of road. The conversion factors are basic parameters in estimating road capacity.

On bicycle traffic, lots of researches have been completed home and abroad. Smith and Walsh (1988) studied the relationship between bicycle lane-width and safety. Taylor and Davis (1999) summarized the international research results on bicycle traffic. Smith (1976) and Navin (1994) researched on saturation flow rate, relationship of velocity and density for three types of bicycle lane width. Sharples (1993) developed a set of bicycle simulation software. Tilahun et al. (2007) found that people were willing to travel up to twenty minutes more to switch from an unmarked on road facility with side parking to an off-road bicycle trail, with smaller changes associated with less dramatic improvements. Fukuda and Morichi (2007) analyzed illegal bicycle parking behavior. In recent years, some experiences of promoting bike-and-ride have been summarized in Holland, such as securing bicycle parking at train stations (Martens, 2007).

On bicycle conversion factors, some researches have been done but not detailed enough to apply in engineering. In the third edition of highway capacity manual (HCM), the bicycle conversion factors were published simply depending on one-way or two-way traffic under different lane widths without a detailed description of situations (TRB, 1994). The factors were not mentioned even in the 4th edition (TRB, 2000). In addition, due to traffic pattern variation, the factors provided by HCM cannot be directly used in developing countries with heavy bicycle transport. By far, the value of 0.2 has been regarded as the bicycle conversion factor in most countries (such as Britain and China) (Chinese Road Institute Traffic Engineering Manual Edit Board, 1998). The value was calculated under the condition that the motor vehicles and the bicycles use their respective roads. Our research results show that the bicycle conversion factors vary with a variety of road and traffic conditions. There is a large gap between the statistical result and the real value of traffic flow if the value of 0.2 is used under some conditions, so the traffic management and control impact will be affected. Different road and traffic conditions should be considered to get more precise bicycle conversion factors.

In order to accurately estimate mixed traffic and reasonably distribute road resource between motor vehicles and bicycles, then effectively manage and control traffic flow, it is necessary to precisely calculate bicycle conversion factors relative to pcu (passenger car unit).

The bicycle conversion factors have various meanings in different research aspects. In this paper the bicycle conversion factor is defined in research of road capacity. Namely, it is a number that 1 bicycle can be converted into 1 pcu. The main idea to calculate bicycle conversion factor is to determine the spatio-temporal quantity ratio of 1 bicycle to 1 pcu. These two spatio-temporal quantity values are measured under the saturation state of the mixed traffic. The saturation is a steady state, and the spatio-temporal resource occupied by each motor vehicle and each bicycle is steady. It is vital to choose the suitable investigation time when the flow is saturated. We can get the duration of saturation flow from accumulated arriving curve with maximum of differential coefficient.

In the paper, there are four parts researched: they are through and left-turn bicycle conversion factors at intersections, the bicycle conversion factors in road section with physical separation and without physical separation. Because conflicts between right-turn bicycles and motor vehicles have little effect on the traffic flow at intersections with signals, the right-turn bicycle conversion factor is not mentioned in the paper.

2. Through bicycle conversion factor at intersections

2.1. Conversion factor model

Through motor vehicles share the same road resource with through bicycles at intersections without physical separation. There are conflicts at interface between two traffic flows (Tiwari et al., 1998; Jing and Wang, 2004). Fig. 1 illustrates the conflicts between two traffic flows at mixed traffic intersections. The area within the dashed circle shows the conflict zone for the through bicycles and the through motor vehicles. Considering the interaction between bicycles and motor vehicles in the adjacent lane, the bicycle conversion factor is calculated.

At two-phase signal intersections, through motor vehicles and through bicycles pass the intersection together. General saturated flow of through bicycles and through motor vehicles should be a constant after being converted into pcu at whole approach within given time. The constant can be defined as b_1 (pcu/h) with the through bicycle conversion factor converted to pcu as follows:

$$y + m_1 x = b_1 \tag{1}$$

where x is the bicycle flow rate (bicycles/h), y is the motor vehicle flow rate (pcu/h), and m_1 is the through bicycle conversion factor. The value of m_1 is determined from field data discussed later.

2.2. Traffic survey

To determine the bicycle conversion factor, data were collected at typical intersections.

