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THE DEVELOPMENT OF A CONFLICT HAZARDOUS ASSESSMENT MODEL FOR EVALUATING URBAN INTERSECTION SAFETY

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Abstract. Road safety conditions in China have worsened following rapid urbanization and motorization. For a long time now, China has ranked first in the world in the number of road accidents and fatalities. Therefore, evaluating safety levels is essential to implementing effective countermeasures. For developing countries like China, however, assessing safety levels via crash data statistical analysis is difficult because of limitations on a short history of collecting crash data, small samples and an incomplete collection of information. To address these limitations, the method of surrogate safety analysis using the traffic conflict technique (*TCT*) has become a widely used evaluation procedure. On the basis of the mechanism analysis of *TCT*, the paper presents a conflict hazardous assessment model (*CHAM*) for the mixed traffic safety evaluation of urban intersections. In the proposed model, the principle of the conservation of momentum is used. *CHAM* is a model used for assessing safety levels from the aspects of severe conflict numbers and conflict hazardous levels (*CHL*s) when traffic conflicts among mixed-traffic modes occur. Factors such as the conflict type and conflict angle of different traffic modes, weight and velocity are considered and incorporated into the model through the integration of the accident collision theory and the head injury criterion (*HIC*) index for head hazard assessments. The calibration and validation of *CHL* models are also carried out using 341 intersection crash reports in Beijing from 2006 to 2008. The results show that the established *CHL* models have good validity.

Keywords: urban intersection, traffic safety, conflict hazardous assessment model (*CHAM*), safety assessment, traffic conflict technique.

1. Introduction

Compared with other urban road locations, urban intersections generate more traffic crashes because of considerable conflicts in motorized and non-motorized traffic, conflicts between motorized traffic and non-motorized traffic, motorized traffic and pedestrians and non-motorized traffic and pedestrians. According to past statistics, about 55% of total traffic crashes and 23% of total fatal crashes in urban areas in the US occur at intersections (Antonucci *et al.* 2004). In China, about 30% of urban traffic crashes take place at intersections (Annual Bulletin… 2008). These statistical data indicate that intersections are the places of significant safety concerns. There is a need to establish a feasible model for evaluating intersection safety levels, specifically in China.

The traffic safety evaluation model currently used in the country is based mainly on historical traffic crash data or the traffic conflict technique (*TCT*). Although these models can provide an objective evaluation of safety levels, the specific circumstances of China present a number of challenges:

- The safety level evaluation model based on crash data is a post-mortem analysis method intended for use after accidents. Obtaining the accident characteristics of small samples, a long collection cycle and stochastic processes necessitate a long period in determining safety improvement outputs; the length of time consumed translates to increased safety risks (Chin, Quek 1997; De Leur, Sayed 2002).
- The safety level evaluation model based on *TCT* focuses on conflicts arising in motorized traffic. Studies on conflicts among mixed-traffic modes are scarce (Lu *et al.* 2008), although mixed-traffic modes are a typical characteristic of urban road traffic in China.

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With the limited capabilities of the basic model in analyzing traffic crash data and *TCT*, some researchers (Lu *et al.* 2008) have taken the weighted sum of the crossing point numbers of ideal movement trajectories as the basic conflict model for the safety level evaluation of highway intersections. In this model, the physical conditions of intersections are used for assessing safety levels without need for crash data. This method is a pre-analysis procedure of safety level; however, it is still hindered by some limitations:

- The model depends on the crossing point numbers of different movement trajectories. In reality, however, vehicles or other participants do not encounter one another at these points to become traffic conflict events (*TCE*s) for signal controls or channel designs. *TCE*s are highly related to traffic safety (Kaub 2000), whereas the crossing points of ideal movement trajectories influence only the factors of *TCE*.
- This model is mainly used for un-signalized highway intersections. Therefore, identifying the factors influencing safety, such as signal controls in urban intersections, is difficult to carry out. Its applications have limitations in terms of urban intersection design and operation stage, even though it presents advantages at the planning stage.

