



## TRAFFIC SAFETY PERFORMANCE ASSESSMENT AND MULTIVARIATE TREATMENTS FOR INTERSECTION LOCATIONS

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**Abstract.** There is a need to evaluate the safety performance of road intersections in a vehicle platoon environment. For this purpose, this study attempts to quantify intersection related accidents and develop countermeasures to reduce injuries resulting from such accidents, using the selected data of 3520 casualties over the period 1992–2007 in Harbin. Then the distribution characteristics of accident number and rate via a half experience model are statisticed and find that proportionately 89.15% of total records occurred at unsignalized intersections and the injuries and fatalities account for approximately 62.35% at irregular ones. Using techniques of linear regression, several different explanatory models are constructed to identify the factors associated with annual average daily traffic, junction numbers and volume/capacity and thus 3 stages are classified in response to diverse risk level. Moreover, we developed a pedestrian risk factor to quantify the crossing risk around intersection locations, due to pedestrian are more likely to be at-fault in accidents, and 8 roads in Harbin, including Hongqi Str., Nanzhi Rd., etc., are consequently detected with higher crosswalk risk. For safety enhancement approaches, effective measures are proposed to be a combination of facilities improvement, intelligent transportation system application, enforcement and educational programs implemented for both drivers, pedestrians and other users to reduce the overall number of crashes and provide a safer traffic environment.

**Keywords:** safety performance, road intersection, annual average daily traffic, linear regression, pedestrian risk factor.

### 1. Introduction

Intersections are recognized as being among the most dangerous locations of a roadway network. Collisions and crashes at intersections have caused a huge cost to society in terms of death, injury, lost productivity, and property damage, especially for developing countries, and thus attracted numerous research efforts. It's reported that more than 30% of all vehicle crashes in the United States occurs at intersections and these crashes lead to approx 1.5 mln injuries, nearly 9000 fatalities per year, accounting for approx 50% and 25% of all traffic injuries and fatalities (Lee *et al.* 2006). In Singapore, about 35% of traffic-related deaths result from intersection occurrence (Tay, Rifaat 2007). Intersections are prone to be definitely high-risk locations, possibly due to their disorder traffic, involving pedestrian, bicycles and motor vehicles, easier to occur bicycle-motor vehicle (BMV) collisions, induced by frequent conflicts between bicycle flow and automobile flow. More seriously in Beijing, about 38.7% of intersection fatalities died from BMV collisions and

nearly 7% of the total traffic accidents were related to bicycles (Ma *et al.* 2010).

To provide a broad overview, intersection presents a novel and hazardous condition to drivers and conflict between vehicular traffic and pedestrian activity, and thus are likely to reduce its capacity and increase the crash probability for all involved. Garder (2004) looked at how actual vehicle speeds and characteristics of intersections affect crash numbers by 122 locations data in varying environments throughout Maine. Kumara and Chin (2005) studied 104 three-legged signalized intersections in Singapore and found the presence of right-turn channelization and existence of a surveillance camera, etc, may reduce the occurrence of intersection approach accidents. In a recent study, Ye *et al.* (2009) argued that a severe intersection collision was due to large numbers of conflicts, and wide variety of geometric and operational features in such specific maneuvers. Pulugurtha and Sambhara (2011) found that characteristics of demographic, socio-economic, land use and road network and the number of transit stops have

different influence on crash features of all signalized intersections, high pedestrian activity signalized intersections and low pedestrian activity signalized intersections, respectively.

In particular, multinomial models were specified for such accidents. Haleem and Abdel-Aty (2010) developed the ordered and binary probit models of intersection injury severity estimation by using the Florida crash database. Spek *et al.* (2006) used a statistical model derived from gap acceptance at intersections, taking into account limitations of human perception, to quantify the relation between approach speed and accident probability. Obeng (2007) applied the binary logit to analyze crash injury at signalized intersections. By far, previous research made more efforts into analyzing the distributing feature of the total accidents. However, these disposal methods are more suitable for networks rather than just individual intersection. Vehicle type, road type, collision type, driver's feature and time of the day are all contributing factors to the occurrence and severity of crashes at intersections (Tay, Rifaat 2007). Actually, intersections have different characteristics due to geometric design, conflicting flows, as well as pedestrian involvement. Therefore, it could hardly assess the safety level only from one aspect proved by pointloads of practices.

Despite of various efforts, however, many problems related to intersection accident remain unsolved today. Facing continued population growth, automobile revolution, shrinking per capita infrastructure investment and tighter environmental constraints, however, it still has a long way to go. Upon the urgent requirement, the primary focus of this paper is to address the traffic safety performance related to road intersections in Harbin, using collected accident data over 1992–2007. It is organized as follows: Data resource is introduced firstly, and then some statistical characteristics are analyzed quantitatively for intersection involved accidents in a macro-scope and in the forthcoming part, micro-modeling approaches are proposed to assess the risk level of pedestrian crossing behaviors. The paper presents some measures for improving traffic safety at intersections and concludes consequently with general remarks and comments about the overall works in the final section.