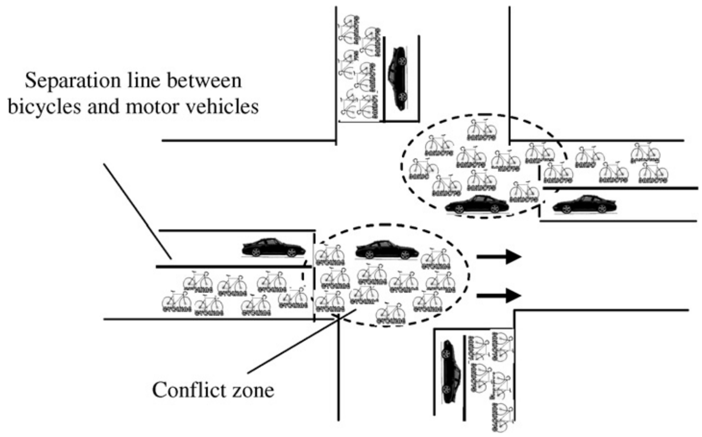

Fig. 1. The conflict between through bicycles and through motor vehicles.

2.2.1. Site selection

The principles used to select sites for the data include:

(a) Mixed traffic intersections with heavy bicycle traffic.
(b) Saturated mixed traffic flow during the observation periods.

Above situations are ideal preconditions for the bicycle conversion factors with motor vehicle–bicycle conflicts. The conversion factors from different locations have wider application. We choose typical intersections in Tianjin and Shenyang, which meet the criteria better than other potential sites.

2.2.2. Data collection

Data were collected in Tianjin and Shenyang from January to April 2003, with dry bicycle lane conditions and mostly sunny and sometimes cloudy weather conditions.

Table 1
Main characteristics of data collection sites

Items	Sites		
	Tianjin	Shenyang	
Intersection names	Dazhigu Road and Liuwei Road	Danan Street and Nanshun Road	Xiaonan and Nanguan Road
Bicycle lane description	Two-way, shared	Two-way, shared	Two-way, shared
Bicycle lane-width (m)	3.2	2.4	4.3
Surveyed motor vehicle lane-width (m)	3.2	3	3.1
Number of motor vehicle lanes	2	2	2
Signal phases	2	2	2

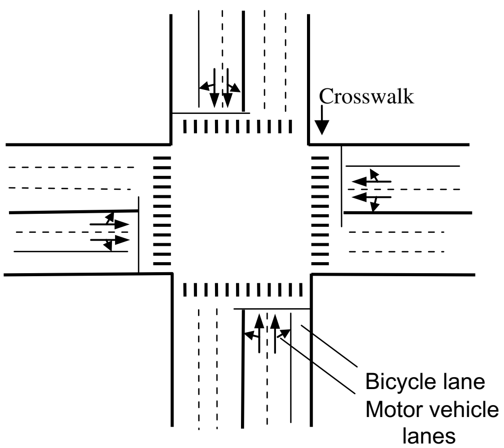

Fig. 2. Data collection site sketch.

Video cameras were used to record the motor vehicles arrival and the conflicts at each site. All data were recorded during normal traffic flow conditions without accidents. Table 1 lists the main characteristics of the sites. Fig. 2 illustrates a typical site sketch used for data collection.

2.3. Bicycle conversion factor calibration

The through bicycle conversion factor is determined using data for two-phase intersections in Tianjin and Shenyang. The saturation flow rate of through motor vehicles and through bicycles were recorded and analyzed by Microsoft Excel.

The morning peaks at the intersections of Danan Street and Nanshuncheng Road in April 17th, 2003 were taken as example. The recorded data are shown in Table 2. Fig. 3 is the scatter plot of morning peaks in April 17th in 2003 at the intersections of Danan Street and Nanshuncheng Road. The linear relationships for the data sets from other sites are quite similar which indicates that there is little regional influence on the result.

Therefore, Eq. (1) can be calibrated by linear regression analysis on the data, then b and m_1 are obtained. The through bicycle conversion factors for each site are listed in Table 3. The r is the correlation coefficient.