Using the present studies on *TCT* as bases, we propose a conflict hazardous assessment model (*CHAM*) for the evaluation of urban intersection safety. The following objectives are targeted:

- *CHAM* is established, incorporating factors such as conflict types, conflict angles, velocity, weight and *TCE* in different traffic modes. Therefore, the model can be used for the safety assessment of specific schemes in both urban signalized and un-signalized intersections.
- The method of determining conflict hazardous level (*CHL*) of different conflict types among mixed-traffic modes is proposed through the integration of the accident collision theory and *HIC* index for head hazard assessment.
- The calibration and validation of *CHL* are carried out using 341 intersection crash reports in Beijing within the period from 2006 to 2008.

The remainder of the paper is organized as follows. Section 2 reviews previous research on the validity and severity of *TCT*. Section 3 explains the approach to urban intersection *CHAM*. Section 4 illustrates the *CHL* determination procedure of *CHAM*. The applications are stated in Section 5. Conclusions are drawn and recommendations for future studies are presented in Section 6.

2. Research Review

For the purpose of this study, traffic conflict is defined as an observable situation, in which two or more road users approach each other in time and space to the extent that the risk of collision presents itself if their movements remain unchanged.

TCT has a long history of development covering research on its validity (Kaub 2000; Glauz *et al.* 1985; Migletz *et al.* 1985; Hauer, Garder 1986) and severity measures (Williams 1981; Sayed, Zein 1999; Minderhoud, Bovy 2001; Gettman, Head 2003; Kiefer *et al.* 2005; Svensson, Hydén 2006; Gettman *et al.* 2008).

TCT validity is often judged by adequacy in the correlation between observed conflict counts and accident records. Glauz (1985) established relationships between traffic conflicts and accidents and found that traffic conflicts of certain types were good surrogates for accidents, in which the estimates of the average accident rates were produced nearly as accurately as those produced from historical accident data. Based on this perspective and using the statistical analysis of historical accident data, Glauz (1985), Migletz *et al.* (1985), Hauer and Garder (1986) and Kaub (2000) reported that traffic crashes were highly related to severe traffic conflicts. The aforementioned authors attempted to build some models considering traffic crashes and severe conflicts. All these studies reflect the validity of *TCT*.

Because traffic crashes are strongly correlated with severe traffic conflicts, many studies focus on how to express conflict severity; some severity measures such as traffic conflict frequency (Williams *et al.* 1981; Sayed *et al.* 1999), time-to-collision (*TTC*) (Minderhoud, Bovy 2001; Gettman, Head 2003; Kiefer *et al.* 2005), post-encroachment time (*PET*) (Gettman, Head 2003), speed (Gettman, Head 2003), time-to-accident / conflicting speed value (Svensson, Hydén 2006), etc. have been proposed. The primary proposed conflict severity measure is *TTC*. Williams (1981) suggested that a hierarchy of *TCE* ranging in severity from minor conflicts to fatal accidents existed. Sayed and Zein (1999) established traffic conflict frequency and severity standards of motorized traffic for signalized and un-signalized intersections using data collected from 94 conflict surveys. To obtain critical *TTC* values, Minderhoud and Bovy (2001) promoted the basic idea of sampling *TTC* values over time to examine how well a driver understood the given lower safety limit. Gettman and Head (2003) proposed the best indices such as *TTC*, *PET*, deceleration rate, maximum speed and speed differential to measure the severity of conflicts in motorized traffic. They also presented definitions of possible conflict events and algorithms for calculating surrogate indices for conflict points and lines. Kiefer *et al.* (2005) developed an inverse *TTC* model to implement motorized traffic crash alerts when thresholds were surpassed. Svensson and Hydén (2006) constructed severity hierarchies based on a uniform severity dimension (time-to-accident/conflicting speed value) to acquire a comprehensive understanding of a connection between behaviour and safety. Gettman *et al.* (2008) established the Surrogate Safety Assessment Model (*SSAM*) and developed corresponding software for calculating surrogate indices according to the principles of the aforementioned five surrogate indices (Gettman, Head 2003).