## 2. Data collection

Due to the specific geographical location, Harbin, the capital of Heilongjiang Province, has witnessed alarming number of intersection related crashes and collisions (Ma *et al.* 2007). Therefore, these locations are sure to be the problematic locations in daily traffic management. To provide enough scientific basis for such a belief, consequently, the areas within the 2<sup>nd</sup> Ring Road and a total of 238 intersections were considered, including three-legged, four-legged and five or more legged intersections. The number of four-legged accounts for 58.9% of total intersections and covers quite a large area of more than 12% among the surveyed area. A total of 3520 accidents observations over 1992–2007 are collected and used in the forthcoming explanatory analysis, in which 1.12% is fatal, 32.2% resulted

in medium and major serious injuries and the rest in slight injuries.

In addition, the number of annual average daily traffic (AADT) entering these intersection locations are considered for safety appraisal, and geometric elements and facilities of intersections are also collected for each crash observation from the official accident reports, including approach curvature, sight distance at intersection, road width, left-turn length on slip roads, bus stops from intersection, uncontrolled left-turn lane and exclusive right-turn lane, et al. Regulatory control measures refer to existence of surveillance camera, signal control types and pedestrian signal, and depend on spot survey message.

Unfortunately, such reports possess a common problem at some times: missing or incomplete data and required accident message, such as the time, accurate location, cause and type of accident. In addition, details about lights, road conditions, and surrounding environment are not filled in. All these add difficulty to decision-making for accident statistics, contributing factors and location features to a certain extent.

## 3. Accident features and contributory factors

Accident number, frequency and occurrence – traffic flow relationship are modeled in regression pattern, respectively, using the overall observation data.

### 3.1. Accident number

Generally, crash injuries are categorized into five levels considering the seriousness of death, bodily injury and property damage involved in a crash: no injury, possible injury, non-incapacitating injury, incapacitating injury and fatal injury (Wang *et al.* 2010). However, this division is not familiar to general people. Therefore, here accident is divided into four categories: minor accident, medium accident, major accident and fatal accident, by death and serious injury number (1 death = 1.7 serious injuries).

Fig. 1 shows the intersection accidents in Harbin from 1998 to 2007, and minor accidents mainly refer to side scrape and minor rear-end/merge collision on snow-

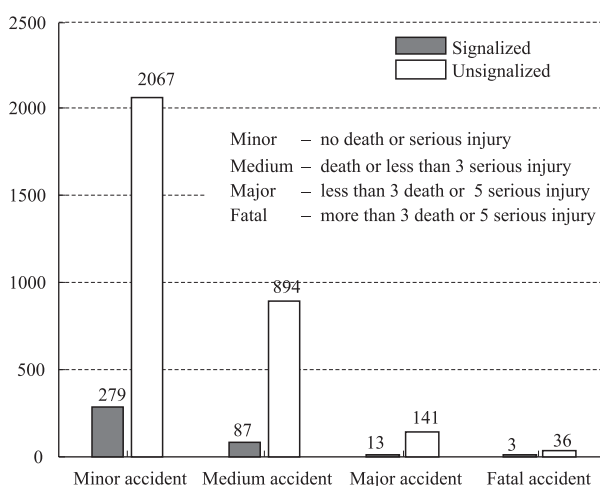


Fig. 1. Accident statistics in 1998–2007

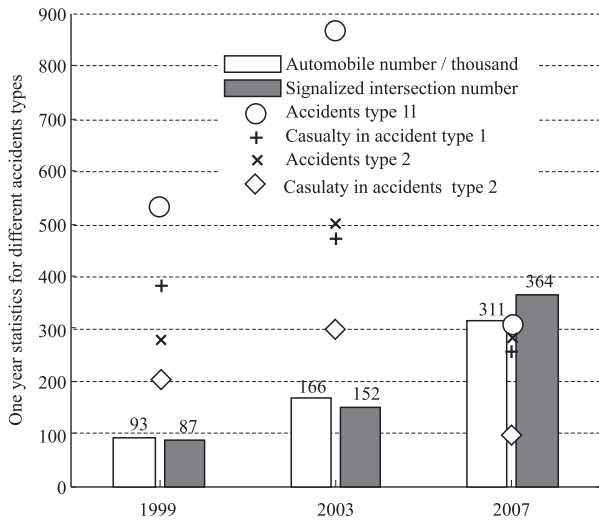


Fig. 2. Accident type categorization for three typical years

ice road. From the statistics, it's easily concluded that accidents at signalized intersections account for 10.85% among the total records, with a better performance of traffic safety, and as much as nearly 90% occurred at uncontrolled intersections.