Table 2
Data summary of the flow rate of bicycles and motor vehicles

Start time		End time		Time gap (s)	PCU amount	Bicycle amount	Flow rate of motor vehicles (pcu/h)	Flow rate of bicycles (bicycles/h)
m	s	m	s					
1	33	1	40	7	5.0	13	2571	6686
5	14	5	22	8	6.0	17	2700	7650
...	...	...	...	...	...	...	...	...
48	22	48	31	9	5.4	20	2160	8000
55	34	55	45	11	7.9	25	2585	8182

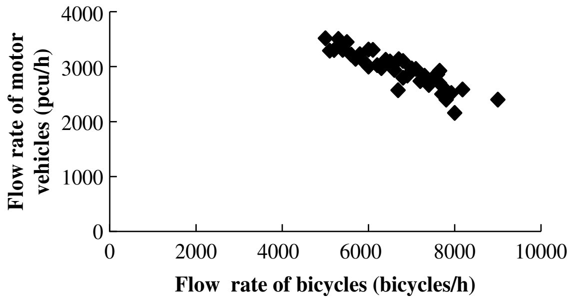

Fig. 3. Scatter plot of intersection.

Table 3
Linear regression results of the data at intersections

Intersections	Regression results	Correlation coefficients
Danan Street and Nanshuncheng Road 1	$y = -0.275x + 4662$	$r = 0.9289$
Danan Street and Nanshuncheng Road 2	$y = -0.278x + 4702$	$r = 0.7891$
Xiaonan Street and Nanguan Road	$y = -0.279x + 2769$	$r = 0.9273$
Dazhigu Road and Liuwei Road	$y = -0.273x + 4906$	$r = 0.9458$

Table 4
The results of through bicycle conversion factors and relative errors at intersections

Intersections	Results	The relative errors to traditional factor 0.2 (%)	Recommendatory value	Relative errors to recommendatory value (%)
Danan Street and Nanshuncheng Road 1	0.275	37.5	0.28	1.8
Danan Street and Nanshuncheng Road 2	0.278	39.0	0.28	0.7
Xiaonan Street and Nanguan Road	0.279	39.5	0.28	0.4
Dazhigu Road and Liuwei Road	0.273	36.5	0.28	2.5

The corresponding conversion factor is 0.275 after linear regression for Fig. 3. The results of bicycle conversion factors and the correlation coefficients of other intersections basing on the same arithmetic, shown in Table 3.

It is commended that through bicycle conversion factor is 0.28 at intersections which motor vehicles and bicycles are not separated based on the regression results. The relative errors are shown in Table 4.

3. Left-turn bicycle conversion factor at intersections

3.1. Conversion factor model

Through motor vehicles have priority over the left-turn bicycles at intersections, so the left-turn bicycles have to wait for an acceptable gap in the traffic flow. Fig. 4 depicts the conflicts between left-turn bicycles and through motor vehicles at two-phase mixed traffic intersections.

The field data show that the left-turn bicycles slow the flow of through motor vehicles through the intersection, but do not affect the headway between successive motor vehicles. Thus, the left-turn bicycle conversion factor can be calibrated as follows:

(a) Calculate the amount of time that the through motor vehicles are delayed by each left-turn bicycle.
(b) Calculate the average headway of successive through motor vehicles to cross the intersection if there is no left-turn bicycle.

The left-turn bicycle conversion factor can be expressed as the following equation:

$$m_2 = D/H \tag{2}$$

where m_2 is the left-turn bicycle conversion factor, D is the average delay of the through motor vehicle caused by each left-turn bicycle (s), and H is the average headway for successive motor vehicles (s).

Data from field observations show that the amount of delay for the through motor vehicles due to the left-turn bicycles varies with the sum of left-turn bicycles. Therefore, the D can be calculated as the following steps:

(a) Calculate the delays of the through motor vehicles for various numbers of left-turn bicycles and the probabilities for these various numbers of left-turn bicycles.
(b) Calculate the average delay, which is the expected delay of the through motor vehicles divided by the expected sum of arriving left-turn bicycles, as Eq. (3).

$$D = \frac{\sum_{i=1}^{\infty}(d_i \times p_i)}{\sum_{i=1}^{\infty}(i \times p_i)} \tag{3}$$

where d_i is the average delay of the through motor vehicles arising from i left-turn bicycles arriving per cycle ($i = 1,2,\ldots$) (s), p_i is the probability of i left-turn bicycles arrive the approach per cycle, and i is the sum of left-turn bicycles arriving per cycle (Wang, 2002).