As previously discussed, *TTC* is the primary conflict severity measure which is mainly focused on conflicts in motorized traffic. Based on these studies, *CHAM* is put forward to carry out the pre-analysis of safety levels by incorporating comprehensive conflict types such as conflicts among motorized traffic, non-motorized traffic and pedestrians as well as comprehensive influencing factors such as *TTC*, velocity and weight. *CHAM* depends on factual *TCE* and can assess safety influence levels of specific schemes at planning, design or operation stages.

3. Approach

3.1. Basic Model

In accordance with the traffic conflict mechanism analysis performed by Gettman *et al.* (2008), Lu (2008), etc, we establish *CHAM* to assess safety levels by considering *TTC*, weight, velocity, conflict types and conflict angles.

CHAM is a model used for assessing safety levels from two aspects: severe conflict numbers and *CHL* when *TCE* between mixed-traffic modes occur. The higher *CHAM* is, the higher hazard level of the intersection is. The relationship can be expressed by the basic model of Equation (1):

$$CHAM = \sum_{i=1}^{N} CT_i \; CHL_i . \qquad (1)$$

In the equation, *CHAM* reflects the entire intersection *CHL*; *i* is traffic conflict type; CT_i represents the severe conflict number of *i*th conflict type singled out according to *TTC* index (Gettman *et al.* 2008; Lu 2008); CHL_i is the *CHL* of ith conflict type influenced by conflict angles, velocity and the weight of different traffic modes.

Traffic conflict types are classified using numerous methods having different rules (Sayed, Zein 1999; Gettman *et al.* 2008). However, these conflicts can be expressed through conflict angles and conflict participants after cluster analysis. Therefore, conflict types are grouped according to conflict angles and conflict participants taken as primary indices and conflict angles as secondary indices. The two hierarchical grouping results of conflict types are presented in Table 1.

According to Equation (1) and Table 1, *CHAM* can be transformed into the following form:

$$CHAM = \sum_{i=1}^{5}\sum_{j=1}^{3}\sum_{k=0}^{n} CT_{ijk} CHL , \qquad (2)$$

where: *i* is the primary index; *j* represents the secondary index; *n* is the severe conflict number of conflict types *i* and *j*; the total severe conflict number is 5×3×*n*. The rest of the symbols are defined similarly as in Equation (1).

In Equation (2), *CT* is a severe conflict number. To identify a severe conflict, some researchers (Minderhoud, Bovy 2001; Gettman, Head 2003; Kiefer *et al.* 2005; Svensson, Hydén 2006; Gettman *et al.* 2008) adopted *TTC* index. Based on *TTC*, Lu (2008) proposed an 85 percentile severe conflict determination method and used it for identifying severe conflicts in the mixed-traffic modes through the field survey. These methods are employed to identify *CT*. This paper, on the other hand, focuses mainly on *CHL*.

3.2. Methodology

The studies by Williams (1981) and Kaub (2000) showed a certain linear relationship (β) between a severe conflict and traffic crash. The hazard level of traffic crash (*HLOTC*) can be derived through the accident collision theory (Mizuno, Kajzer 1999) and *HIC* index for head hazard assessment (Hutchinson *et al.* 1998; Yoganandan *et al.* 2010). The functional relationship of *CHL* can be expressed as Equation (3):

$$CHL = \beta \, HLOTC. \qquad (3)$$

Equation (3) is used for determining *CHL* in Equation (2). The procedure is described as follows:

- ***Step 1. Determination of HLOTC*****:** *HLOTC* is derived through combining the accident collision theory and *HIC* index used for head hazard assessment (Section 4.1).
- ***Step 2. Establishment of CHL models*****:** *CHL* models are developed in line with the linear relationship between a severe conflict and traffic crash (Section 4.2).
- ***Step 3. Calibration and validation of CHL models*****:** A total of 341 intersection crash reports in Beijing from 2006 to 2008 are used for the calibration and validation of *CHL* models (Section 4.3).

