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FATAL MOTOR VEHICLE CRASHES ON ROAD SEGMENTS IN HARBIN, CHINA: COMBINING RATES INTO CONTRIBUTORY FACTORS

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Abstract. In spite of recent advances in traffic surveillance technology and ever-growing concerns over the safety performance improvement, there have been very few conclusive research efforts addressing the segment-involved traffic crashes. This research aims at evaluating the segment-involved crashes using 10 years of documented crash data (2000–2010) in Harbin. The interactions of crash patterns, distribution features, injury severity and potential causes are explored by mining a variety of contributory factors associated with driver demographics, roadway geometric design, environmental state, distribution of traffic flow, etc. Results show that different crash patterns are correlated with a number of risk factors at different roadway locations such as the driver's age and experience, weather, with or without median/division, number of lane, deviation of travelling speed, Annual Average Daily Traffic (AADT), volume to capacity ratio (*v*/*c*), and so on, and different combinations of factors may lead to some specific crash patterns such as head-on, angle or rear-end collisions. Moreover, four black locations with a huge number of crashes are identified due to heavy truck involvement on these in/out roads. These findings will help to better understand what, when and why these crashes occur and develop more targeted and cost-effective countermeasures to enhance the overall safety performance of the roadway network.

Keywords: traffic safety; segment crash; contributory factor; black location; collision pattern; roadway network.

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Introduction

Even though the number of dead and wounded in traffic accidents has decreased over the previous decade, the statistics are still alarming. In 2010, the number of accidents decreased to 2,195,212 with 65,225 fatalities and 254,075 injuries in China, dropped by 7.9%, 3.7% and 7.7%, respectively. Jiangxi also witnessed a decline of 3354 crashes, 1507 fatalities and 3910 injuries in 2011.

Fatalities were reduced to about 65,000 in China, 40.37% lower than the peak year of 2002, and 253 persons were killed on urban roads with the highest rate of facilities in Jiangxi. In Israel, a recent statistical research by Gitelman *et al*. (2012) found that 75% of fatalities and 95% of injuries in pedestrian accidents occurred in urban areas and 80% was due to wrong or poor street-crossing behaviours. Therefore, recent years have seen an increasing need to address the higher fatality rates and enhance the overall safety performance of road networks (Park, Abdel-Aty 2011). Several findings from Europe and North America have also matched this claim, but have not explored the causes in depth.

To cope with the particular challenges of urban crashes, a multiple of scales and scopes have been conducted to measure the effects of different factors on crash occurrence and injury severity. Earlier, Rumar (1986), using British and American crash reports as data, found that human or behaviour factors, such as excessive speed, inattention, fatigue, alcohol and/or drugs impairment, failure to wear the seat belt, etc., were wholly or partly due to about 93% of the crashes. Similar results were also reported in many other researches later (Haleem, Gan 2011; Thygerson *et al*. 2011). Alam and Spainhour (2008) examined the drivers who were involved in crashes in Florida and found that indicated confusion, inappropriate action, or illegal manoeuvres as crash-contributing factors were often witnessed in drivers aged 75 years and older. A Taiwan study (Huang, Lai 2011) showed that alcohol impairment contributed to approximately 60% of car driver fatalities and 40% of motorcycle driver fatalities.

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In New Zealand, fatigue was identified as a contributing factor to 5.1% of the official truck crash records (Gander *et al*. 2006). Kashani *et al*. (2011) studied the rural road crashes in Iran and found that failure to wear the seat belt was the major contributory factor to crashes and particularly to the severity of injuries, but it may be only one of the potential contributing factors. Unfortunately, this is often underestimated.

There are overwhelming evidences that prove excessive speed has a close and potential relationship with crashes and severe injuries. Sun *et al*. (2007) examined the characteristics of traffic crashes on the Jingjintang freeway in China and found that the deviation of speeds between passenger cars and large trucks is the main cause of fatal crashes, particularly for rear-end collisions. Obviously, lower speeds result both in fewer crashes and in reduced injury severity of crashes (Eustace *et al*. 2011). Through the analysis of 812 pedestrian casualties in Ghana, it was estimated that the probability of a pedestrian-involved crash fatality is 65% attributable to over-speeding, using a multinomial logistic regression. Based on police reports of the 243 km Yaounde-Douala road section in Cameroon over 2004–2007, over-speeding was identified as the third most frequent causal factor that accounted for approximately 20% of the fatal crashes (Sobngwi-Tambekou *et al*. 2010). An examination of 1185 fatal vehicle crashes in the UK from the years 1994 to 2005 inclusive also showed that over 65% of the crashes occurred while over speeding (Clarke *et al*. 2010). Moreover, in our earlier study in examining the two Ring Expressway crashes in Xi'an, it was concluded that the risk of being involved in an injury crash was the lowest at speeds near or below the median speed, 56 km/h, and increased sharply beyond this mean value (Wang *et al*. 2011a), which also confirmed the earlier studies (Ma *et al*. 2010; Dell'Acqua, Russo 2011). However, Quddus *et al*. (2010) had found that the level of traffic congestion does not have a direct and significant effect on the severity of road crashes while exploring their relationship with the 2003–2006 crash records from the M25 London orbital motorway. Based on this view, it is impossible to give a decisive result.