The d_i can be calculated from observed delays of through motor vehicles and the sum of left-turn bicycles, as showed in Table 5. The p_i can be obtained from probability theory and traffic flow theory. When the variance is larger than the mean sum of arriving left-turn bicycles, p_i exhibits a negative binomial distribution; otherwise, p_i exhibits a binomial distribution. When the variance is equal to the mean, p_i exhibits a Poisson distribution.

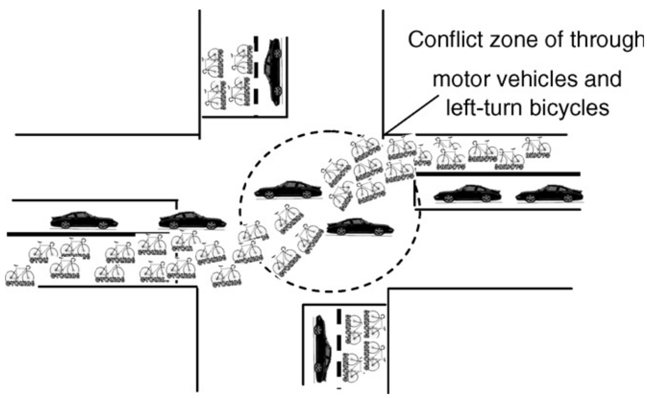

Fig. 4. The conflict at intersection.

Table 5
Statistics of the sum of left-turn bicycles arriving and the total delay of the through motor vehicles

The sum of left-turn bicycles	6	7	...	18	20	21
The total delay of the through motor vehicles (s)	5.6935	3.2581	...	9.7581	10.7581	18.3226

3.2. Traffic survey

3.2.1. Site selection

The site selection principle is the same as the principle for through bicycle at intersections, but the intersections should be with two-phase timing plan.

3.2.2. Data collection

Video cameras were used to record the motor vehicles arrival, the average delay of the through motor vehicle caused by each left-turn bicycle and the average headway for successive motor vehicles.

3.3. Bicycle conversion factor calibration

We take intersection of Dazhigu Road and Liuwei Road as an example to calibrate the bicycle conversion factor.

The average motor vehicle headway is 1.851 s when successive motor vehicles cross the intersections where the data were collected. The sum of left-turn bicycles arriving per cycle and the total delay of the through motor vehicles arising from arriving left-turn bicycles per cycle are shown in Table 5.

From the data in Table 5, the relation is ascertained between the sum of left-turn bicycles and the total delay of the through motor vehicles for Dazhigu Road and Liuwei Road intersection, see Fig. 5.

The sum of the left-turn bicycles per cycle is counted to get the following results: deviation s^2 is 36.073, mean value m is 13.455, deviation is larger than mean value obviously, the sum of the left-turn bicycles per cycle exhibits a negative binomial distribution based on traffic theory

$$p(i) = c_{i+\beta-1}^{\beta-1} p^{\beta} (1-p)^{i} \tag{4}$$

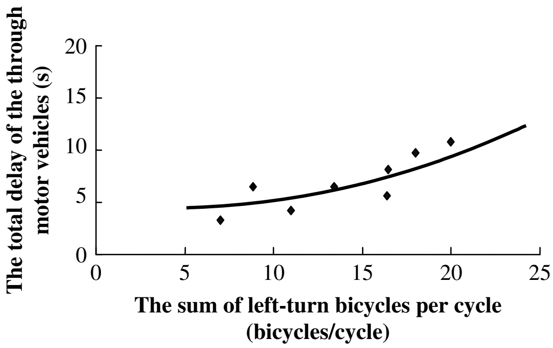

Fig. 5. The relation between the sum of left-turn bicycles and the total delay of the through motor vehicles.