In the term of location, accidents are divided into two categories: type 1 for accidents that occurred on expressway and arterials intersection and type 2 for these on minor and branch road intersection. Fig. 2 presents the deep insight into data features for three individual years, 1999, 2003 and 2007. Obviously, the number of crashes of 2007 is two times of that in 2003, due to the increasing number of vehicles and daily trips performed by expanding population in urbanized Harbin metropolitan region.

Table 1 gives the three peak periods in intersection accidents in detail at 2 yearly intervals. In 2002–2003, it kept higher accident frequency, because there were not too many signals added in minor roads and branches. However, the road crashes in 2006–2007 are also alarming. Unsurprisingly, it is partially due to the rapid economic progress over this period which helped more and more families to afford automobiles for daily trip use instead of public transit supply. Moreover, it also contributed to the lack of effective attention paid on the safety facilities of minor and branch roads.

For a certain type intersection, the mean  $E_i$  and standard deviation  $\sigma_i$  of the total number of accidents are determined by:

Table 1. Accident characteristics at three typical peaks

Year	Expressway & arterial		Minor & branch street	
	Count	Casulaty	Count	Casulaty
1998–1999	539	381	271	216
2002–2003	818	473	493	307
2006–2007	305	243	287	124

$$E_i = \frac{1}{N} \sum_{j=1}^N NOA_{ij}, \quad (1a)$$

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^N (NOA_{ij} - E_i)^2}{N_i - 1}}, \quad (1b)$$

where  $NOA_{ij}$  – number of accidents at intersection  $j$  in category  $i$ ;  $N_i$  – number of intersections at which accidents are counted in category  $i$ .

Different types of intersection perform diverse safety performance. Table 2 presents the accident statistics results by main intersection types and then we can clearly see that orthogonal intersections have bigger  $E_i$  and  $\sigma_i$  of crash statistical parameters, what means that these locations are more prone to crash, because of more passing through pedestrians and complex traveling environment. Since all  $\sigma_i > E_i$ , in addition, we could confirm that the series of crash numbers complies with binomial distribution (Lanović 2009).

Table 2. Accidents statistics by intersection type

Category	Total number	$E_i$	$\sigma_i$
X orthogonal	21	10.81	57.36
X diagonal	105	9.73	36.27
Y orthogonal	7	24.14	70.51
Y diagonal	30	16.57	37.72
T orthogonal	25	21.72	147.63
T diagonal	38	16.71	128.79
Five-legged or roundout	12	35.58	328.04

Plenty of practices prove that irregular intersection is more prone to induce accident occurrence (Pei, Hu 2004). For example, the mean value is as high as 35.58 for five-legged intersections or roundouts, though the accident number is only 12, a higher traffic risk. The same findings also come from orthogonal cross ones. Thus, intersections with regular modes behave better safety performance.

Despite that the whole city's automobile amount increased from 9.3 thousand in 1998 to 311 thousand in 2007, the accidents on expressways and main roads reduced from 539 to 305, and the injured and death number reduced from 381 to 243. The number of signalized intersections increased from 87 to 364 in 1998–2007, which partially contributed to the reduction of traffic accidents.

### 3.2. Accident frequency

Various proofs show that the accident rate on road segment has an inverse relation to signalized degree and a direct proportion to AADT (Jones, Sisiopiku 2007). In this research, average accident rate (AAR) for type  $i$  intersection can be defined as the number of accidents ( $NOA_i$ ) per 100

mln entering vehicles (100 MEV = 10<sup>8</sup> passenger car unit (pcu)) over the period of  $N_{year}$  years and thus it reaches:

$$AAR_i = \frac{NOA_i}{100MEV} = \frac{NOA_i}{365N_iN_{year}AADT} \times 10^6. \quad (2)$$

As an arterial linking Nangang and Xiangfang, Wenchang Rd. has 15 major intersections, its accident features are typical in Harbin. When analyzing the accident records over 1992–2007, Table 3 presents that AAR at signalized intersection is lower significantly than that at non-signalized one.

**Table 3.** AAR estimation for intersections in Wenchang Rd.

Type	N	AADT/1000 pcu	NOA	AAR
Unsignalized	6	32.5	168	15.74
Signalized	9	43.8	143	6.63

However, Eq (2) does not consider the road features. Let us suppose that road satisfies the general user's need (e.g. such as the smooth road surface, etc.), then re-arrange Eq (2) and AAR could be approx estimated as follows:

$$AAR_i = \frac{k \times NOA_i}{365\rho_i N_i N_{year} AADT_i^*}, \quad (3a)$$

$$AADT_i^* = \sum \left( \frac{N_i \times AADT_i \times l_i}{L_i} \right), \quad (3b)$$

where  $k$  – pedestrian violation parameter, complying with road condition and traffic volume, we choose  $k = 10$ –13 in this research;  $AADT_i^*$  – entering traffic volume of intersection  $i$  measured through observed average annual daily traffic  $AADT_i$ , pcu;  $l_i$  – influence length of intersection  $i$ , km;  $L_i$  – influence radius of intersection  $i$ , km;  $\rho_i$  – signalized level of research road with intersection  $i$  that is determined by the overall number of signalized intersections divided by  $L_i$ , num/km.