4. Core Technique – A *CHL* Determination Procedure for *CHAM*

CHAM evaluates safety levels based on *CT* number and *CHL*. In *CT* identification, we adopt the current 85 percentile severe conflict determination method (Lu 2008). This paper focuses mainly on *CHL*, and this section specifically illustrates a procedure for *CHL* determination.

4.1. Determination of *HLOTC*

HLOTC (marked y in the deduction process) is primarily affected by traffic modes (x_1), collision types (x_2), veloc-

Table 1. Hierarchical grouping results of conflict types

Primary indices / Secondary indices	Motorized traffic	Motorized and non-motorized traffic	Motorized traffic and pedestrians	Non-motorized traffic	Non-motorized traffic and pedestrians
Head-on (135°÷180°)	11	21	31	41	51
Crossing (45°÷135°)	12	22	32	42	52
Rear end (0°÷45°)	13	23	33	43	53

ity (x_3) and weight (x_4) (Abdel-Aty, Abdelwahab 2004; Conroy *et al.* 2008). It can be expressed as Equation (4):

$$y = f\left(x_1, x_2, x_3, x_4\right). \tag{4}$$

For conflicts in specific traffic modes and collision types, Equation (4) can be transformed into Equation (5), and thus:

$$y_{x_1,x_2} = f_{x_1,x_2}\left(x_3, x_4\right). \tag{5}$$

According to grouping conflict types in Table 1, collision types are categorized via a similar classification method (Abdel-Aty, Keller 2005). Therefore, Equation (5) can be expressed as Equation (6):

$$y_{ij} = f_{ij}\left(x_3, x_4\right). \tag{6}$$

As to functional relationship f in Equation (6), related research (Hutchinson *et al.* 1998; Yoganandan *et al.* 2010) adopted the head hazard level as the equivalence foundation. Versace proposed *HIC* index in 1971 adopted as the hazard level criterion of passenger protection system FMV SS208 by the US National Highway Traffic Safety Administration. Currently, *HIC* value is employed as one of the vehicle safety criteria by nearly all the countries in the world. It is expressed as Equation (7), and thus:

$$HIC = \left(t_1 - t_2\right)\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}|a|\,dt\right)^{2.5} = y_{ij}. \tag{7}$$

In the equation, a is head C.G. acceleration and its value is the multiple of gravity acceleration; t_1 represents time on acceleration wave; t_2 denotes the maximum time of *HIC* corresponding to *t1* with an interval time of less than 36 ms. As difference in interval time $|t_2 - t_1|$ is nonsignificant in different collisions, it can be taken as a constant. Thus, Equation (7) can be expressed as Equation (8):

$$HIC = K\left(\int_{t_1}^{t_2}|a|\,dt\right)^{2.5}. \tag{8}$$

In the equation, K is a constant and all other symbols are defined similarly to those in the previous equations.

HLOTC y can be stated as Equation (9) by combining Equations (6) and (8):

$$y_{ij} = HIC_{ij} = K_{ij}\left(\int_{t_{ij1}}^{t_{ij2}}|a|\,dt\right)^{2.5}. \tag{9}$$

In the equation, i and j are collision types. They have similar classification methods as those of the conflict types in Table 1. All other symbols are similar to those in the previous equations. Symbol a is an independent variable.

Regarding the determination of head C.G. acceleration a in Equation (9), the principle of the conservation of momentum in the crash collision theory can be employed to compute this index. The *HLOTC* of different collision types can then be deduced. The following section presents the deduction process of head-on collisions in motorized traffic.