Table 6
The sum of left-turn bicycles and the total delay of through motor vehicles per cycle

i	p_i	d_i	$d_i \times p_i$	$i \times p_i$
1	0.0019	13.5021	0.0254	0.0019
2	0.0053	11.3610	0.0602	0.0106
3	0.0111	9.4587	0.1048	0.0332
4	0.0191	7.7952	0.1489	0.0764
5	0.0287	6.3705	0.1831	0.1437
...	...	...	...	...
60	0.0000	295.7640	0.0001	0.0000
61	0.0000	307.7121	0.0000	0.0000
62	0.0000	319.8990	0.0000	0.0000
63	0.0000	332.3247	0.0000	0.0000
64	0.0000	344.9892	0.0000	0.0000
65	0.0000	357.8925	0.0000	0.0000
...	...	...	...	...

Table 7
Left-turn bicycle conversion factors at intersections

Sites	Intersection names	D	H	Conversion factors
Tianjin	Dazhigu Road and Liuwei Road	0.607	1.851	0.328
Shenyang	Danan Street and Nanshuncheng Road 1	0.558	1.657	0.337
	Danan Street and Nanshuncheng Road 2	0.548	1.657	0.331

Table 8
Results of bicycle conversion factor and relative errors at intersections

Intersection names	Results	The relative errors to traditional factor 0.2 (%)	Recommendatory value	Relative errors to Recommendatory value (%)
Dazhigu Road and Liuwei Road	0.328	64.0	0.33	0.6
Danan Street and Nanshuncheng Road 1	0.337	68.5	0.33	2.1
Danan Street and Nanshuncheng Road 2	0.330	65.0	0.33	0

where i is the sum of the left-turn bicycles per cycle. Thus $p = \frac{m}{s^2} = 0.37298$ and $\beta = \frac{m^2}{s^2 - m} = 8$.

So the following equation is got:

$$p(i) = c_{i+7}^{7} p^8 (1-p)^i$$

Table 6 is the calculation table about the sum of the left-turn bicycles per cycle and the total delay of the through motor vehicles.

From the data in Table 6, the result is

$$\sum_{i=1}^{\infty}(d_i \times p_i) = 8.16473$$

$$\sum_{i=1}^{\infty}(i \times p_i) = 13.44887$$

$$D = \frac{\sum_{i=1}^{\infty}(d_i \times p_i)}{\sum_{i=1}^{\infty}(i \times p_i)} \approx \frac{8.16473}{13.44887} = 0.6071$$

So the left-turn bicycle conversion factor is 0.328 from Eq. (2).

The bicycle conversion factor and the correlation coefficient of other intersections are obtained based on the same arithmetic. All the results are showed in Table 7.

It is commended that 0.33 is left-turn bicycle conversion factor at intersection based on the results. The relative errors are listed in Table 8.

4. Bicycle conversion factor without physical separation

4.1. Conversion factor model

On the roads where motor vehicles and bicycles are not separated, when bicycles are more crowded than motor vehicles, bicycles will occupy motor vehicles lanes. Contrarily, motor vehicles will occupy bicycle lanes. Motor vehicle–bicycle conflicts on road which motor vehicles and bicycles are not separated are shown in Fig. 6. The sum of the flow rate of motor vehicles and bicycles on road section should be constant if no motor vehicles arrive from other directions, namely, the

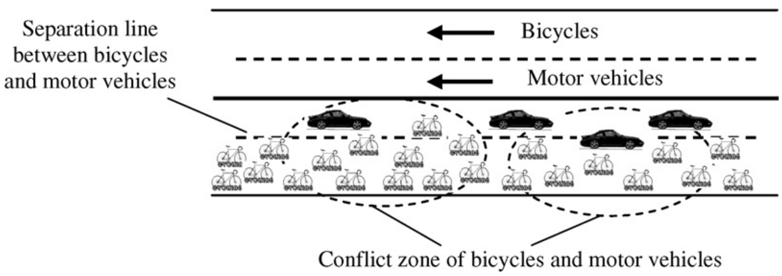

Fig. 6. Conflicts of bicycles and vehicles.

reduced amount for one traffic flow is equivalent to the increased amount for another. So the conversion factor of road section without physical separation can be calibrated bicycle.