It should be pointed out that Eq (3) may be invalid for branch road, since central isolation barrier of road segments limits the free road crossing behavior. Therefore,  $k$  should be reduced to 8–10 for medial divider use. Table 4 presents the AAR for 4 typical roads (without medial divider), respectively. Here we only consider the major intersections.

**Table 4.** Road features and traffic parameters

Road	L, km	$l_i$ , 10 m	$k$	$\rho_i$ , n/km	AADT, 1000 pcu	AAR
Fendou	2.82	6	10.2	3.2	32.6	87.37
Dacheng	2.18	5	12.3	1.4	24.8	187.36
Jingwei	2.33	7	10.5	3.8	34.7	51.82
Anguo	1.35	6	12.9	2.9	31.0	107.31

Notes:  $N = [7, 8, 8, 5]$ ;  $NOA = [102, 85, 137, 91]$ ;  $AADT^* = [9.71, 9.10, 16.68, 13.78] \times 10^3$  pcu

Obviously, the influence of control mode on accident rate could extend to the adjacent road segment beyond the controlled intersections. Dacheng Str. has the highest accident rate, though its length and AADT are not the max, traffic volume, by the lowest signalized degree.

### 3.3. AADT consideration

For a long period, the accident number has a statistical relation with traffic volume, road and environmental conditions, sidewalk facilities, and other factors. In this research, only AADT and number of intersections ( $N$ ) and in this limited view, accident number  $Y$  could be specified through AADT and  $N$  as

$$Y = \alpha \times AADT^p \times \exp(\beta N), \quad (4)$$

where  $\alpha$ ,  $\beta$ ,  $p$  – underdetermined parameters for function description;  $N$  – number of intersections counted from 7 types as shown in Table 2.

Then Eq (4) can be simplified by natural logarithm change to a linear regression relation between  $\ln Y$  and  $\ln AADT$  with three coefficients ( $\ln \alpha$ ,  $\beta$ , and  $p$ ), as expressed by Eq (5):

$$\ln Y = \ln \alpha + p \ln AADT + \beta N. \quad (5)$$

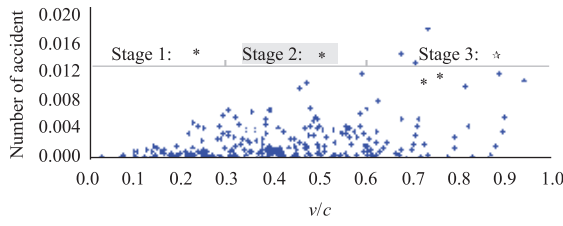
Accidents include 4 groups: frontal crash, side crash, rear-end collision and scrape. Combining Eqs (4) and (5), Table 5 then gives the regression expressions. In fact, these fitting models present general information about overla accident states instead of data accuracy and could be limitedly used to assess safety level of a total network or certain areas. Significantly, it does not work for small amount focus of accident samples.

**Table 5.** Linear regression model by types of accidents

ID	Pattern	Samples	Model	$t$ test
1	Total	1042	$0.0208AADT^{0.0072}e^{0.1472N}$	
	Frontal crash	183	$0.5717AADT^{0.1271}e^{0.0674N}$	
	Side crash	594	$0.6914AADT^{0.2606}e^{0.2531N}$	
	Rear end	153	$0.0116AADT^{0.1743}e^{0.2501N}$	×
	Scrape	112	$0.0245AADT^{0.1440}e^{0.3402N}$	
2	Total	265	$0.0013AADT^{0.5276}e^{-0.1864N}$	
	Frontal crash	54	$0.5396AADT^{0.1205}e^{0.0298N}$	×
	Side crash	128	$0.5569AADT^{0.1650}e^{0.1004N}$	
	Rear end	48	$0.0194AADT^{0.4619}e^{0.1630N}$	
	Scrape	35	$0.0091AADT^{0.3917}e^{1.4612N}$	×

Note: × - means that the fitting precision of proposed regression model is beyond the level of expectation and the function does not actually fit the crash data in this group very well





**Fig. 3.** Accident distribution at peak hours in response to  $v/c$   
Note: \* \* denotes high frequency and low number

To decide the influence of volume/capacity ( $v/c$ ) on accident occurrence, let check the average accident number under a fixed  $v/c$  value. Samples are divided into 3 stages: stage 1, for high frequency & low number under  $v/c \in [0, 0.3]$ ; stage 2, for high frequency & high number under  $v/c \in (0.3, 0.6]$ ; and stage 3, for low frequency & low number under  $v/c \in (0.6, 1.0]$ , as shown in Fig. 3, which presents the observations at peak hours for major roads and streets. It also states that accident occurrence depends on traffic state, due to its direct influence on driving process in judgement, decision-making, response and operation.