Collisions can be taken as completely inelastic collisions, i.e. two vehicles stick to each other having the same velocity v after the collision (Abdel-Aty, Abdelwahab 2004; Conroy *et al.* 2008; Teresiński, Madro 2001; Fricke 1990). When the velocity of the two vehicles is marked v_1' and v_2' after the collision, relationship $v = v_1' = v_2'$ is obtained. The weights of the two vehicles are assumed as m_1 and m_2, and velocities before the collision are v_1 and v_2. The principle of the conservation of momentum can then be applied as Equation (10):

$$m_1 v_1 + m_2 v_2 = \left(m_1 + m_2\right)v \text{ or}$$

$$v = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}. \tag{10}$$

Equation (10) can be transformed into Equation (11), and thus:

$$\begin{aligned} &v = v_1' = v_2'; \\ &v_1' = v_1 - \frac{m_2}{m_1 + m_2}\left(v_1 - v_2\right); \\ &v_2' = v_2 + \frac{m_1}{m_1 + m_2}\left(v_1 - v_2\right). \end{aligned} \tag{11}$$

The head C.G. acceleration a of the two vehicles can be deduced as Equations (12) and (13) respectively.

$$\begin{aligned} a_1 &= \frac{v_1' - v_1}{t} = \frac{v_1 - \frac{m_2}{m_1 + m_2}\left(v_1 - v_2\right) - v_1}{t} = \\ &-\frac{1}{t}\frac{m_2}{m_1 + m_2}\left(v_1 - v_2\right); \end{aligned} \tag{12}$$

$$\begin{aligned} a_2 &= \frac{v_2' - v_2}{t} = \frac{v_2 + \frac{m_1}{m_1 + m_2}\left(v_1 - v_2\right) - v_2}{t} = \\ &\frac{1}{t}\frac{m_1}{m_1 + m_2}\left(v_1 - v_2\right). \end{aligned} \tag{13}$$

When Equations (12) and (13) are substituted into Equation (9), the hazard levels of the two vehicles can be acquired. They are added together to obtain the *HLOTC* of the collision (Equation (14)). In the deduction process, $|t_2 / t_1|$ is nonsignificant in different collisions and taken as a constant.

$$\begin{aligned} y_{ij} = K_{ij}'\Bigg(&\left(\left|\frac{m_2}{m_1 + m_2}\left(v_1 - v_2\right)\right|\right)^{2.5} + \\ &\left(\left|\frac{m_1}{m_1 + m_2}\left(v_1 - v_2\right)\right|\right)^{2.5}\Bigg). \end{aligned} \tag{14}$$

In the equation, K_{ij}' is a constant and the other symbols are similar to those in the previous equations.

4.2. Establishment of CHL Models

Head-on conflicts in motorized traffic are also taken as examples. When the relationship between *CHL* and *HLOTC* is marked β_{ij}, *CHL* can be expressed as Equation (15) by combining Equations (3) and (14):

$$CHL_{ij} = \beta_{ij}\, y_{ij} =$$
$$\beta_{ij} K'_{ij}\left(\left(\left|\frac{m_2}{m_1+m_2}(v_1-v_2)\right|\right)^{2.5}+\left(\left|\frac{m_1}{m_1+m_2}(v_1-v_2)\right|\right)^{2.5}\right)=$$
$$\beta'_{ij}\left(\left(\left|\frac{m_2}{m_1+m_2}(v_1-v_2)\right|\right)^{2.5}+\left(\left|\frac{m_1}{m_1+m_2}(v_1-v_2)\right|\right)^{2.5}\right). \quad (15)$$

In the equation, the multiple of constant β_{ij} and K'_{ij} is marked β'_{ij}. Other symbols are similar to those in the equations above. Regarding *k*-th severe conflict among conflict types *i* and *j*, the *CHL* model is expressed as Equation (16):

$$CHL_{ijk} = \beta'_{ij}\left(\left(\left|\frac{m_{2k}}{m_{1k}+m_{2k}}(v_{1k}-v_{2k})\right|\right)^{2.5}+\left(\left|\frac{m_{1k}}{m_{1k}+m_{2k}}(v_{1k}-v_{2k})\right|\right)^{2.5}\right). \quad (16)$$

A similar method can be used for deriving the *CHL* of other conflict types. The results are provided in Table 2.

4.3. Calibration and Validation of *CHL* Models

392 urban intersection crash reports in Beijing from 2006 to 2008 are collected for calibration and validation. In these reports, incomplete records are filtered and yielding 341 valid samples. Their spatial distribution is indicated in Figure.