The constant can be defined as b_2 (pcu/h) with the through bicycle conversion factor converted to pcu as follows:

$$y + m_3 x = b_2 \tag{5}$$

where x is bicycle flow rate (bicycles/h), y is motor vehicle flow rate (pcu/h), and m_3 is the through bicycle conversion factor.

4.2. Traffic survey

4.2.1. Site selection

We should obey the following principles on selecting survey sites:

(a) The distance from upstream intersection to the survey site should be 50–200 m.
(b) Mixed traffic flow is saturated during the observation periods.
(c) The road section is flat and straight.

4.2.2. Data collection

Video cameras were used to record motor vehicle arrival. Qingyuan Street and Yucai Street in Shijiazhuang were selected as observation sites to obtain necessary data. The main characteristics of the sites are listed in Table 9.

4.3. Bicycle conversion factor calibration

Qingyuan Street Morning Peak in July 14th in 2005 is taken as an example to calibrate the bicycle conversion factor. Survey data of the flow rate of bicycle and motor vehicle are listed in Table 10.

Based on Table 10, the scatter plot of bicycle and motor vehicle flow rate is illustrated in Fig. 7.

Table 9
Main characteristics of data collection sites

Road section names	Qingyuan Street 1	Qingyuan Street 2	Yucai Street
Signal phases of upstream intersections	2	2	2
Recording time	14th July, 7:00–8:30	14th July, 17:30–19:00	15th July, 7:00–8:30
Bicycle lane-width (m)	2.8	2.8	1.8
Motor vehicle lane-width (m)	2.7	2.7	3.2

Table 10
Data summary

Start time		End time		Time gap (s)	PCU amount	Bicycle amount	Flow rate of motor vehicles (pcu/h)	Flow rate of bicycles (bicycles/h)
m	s	m	s					
3	37	3	59	22	10	25	1636	4091
6	16	6	31	15	5	24	1200	5760
...	...	...	...	...	...	...	...	...
79	17	79	33	16	6	24	1350	5400
89	57	90	20	23	9	32	1409	5009

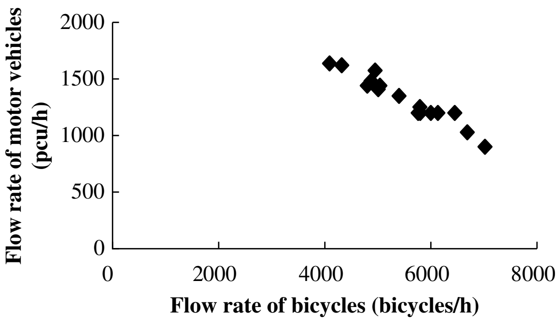

Fig. 7. Scatter plot on road section.

Table 11
Linear regression results on the scatter plot

Road sections	Regression results	Correlation coefficients
Qingyuan Street 1	$y = -0.242x + 2653$	$r = 0.9383$
Qingyuan Street 2	$y = -0.237x + 2687$	$r = 0.8637$
Yucai Street	$y = -0.245x + 2663$	$r = 0.8843$

Table 12
Results of bicycle conversion factors and relative errors without physical separation

Road sections	Results	The relative errors to traditional factor 0.2 (%)	Recommendatory value	Relative errors to recommendatory value (%)
Qingyuan Street 1	0.242	21.0	0.24	0.8
Qingyuan Street 2	0.237	18.5	0.24	1.3
Yucai Street	0.245	22.5	0.24	2.1

From Fig. 7, a linear regression equation is $y = -0.242x + 2653$, and the bicycle conversion factor is 0.242 from the linear regression equation. The correlation coefficient r is 0.9383. The bicycle conversion factor and the correlation coefficient, based on the same arithmetic on other road sections, are listed in Table 11.

It is commended 0.24 as bicycle conversion factor on road section without physical separation based on the regression results. The results of bicycle conversion factors and relative errors are listed in Table 12.