For  $v/c$  ranges within 0.3–0.6, a relative free flow environment, more accidents recorded reach a higher accident likelihood ratio, for drivers operate under weak safety awareness and slow response to emergency alarm. While  $v/c > 0.6$ , careful driving causes less accident. However, traffic jam state adds to the severity of injuries. To branch and minor roads, we ignore the statistics due to the lack of original accident records. Actually, risk level complies with  $u$ -distribution and the range ( $v/c = 0.3$ – $0.6$ ) sees a higher risk level involved moderate crowded conditions under stable flow, compared with free or congestion states.

#### 4. Pedestrian crossing risk assessment

Pedestrians have the right to travel on sidewalks and intersections without any risk. Pedestrian accidents can happen to anyone, however, at anytime, and anywhere.

##### 4.1. Gap acceptance approach

Generally, pedestrian involved crashes include all types of claims, such as crosswalk and intersection accidents, sidewalk accidents, bicycle accidents, induced by a car, truck, motorcycle, and bicycle in a crosswalk through intersection or hit-and-run accident (Zegeer et al. 2006). Most such crashes happen because drivers aren't paying attention or fail to yield the right of way in crosswalks or at intersections. Conflicts among disorder traffic are more prone to cause crashes (Chen et al. 2010).

Suppose the unidirectional vehicular number is  $X$  passing the intersection in the phase of  $t$ , then the average number per second can be described as  $\lambda = X/t$ . Vehicular flow is in Poisson distribution:

$$P(X = m) = \frac{(\lambda t)^m e^{-\lambda t}}{m!}, \quad m = 0, 1, 2, \dots \quad (6)$$

Crosswalk is considered as a kind of intermittent activity. Let the time head of vehicular platoon is  $T$ , an independent parameter subject to negative exponential distribution by  $P(T > x + \frac{t}{T} > x) = P(T > t)$ .

$$P(T \leq t) = \begin{cases} 1 - e^{-\lambda t} & t \geq 0, \\ 0 & t < 0. \end{cases} \quad (7)$$

Suppose pedestrian spends  $t_0$  to pass the crosswalk and  $T'$  to wait for the crossing gap in vehicular platoon. Then, pedestrian can cross directly without any wait ( $T' = 0$ ), if the wait time  $T \geq t_0$ , before the leading vehicle arrives. Otherwise, the wait possibility is defined as Eq (7), if  $T < t_0$  and  $T' > 0$ .

$$P(T' > 0) = P(T < t_0) = 1 - e^{-\lambda t_0}. \quad (8)$$

During the wait time  $T \geq t_0$ , a total number of  $Y$  vehicles have passed, and thus  $Y$  is given:

$$P(Y = h) = (1 - e^{-\lambda t_0})^h \times e^{-\lambda t_0}. \quad (9)$$

Substituting probability theory and mathematical statistics into Eq (9), the average amount of passing vehicles is:

$$E(Y) = \sum_{h=0}^{\infty} h P(Y = h) = \sum_{h=0}^{\infty} h (1 - e^{-\lambda t_0})^h \times e^{-\lambda t_0}. \quad (10)$$

For such a case, the wait time distribution could be further determined as

$$\begin{aligned} F(t) &= P(T' \leq t) = P(T' = 0) + P(0 < T' \leq t) = \\ &= e^{-\lambda t_0} + \sum_{h=1}^{\infty} P(Y = h) P(0 < T' \leq t | Y = h) = \\ &= e^{-\lambda t_0} + \sum_{h=1}^{\infty} (1 - e^{-\lambda t_0})^h \times e^{-\lambda t_0} \int_0^t \frac{\lambda (\lambda x)^{h-1}}{(h-1)!} e^{-\lambda x} dx = \\ &= e^{-\lambda t_0} + \lambda e^{-\lambda t_0} (1 - e^{-\lambda t_0}) \int_0^t e^{-\lambda x} e^{\lambda x (1 - e^{-\lambda t_0})} dx = \\ &= 1 - (1 - e^{-\lambda t_0}) e^{-\lambda t} e^{-\lambda t_0}. \end{aligned} \quad (11)$$

On expanding and rearranging Eq (11), the wait time distribution of pedestrian is:

$$F(t) = \begin{cases} 1 - (1 - e^{-\lambda t_0}) e^{-\lambda t e^{-\lambda t_0}} & t \geq 0 \\ 0 & t < 0 \end{cases}. \quad (12)$$