341 samples are divided into three groups according to the year, i.e. 102 samples in 2006, 128 samples in 2007 and 111 samples in 2008. They are used for calibrating parameter β'_{ij} of *CHL* model. Three groups of β'_{ij} are acquired. The Friedman test is used for determining the differences among the three groups of β'_{ij}. The status 'difference is not significant' and reflects the validity of *CHL* model.

For the basic *CHL* models in Table 2, hazard level *CHL* is transformed into a comparable level using the same criteria published by the Public Security Ministry of P.R.C. (Rules of Urban Road… 2009) presented in Table 3.

The weight and velocity of the basic *CHL* models in Table 2 are the corresponding weight and velocity in each crash report. The linear regression process in SPSS18.0 is utilized to compute parameter β'_{ij}. The results are shown in Table 4. All the R^2 of the models are greater than 0.8, which reflects good correlation.

The Friedman test (García *et al.* 2010) is then used to determine validity. This test is a nonparametric analogue of two-way ANOVA. The objective of this test is to determine whether there is the difference among treatment effects. The null hypothesis is that there is no difference among treatment effects. The alternative hypothesis is that there is the difference among treatment effects. Test statistics is stated as Equation (17). The decision rule of validity is that the null hypothesis is accepted if the statistical value of the test is less than the critical value at a significant level of 5%.

$$\chi_F^2 = \frac{12}{ls(s+1)}\sum_0 RK_0^2 - 3l(s+1). \quad (17)$$

Table 2. Checklist of *CHL* models

Conflicts in motorized traffic	Head-on	$CHL_{ijk} = \beta'_{ij}\left(\left(\left\|\frac{m_{2k}}{m_{1k}+m_{2k}}(v_{1k}-v_{2k})\right\|\right)^{2.5}+\left(\left\|\frac{m_{1k}}{m_{1k}+m_{2k}}(v_{1k}-v_{2k})\right\|\right)^{2.5}\right)$	The velocity is vector in the equation, namely $v_{1k} - v_{2k}$ for rear-end and $v_{1k} - (-v_{2k}) = v_{1k} + v_{2k}$ for head-on
	Rear-end		
	Crossing	$CHL_{ijk} = \beta'_{ij}\left(\left\|v_k - v_{1k}\right\|^{2.5} + \left\|v_k - v_{2k}\right\|^{2.5}\right)$; $v_k = \frac{m_{1k}v_{1k} + m_{2k}v_{2k}\cos\theta_k}{(m_{1k}+m_{2k})\cos\gamma_k}$; $\mathrm{tg}\gamma_k = \frac{m_{1k}v_{1k} + m_{2k}v_{2k}\cos\theta_k}{m_{2k}v_{2k}\sin\theta_k}$	θ is the forward angle between velocity v_{1k} and v_{2k}
Conflicts between motorized and non-motorized traffic		$CHL_{ijk} = \beta'_{ij}\left(\left\|\frac{m_{1k}}{m_{1k}+m_{pk}}(v_{1k}-v_{pk})\right\|\right)^{2.5}$	There is an assumption that motorized traffic drivers get more protection than non-motorized traffic cyclists do
Conflicts between motorized traffic and pedestrians		$CHL_{ijk} = \beta'_{ij}\left(\frac{m_{1k}}{m_{1k}+m_{pk}}v_{1k}\right)^{2.5}$	There is an assumption that motorized traffic drivers get more protection than pedestrians do
Conflicts in non-motorized traffic/conflicts between non-motorized traffic and pedestrians		The hazard level is small and the adjustment of weight and velocity is not considered *CHL* is directly marked β'_{ij}	