5. Bicycle conversion factor with physical separation

5.1. Conversion factor model

On the road where motor vehicles and bicycles are separated, motor vehicles and bicycles travel on their own lanes. According to the principle of capacity, when the flow rate of motor vehicles and bicycles is saturated, the bicycle conversion factor is a ratio of the saturation flow rate of motor vehicle to that of bicycle on the same road width. The conversion factor model is as follows:

$$m_4 = \frac{S_2/W_c}{S_1/W_{be}} = \frac{S_2 \times W_{be}}{S_1 \times W_c} \tag{6}$$

where m_4 is bicycle conversion factor relative to pcu; S_1 is the saturation flow rate of bicycles at the bicycle lane (bicycle/s); S_2 is the saturation flow rate of motor vehicles at a motor vehicle lane (pcu/s); W_c is lane-width of motor vehicle (m); and W_{be} is effective lane-width of bicycle (m).

Both sides of bicycle lane should be set aside definite distance for safety depending on physical separation facility, so effective lane-width of bicycle is the value of actual lane-width minus the distance on lane both sides, see the following equation:

$$W_{be} = W_b - L \tag{7}$$

where W_b is actual bicycle lane-width (m) and L is safety distance on bicycle lane both sides (m).

5.2. Traffic survey

5.2.1. Site selection

The following principles should be obeyed when selecting survey sites:

(a) The distance from upstream intersection to the survey site should be 50–200 m.
(b) Motor vehicle traffic flow and bicycle traffic flow are saturated during the observation periods.
(c) The road section is flat and straight.

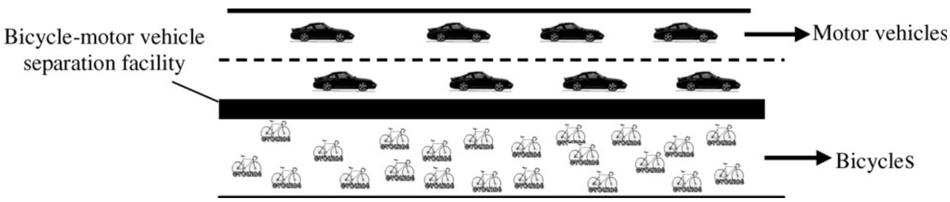

Fig. 8. The situation of survey road section.

Table 13
Calibration of bicycle conversion factor with physical separation

Road sections	W_b (m)	W_{be} (m)	S_1 (bicycle/h)	W_c (m)	S_2 (pcu/h)	Result
Zhonghuabei Street	6.1	5.6	13102	3.7	1903	0.220
Yuhualu Road 1	5.0	4.5	10605	3.3	1697	0.218
Yuhualu Road 2	7.0	6.5	15301	3.4	1817	0.227

Table 14
Results of bicycle conversion factor and relative errors with physical separation

Road sections	Results	The relative errors to traditional factor 0.2 (%)	Recommendatory value	Relative errors to recommendatory value (%)
Zhonghuabei Street	0.220	10.0	0.22	0.0
Yuhua Road 1	0.218	9.0	0.22	0.9
Yuhua Road 2	0.227	13.5	0.22	3.2

The surveyed road section with separation facility is just like Fig. 8.

5.2.2. Data collection

Video cameras were used to observe the saturation flow rate of bicycles and that of motor vehicles separately in workdays in Zhonghuabei Street and Yuhua Road in Shijizhuang. Three sets of data were obtained.

5.3. Bicycle conversion factor calibration

The data of Zhonghuabei Street in Shijiazhuang were taken as example to illustrate the calibration process. The actual bicycle lane-width is 6.1 m. There are the curbs on both sides of bicycle lane. The safety distance is 0.25 m on each side of bicycle lane, so the effective bicycle lane-width is 5.6 m by Eq. (7). The saturation flow rate of bicycles is 13,102 (bicycle/h) and the saturation flow rate of motor vehicle is 1903 (pcu/h) from the video data, so the bicycle conversion factor is 0.220 by Eq. (6).

The factors on other road sections are calibrated as the same method. The all results are listed in Table 13.

It is commended that 0.22 is bicycle conversion factor on road section with physical separation based on the calibration results in Table 13. The relative errors are shown in Table 14.

6. Conclusions

With the analysis of the interaction between bicycles and motor vehicles, a set of models of bicycle conversion factor are established for four situations including through and left-turn bicycle at intersections, also including the bicycle on road section with and without physical separation. The field data from Tianjin, Shenyang and Shijiazhuang are used to calculate the conversion factors. Recommendatory values are given depending on the calculated results: (1) the factor for through bicycle at intersections is 0.28; (2) the factor for left-turn bicycle at intersections is 0.33; (3) the factor for bicycle on the road sections without physical separation is 0.24; and (4) the factor for bicycle on the road sections with physical separation is 0.22. The conversion factors were testified in HiCon traffic control system and the results were satisfactory with better effect. Of course, more detailed research work of bicycle conversion factor should be done aiming at various road widths.