The average wait time can be determined via traffic volume and demographic conditions. In fact, pedestrian's wait time length may be often affected by various fuzzy

factors (e.g. weather condition, platoon size). Therefore, the model is further estimated as

$$E(T') = \int_0^{+\infty} t \frac{d \left[ 1 - \left( 1 - e^{-\lambda t_0} \right) e^{-\lambda t e^{-\lambda t_0}} \right]}{dt} dt = \lambda e^{-\lambda t_0} (1 - e^{-\lambda t_0}) \int_0^{+\infty} t e^{-\lambda t e^{-\lambda t_0}} dt = \frac{e^{\lambda t_0} (1 - e^{-\lambda t_0})}{\lambda}. \quad (13)$$

Assuming the wait time is  $T_w$  for the  $k^{\text{th}}$  crossing gap, and  $T_i$  is the time between the  $(i - 1)^{\text{th}}$  crossing gap and the  $i^{\text{th}}$  one, then the finding  $T_w = \Sigma T_i$ , means that  $T_i$  is dependent. Following negative exponential distribution, it acquires  $\{W = w\}$  and  $T_{w+1}, T_{w+2}$ . Once waiting time is determined for the  $k^{\text{th}}$  member, its average length of the  $k^{\text{th}}$  crossing gap is estimated directly based on Wald regulation as

$$\bar{T} = E(T_w) = E(T_1)E(w) = \frac{1}{\lambda}(k - e^{-\lambda t_0})e^{\lambda t_0}. \quad (14)$$

Derived from Eq (14), the total number of crossing gap  $k$  within the given period  $[0, t]$  could be developed as the following expression:

$$N = (1 + \lambda t)e^{-\lambda t_0}. \quad (15)$$

**4.2. Risk assessment**

Let assume the pedestrians pass the crosswalk in line. The width of crosswalk is  $R$ , pedestrian amount of each direction is  $K$ , space between the passing pedestrians is  $S$ , and walking speed is  $V$ . Then while approaching an interspace  $T = t_0 + \frac{iS}{V}$  in the stream of platoon, it captures the acceptable gap for  $N(i+1)$  pedestrians to pass the crosswalk successfully.

By Eq (15), the number of vehicle's arrival gap satisfy

$T \geq t_0 + \frac{iS}{V}$  that could be estimated by

$$\tau_i = (\lambda \bar{T} + 1)e^{-\lambda \left( t_0 + \frac{iS}{V} \right)}, \quad i = 0, 1, 2, \dots \quad (16)$$

If  $t_0 + \frac{iS}{V} \leq T < t_0 + \frac{(i+1)S}{V}$ , safe crossing amount remains the same in the phase of  $[0, t]$ . Consequently, the safe crossing times is rewritten by

$$Q_i = \tau_i - \tau_{i+1} = (1 + \lambda t)e^{-\lambda \left( t_0 + \frac{iS}{V} \right)} \left( 1 - e^{-\frac{\lambda S}{V}} \right). \quad (17)$$

Thus, the total amount of critical pedestrian crossing as the following expression:

$$P_{critical} = \sum_{i=0}^{\infty} K(i+1)Q_i = \sum_{i=0}^{\infty} K(i+1)(1 + \lambda t)e^{-\lambda \left( t_0 + \frac{iS}{V} \right)} \left( 1 - e^{-\frac{\lambda S}{V}} \right) = K(1 + \lambda t)e^{-\lambda t_0} \left( 1 - e^{-\frac{\lambda S}{V}} \right) \sum_{i=0}^{\infty} (i+1)e^{-\frac{i\lambda S}{V}} = K(1 + \lambda t)e^{-\lambda t_0} \frac{e^{-\frac{\lambda S}{V}}}{\left( 1 - e^{-\frac{\lambda S}{V}} \right)^2} = KN \frac{e^{-\frac{\lambda S}{V}}}{\left( 1 - e^{-\frac{\lambda S}{V}} \right)^2}. \quad (18)$$

Pedestrian risk factor (*PRF*) is defined to reflect the satisfied degree of critical crossing demand to the actual supply amount. The bigger the *PRF* is, the higher risk a road confronts for crossing pedestrians, especially at peak hours.

$$PRF = P(P < P_{critical}) = 1 - \exp \left( -\frac{P_{survey}}{P_{critical}} \right) =$$

$$1 - \exp \left[ -\frac{P_{survey}}{KN} \times \frac{\left( 1 - e^{-\frac{\lambda S}{V}} \right)^2}{e^{-\frac{\lambda S}{V}}} \right]. \quad (19)$$

The *PRF* yields messages of risk severity for crosswalk locations. The appealing features of this methodology include the following:

- crossing risk can be sized using traffic flow messages and surrounding environment data;
- it is fairly suitable for overall estimation of full length road within observation time rather than short term prediction;
- extended *PRF* should consider similar issues for regions or overall road networks.

**4.3. Case application**

Pedestrian safety is a major concern in Harbin and recent fatal intersection accidents raise concerns about this issue. 40.8% of adult pedestrian injuries and 23.6% fatalities occur at intersections in this city (Pei, Hu 2004), more occurring in winter. On July 29, 2007, a serious accident occurred at Hongqi Str caused by an overspeeding truck (Fig. 4.3). Four crossing pedestrians lost their lives and two seriously injured.