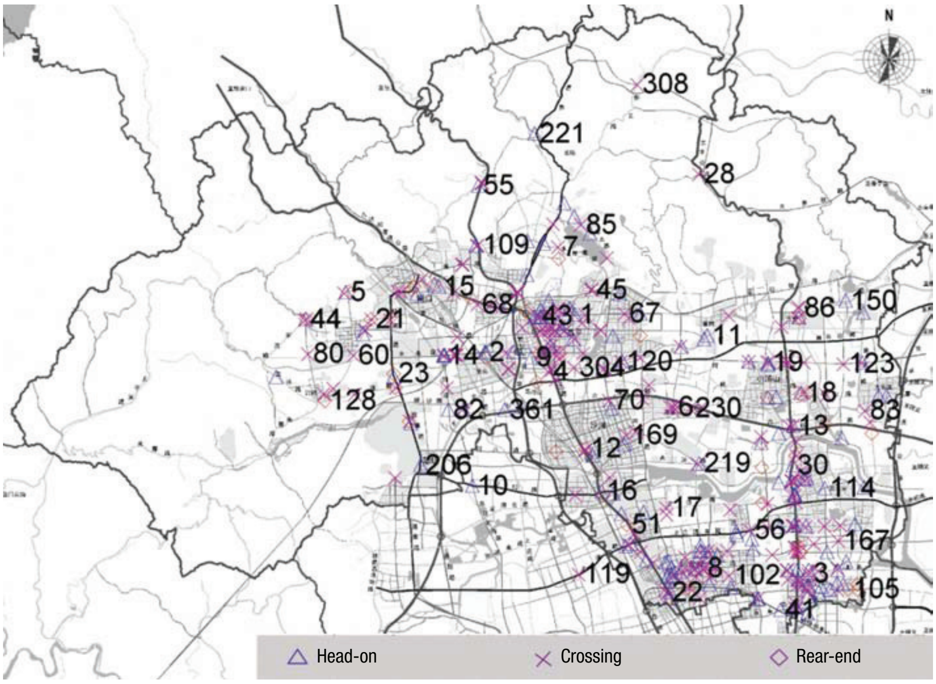

Fig. Spatial distribution of data on crashes at 341 intersections in Beijing within the period from 2006 to 2008

Table 3. Different accident levels

Seriousness	Definition	Score
Minor accident	Slight injury to only 1 to 2 persons, not more than 1000 Chinese Yuan worth of property lost in a vehicle accident, or not more than 200 Chinese Yuan worth of property lost in one cycle accident	0÷30
Moderate accident	Serious injury to 1 to 2 persons, more than 3 persons slightly injured, or not more than 30000 Chinese Yuan worth of property lost in one accident	30÷60
Serious accident	Death of 1 to 2 persons, 3 to 10 persons seriously injured, or 30000 to 60000 Chinese Yuan worth of property lost in one accident	60÷80
Extra serious accident	Death of more than 3 persons, more than 11 persons seriously injured, 1 death with more than 8 persons seriously injured, 2 deaths with more than 5 persons seriously injured, or more than 60000 Chinese Yuan worth of property lost in one accident	80÷100

Table 4. Parameters β'_{ij} of the *CHL* model

Conflict/collision types		β'_{ij}			
		2006	2007	2008	Average
Conflicts in motorized traffic	Head-on	0.0055	0.0059	0.0057	0.0057
	Crossing	0.0215	0.0208	0.0224	0.0216
	Rear-end	0.0811	0.0828	0.0835	0.0825
Conflicts between motorized and non-motorized traffic		0.0046	0.0049	0.0047	0.0047
Conflicts between motorized traffic and pedestrians		0.005	0.0056	0.0052	0.0053

Note: *The valid conflict samples of non-motorized traffic and pedestrians are limited. They are not calibrated and validated in this research, although similar methods can be utilized.*

In the equation, l refers to data sets ($l = 5$); s is the number of groups ($s = 3$); RK_0 represents the average ranks of the algorithm (García *et al.* 2010).

The calculations are presented in Table 5.