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References

Allen, D.P., Joseph, E.H., Naqui, M.R., Joseph, S.M., 1998. Effects of bicycles on capacity of signalized intersections. Transportation Research Record 1646, 87–95.

Chinese Road Institute Traffic Engineering Manual Edit Board, 1998. Traffic Engineering Manual. China Communications Press, Beijing.

Forester, J., 1994. Bicycle Transportation. The MIT Press, London.

Fukuda, D., Morichi, S., 2007. Incorporating aggregate behavior in an individual's discrete choice: an application to analyzing illegal bicycle parking behavior. Transportation Research Part A 41, 313–325.

Gatersleben, B., Appleton, K.M., 2007. Contemplating cycling to work: attitudes and perceptions in different stages of change. Transportation Research Part A 41, 302–312.

Gu, S.H., 1998. Hazard of mixed traffic and countermeasures. China Municipal Engineering 80 (1), 17–18.

Jing, C.G., Wang, D.H., 2004. Analysis and dealing method to conflict of mixed traffic at typical intersection. China Civil Engineering Journal 37 (6), 97–100.

Krizek, Kevin, J., 2004. Estimating the economic benefits of bicycling and bicycle facilities: an interpretive review and proposed methods. TRB 2004 Annual Meeting CD-ROM 04-2070. University of Minnesota.

Martens, K., 2007. Promoting bike-and-ride: the Dutch experience. Transportation Research Part A 41, 326–338.
Navin, F., 1994. Bicycle traffic flow characteristics: experimental results and comparisons. ITE Journal 64, 31–36.
Quan, Y.S., Liu, X.M., 2002. Where is the road: talking about civil traffic. China City Publishing House, 279–284.
Rose, G., Marfurt, H., 2007. Travel behaviour change impacts of a major ride to work day event. Transportation Research Part A 41, 351–364.
Sharples, R., 1993. Modeling cyclists in SATURN. Traffic Engineering and Control 34, 472–475.
Smith, D., 1976. Safety and locational criteria for bicycle facilities. Report FHWA-RD-75-112. Department of Transportation, US.
Smith, R.L., Walsh, T., 1988. Safety impacts of bicycle lanes. Transportation Research Record 1168, 49–56.
Taylor, D., 1998. Contributions to Bicycle-Automobile Mixed-Traffic Science: Behavioral Models and Engineering Applications. Ph.D. Thesis, The University of Texas, Austin.
Taylor, D., Davis, W.J., 1999. Review of basic research in bicycle traffic science, traffic operations, and facility design. Transportation Research Record 1674, 102–110.
Tilahun, N.Y., Levinson, D.M., Krizek, K.J., 2007. Trails, lanes, or traffic: valuing bicycle facilities with an adaptive stated preference survey. Transportation Research Part A 41, 287–301.
Tiwari, G., Mohan, D., Fazio, J., 1998. Conflict analysis for prediction of fatal crash locations in mixed traffic streams. Accident Analysis and Prevention 30, 207–215.
Transportation Research Board, 1994. Highway Capacity Manual: Special Report 209, third ed. National Research Council, Washington DC.
Transportation Research Board, 2000. Highway Capacity Manual, fourth ed. National Research Council, Washington, DC.
US Department of Transportation, 2000. Bicycle and Pedestrian Data: Sources, Needs, & Gaps. Bureau of Transportation Statistics, Washington, DC.
Wang, D.H., 2002. Traffic Flow Theory. China Communications Press, Beijing, pp. 13–18.
Wang, Y.H., Nihan, N.L., 2004. Estimating the risk of collisions between bicycles and motor vehicles at signalized intersection. Accident Analysis and Prevention 36, 313–321.
Wardman, M., Tight, M., Page, M., 2007. Factors influencing the propensity to cycle to work. Transportation Research Part A 41, 339–350.