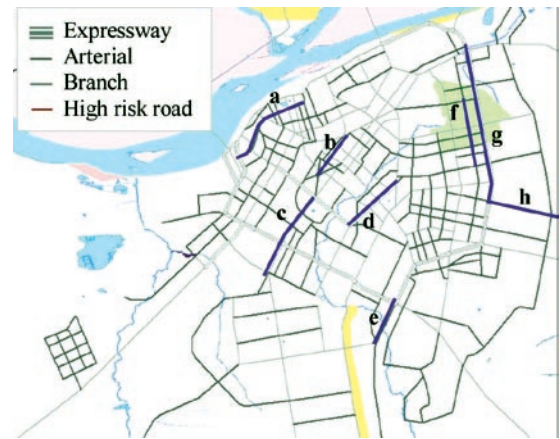


**Fig. 4.** Hongqi Str. as a case study road: 1: three specific intersections; 2: risk crossing behavior; 3: '729' accident site. Note: a – main lane 1, b – main lane 2, c – main lane 3, d – auxiliary lane for bus and non-motorized vehicles

Fig. 4.1 shows that this street has three vehicle lanes and one bus lane at one side and general automobiles are not permitted to drive in blue lane, which induces this lane having few chances to meet with heavy traffic flow state. Thus, we mainly consider other three lanes and three locations, Loca. A, Loca. B and Loca. C, are chosen because of the frequency pedestrian accident rate around these three intersection. Loca. A is an entrance to a newly built residential area, Loca. B is near to a supermarket, Loca. C connects two residential areas and all of them lie in the intersection of branch road connected to arterial (Hongqi Str.).

The spot survey was carried out at 17:00–18:00 on May 14<sup>th</sup>, 2008 and record time is 15 min. Here the average crossing speed is set as 1.2 m/s (Feng, Pei 2007). Due to the isolation barrier at Loca. A, this site's crossing behavior is divided into two parts and only one is considered. In addition, crossing time has a little difference for the composition of pedestrian. The modeling order is from right to left.

From Table 6, it can be decided that Loca. A (right side of cross section with four lanes) has the most likelihood to cause pedestrian involved collisions and the second is Loca. C on the right side of Hongqi Str. Following the similar procedure, 8 roads with related intersections are identified as the higher risk locations, as marked in Fig. 5, which are located mostly in the old districts. Due to lack of



**Fig. 5.** Higher risk road identification prone to pedestrian accidents in Harbin: a – Youyi Rd.; b – Yiman Str.; c – West Dazhi Str.; d – Wenchang Str.; e – Haping Rd.; f – Hongqi Str. (Nantong Str. – Changjiang Rd.); g – Nanzhi Rd. (Hadong Rd. – Gongbin Rd.); h – Gongbin Rd.

investment, traffic control, speed bumps, makes and signs, as well as other kinds of safety facilities, are inadequately equipped in quantity and rational distribution.

**4.4. Safety improvement initiatives**

Recently, a new approach called Context Sensitive Design (CSD) has been utilized to enhance the traffic safety performance (Stamatiadis 2005). As a philosophy in safe transportation solutions, CSD seeks to design new roadways, intersections or modify existing ones to suit all users – drivers, bicyclists, and pedestrians. A fundamental concept of CSD is positive guidance, including understanding the needs of road users, especially that of automobiles information transmission to drivers and providing definite and unambiguous travel messages before intersections to help drivers detect hazards, select an appropriate speed, initiate and complete their tasks safely.

The idea of well designed intersection means to minimize traffic conflicts and decrease the occurrence likelihood of accidents. The effective measures consist of providing exclusive left-turn lanes to separate through and turning traffic, restricting or eliminating turning behaviors by providing clear channelization or closing median openings, setting acceleration lanes, and closing or relocating an intersection leg, realignment disposal, for skew intersections. As Fig. 6 shows, open intersection catches

**Table 6.** PRF determination along Hongqi Str. segment

Loca.	$t_0, s$	Vol, pcu/h	K, per	S, m	N	$P_{sur}$ per	$P_{cri}$ per	PRF
A	9.5	2648	8	1	3.52	76	132	0.672
B	9.0	2632	13	0.8	4.57	245	183	0.526
	9.0	2645	11	0.8	4.44	200	197	0.627
C	10.0	2574	15	0.8	2.53	164	186	0.679
	10.0	2586	18	0.8	2.45	200	164	0.484



**Fig. 6.** Safety enhancements at intersections: a – unsigned, open mode; b – textured crosswalks and expanded islands

more chances of collision and crash involvement and safety facilities (e.g. median and curb, signal, striped bike lane and stop line) could increase driver's predictability and make pedestrian's crosswalk safer (King *et al.* 2003). Studies reached the same findings that canalization may contribute to 15–57% reduction (Pei, Hu 2004).