From the results in Table 5, the critical value of test statistics for $l = 5$ and $s = 3$ at a significant level of 5% is 6.40. Test statistics is $\chi_F^2 = 4.80 < \chi_\alpha^2 = 6.40$, which reflects the acceptance of the null hypothesis and the rejection of the alternative hypothesis. Thus, the difference in β'_{ij} among three groups is non-significant. The test index illustrates the good validity of *CHL* models. The average values of β'_{ij}, as stated in the last column of Table 4, are used for computing the *CHAM* of the entire intersections.

Table 5. Results of the Friedman test

Conflict/collision types		Ranks		
		2006	2007	2008
Conflicts in motorized traffic	Head-on	1	3	2
	Crossing	2	1	3
	Rear-end	1	2	3
Conflicts between motorized and non-motorized traffic		1	3	2
Conflicts between motorized traffic and pedestrians		1	3	2
Values of $\sum RK_0$		6	12	12
Values of $\sum RK_0^2$		36	144	144
$\sum RK_0^2$			324	
$12/ls\left(s+1\right)$			0.20	
$3l\left(s+1\right)$			60	
Test statistics χ_F^2			4.80	

5. Applications

5.1. Software Development

VISSIM, developed by PTV Corporation, is microscopic traffic simulation software based on time step and driving behaviour. *SSAM* is an identification model of severe conflicts in motorized traffic (Gettman *et al.* 2008). We have developed a platform by integrating VISSIM software (VISSIM 5.20 User Manual 2009) and *SSAM* model to achieve severe conflict identification in mixed traffic through *Vb.net* programming (Zhou *et al.* 2009, 2010). In this research, *CHAM* is embedded into the platform to form an auxiliary software analysis tool, which enables the safety level pre-analysis of mixed-traffic design or operation schemes.

5.2. Practical Application

CHAM can evaluate the safety levels of planning, design and operation schemes. The basic application characteristics are as follows:

- *CHAM* cannot be directly applied because of the deficiencies of specific design schemes at the planning stage. However, as in Lu *et al.* (2008), the idea of taking the crossing points of ideal movement trajectories as reference can be adopted to evaluate safety performance at the planning level.
- At design stage, the developed auxiliary software analysis tool can be employed to carry out the pre-analysis of intersection safety levels.
- At the operation stage, the field video survey can be conducted to acquire factual conditions for mixed traffic. Conflict types, angles, weight and the velocity of severe conflicts can be surveyed. These factors are used to directly compute *CHAM*. The auxiliary software analysis tool can also be utilized through simulation analysis.

Since 2005, *CHAM* has been used in a research program of the Ministry of Construction. Thirty-four urban intersections in Sichuan Province are taken as demonstration projects of safety improvement measures. For the existing traffic safety problems, safety improvement actions are implemented and *CHAM*s are used for evaluating the safety levels of improvement schemes. With the implementation of safety improvement actions, the results of *CHAM* and factual traffic crash reports have high consistency.

6. Conclusions

1. A novel *CHAM* procedure for urban intersection safety evaluation based on the current *TCT* research is proposed. The *CHAM* procedure can assess the safety levels of intersection schemes at planning, design and operation stages. It is also suitable for mixed-traffic safety evaluation.
2. *CHAM* evaluates safety levels using conflict numbers and *CHL* as bases. This paper mainly illustrates the establishment, calibration and validation of *CHL* model. The *CHL* of different conflict types are first built by integrating the crash collision theory and HIC index for head hazard assessment. The calibration and validation of *CHL* model are then carried out using 341 intersection crash reports in Beijing from 2006 to 2008. The auxiliary software analysis tool is developed to enable the safety level pre-analysis of design or operation schemes.
3. We study *CHAM* as an import component of a management tool for traffic safety quality. A recommendation for the future study is encouraging the gradual acceptance of *CHAM* applications by traffic engineers and practitioners, and acquiring feedback in different cities in China. *CHAM* can be perfected so that it can be adopted as the index at national traffic safety levels. Another recommendation is to determine the safety level criterion of *CHAM*, which is the decision core of the six-sigma traffic safety quality management of 'Define–Measure–Analysis–Design–Verify' model used for improving the level of traffic safety from the viewpoint of total quality management.

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