By Midwest Research Institute (MRI), installation of left-turn lanes reduces 22% crashes at three-legged unsignalized intersections and 24% at four-legged ones for urban major roads. MRI also found that right-turn lane installation reduced crashes on individual approaches to four-legged intersections by 27% at rural unsignalized intersections (Levinson *et al.* 2005), and may be more effective in urban areas.

Traffic claiming is an effective measure to improve pedestrians and bicyclists safety, involving a series of physical treatments ranging from decreasing vehicle speed and volumes for certain roads that are not intended for high-speed or "cut-through" traffic to alerting the driver's attention. People use pedestrian safe islands and passive signs to estimate approaching vehicles' speed and protect the vulnerable road users. Traffic lighting, guiding sign, and rumble strips et al can help claim the intersection presence (Madanu *et al.* 2010). It is encouraged strongly to clear any obstacle in sight triangles near intersections, to eliminate parking that restricts sight distance, to implement lighting for pedestrians, and to take crosswalk illumination measures. Inadequate sight distance for drivers at approaches to intersections has long been recognized as among the most significant factors contributing to intersection crash. A shape bend with unguarded lighting columns is prone to make rear-end collision, especially when the horizontal curve is sharp and the minor road is close to the horizontal curve. Safety effectiveness can be expected up to a 20% reduction in related crashes (Ali *et al.* 2009).

Law and enforcement always play an important role in safety management. Since the 1970s, photo enforcement measure has been used widely in Europe, Australia, and North America to improve safety at intersections and Edmonton, Canada, has also used automated photo enforcement as part of the overall enforcement activity (Sayed, Leur 2007). According to the Ministry of Public Security of P. R. China, only 749 road accidents with 130 injuries occurred in 50 days after in effect in Hubei, and accident number and injury decreased 56% and 26.9%, respectively, compared with 2005. As we all now, driver boredom easily leads to self-reporting of cognitive failure and error-proneness and finally causes accidents (Heslop *et al.* 2010). Therefore, law is necessary to forbid long-time driving. Each region has different conditions and thus local rules and regulations should be permitted.

Besides the security facilities construction, education is also another effective measure to improve safety. The internal concern of employing education and information is a strategy that reaches pedestrians and motorists with safety awareness tips for travel, driver or operator education, or the safety instructions given on an airplane. In Shenzhen, a so-called seat belt safety campaign was encouraged

since 2008 and a two-week media advertising was to inform the public about benefits of safety belts, child safety seats and punitive rules (Ma *et al.* 2007). In 2004, Washington State applied NHTSA's High-visibility enforcement (HVE) campaigns to heighten public awareness of safety driving and better educate operators in an effort to reduce accident occurrences, and continued efforts are being made to increase data exchange at the inter-modal, inter-governmental and with other sectors to have an interest in safety (Thomas *et al.* 2008). Especially, there are such organizations as Texas in-school driver education and traffic safety unit to provide all drivers in all grade levels the knowledge and skills to safety driving. Norwegian driver education program is extensive and systematic and educates drivers with different contents according to their age, experience, education and driving aims in licensing stage. However, most of these efforts is only symbolic and has little substantial effect (Jauneikaitė, Carreno 2009), where, of course, active prevention measures and technologies are urgently welcomed.

## 5. Conclusions

The study presented in this paper attempts to evaluate the safety performance of accidents and identify the factors contributing to mortality and severe injury, using the comprehensive historical crash records that are maintained by the Harbin Transport Dept. The paper addresses some statistical process to discuss the intersection involved accidents, including crash number, crash rate, AADT and  $v/c$  rate, and accident locations, at expressway, branch and minor urban roads in a mixed roadway network, and they are expected to help understand and couple with the alternating safety tendency effectively.

One of the most significant contributions of this study is the newly proposed concept of pedestrian risk factor (*PRF*), a practical indicator to identify locations that are risky in the total network and to suggest improvement measures for dangerous locations, especially around large traffic generators/attractors area through monitoring traffic flow data and environmental factors. Noteworthy, all these concerns should be paid to the most vulnerable groups (e. g. elderly and disabled persons) and simultaneously identifying areas of hazardous locations.

There are some important notes from this study useful for the real application along intersection involved traffic crashes. It is very important, but very difficult, to choose and process the effective safety performance improvement measures over a long period of time for trends. Thus, it is recommended that future research lies in exploring an intelligent data processing technique. How can bridge intelligent management tool and security facilities supply be conducted within a multidisciplinary set of perspectives (e.g., traffic equity, conflict separation, driver training)? There is a need for continued or more in-depth discussion in certain topics.

The authors believe that it will become an important topic that has not ever been drawn intensive attention in past and further research will focus on a system design of



safety management and improvement for intersection locations in the overall urban areas.

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