Furthermore, traffic flow, roadway design, adverse weather conditions and associated environment hazards have also been studied as specific contributing factors that could influence the risk threshold, driving manoeuvers and finally safety (Lum, Reagan 1995). Haque *et al*. (2010) determined that the number of lanes, a wide median and an uncontrolled left-turn lane at four-legged intersections increase the potential hazard largely that will cause motorcycle-involved crashes, as claimed by Ewadh and Neham (2011). Daniels *et al*. (2011) argued that three-leg roundabouts had a worse safety performance than those with four or more legs and larger central islands witnessed more single-vehicle crashes. A recent research from Haleem and Gan (2011) indicated that gender, traffic volume, speed limit, road surface condition, and left and right shoulder widths, etc., all influence the occurrence of crashes and injury severities and that the afternoon peak period had the highest rate in fatality/severity in one day. In our previous study of roadside crashes using 172 records from three freeways in Jiangxi over a three-year period, type of roadside and median barriers, width of shoulders, and pattern of embankments were identified as contributory factors in run-off-road crashes (Wang *et al*. 2011b). This is consistent with the findings in Sweden (Ydenius 2009).

Thus, there is an urgent need to create a safe road environment and a harmonious traffic society. Since October 2005, a safety improvement campaign, titled 'Sustainable Livelihoods Access and Safety (SLAS) project', has been launched to diagnose and improve the safety performance of the overall roadway network, in which more effective enforcement policies and measures would be taken into action including implementing safety-driving laws, setting of speed limits and speed enforcement systems such as speed cameras, etc., in Harbin (Wang *et al*. 2011c). However, the design of all these efforts needs better understanding of the contributor's features of road crashes and in particular those of the most severe type. One possible measure of achieving this remand is to examine the specific characteristics, in terms of seriousness and contributors of crashes. Upon such a basis, this study attempts to explore the relationship between crash features and contributory factors. The findings of this study will help to better understand the occurrence of traffic crashes and develop more targeted measures to improve the overall safety performance of the roadway network in Harbin, as well as in other major cities.

1. Data collection and processing activities

This section presents the data preparation process undertaken to assemble a database for addressing and analysing segment-involved crashes, including crash records, road network messages and traffic volumes.

1.1. Crash records

Harbin, the capital of Heilongjiang Province, China, consists of 8 districts (Daoli, Nangang, Daowai, Xiangfang, Pingfang, Songbei, Hulan and Acheng) and 10 satellite cities, with an area of 53,796 km^2 and a population statistics of 10,635,971 as of 2010. As most of the Harbin area belongs to rural villages, we limit the study area in our analysis within the scope of Harbin city, mainly including the first three districts; the crash data are all from policy accident reports and statistical database. Within Harbin's electronic crash database, a crash can be classified as intersection, intersection-related, driveway or non-intersection. The intersection crash and intersection-related crash are both associated with intersection, accounting for those occurring at intersection locations rather than the road segment portions. A driveway crash influenced by the number of driveways, however, witnesses a small amount of accidents. Therefore, such a crash is included into the non-intersection crash (called segment crash) and additional research is conducted by these two types of crashes.

A sample of 8036 fatal segment-related crash cases during the 10-year period of 2000–2010 inclusive is selected from 30,647 traffic crashes that were recorded and considered in this research. Crashes that were not reported could not be included in this study; Property Damage Only (PDO) that resulted in vehicle or facilities damage, with no injury to drivers, passengers or other road users, makes up for 46.32% of the total crash records, are not used in the analysis. Additionally, 1025 records with incomplete information are also removed from the final database. Contained in each police file is a report sheet/card, which summarises the crash messages about data, time, location, roadway geometries, pavement conditions, weather conditions, intentions and behaviours of drivers and witnesses, collision types, crash severity and a range of other items. Such a sheet also gives a detailed crash history about the interpreted comments of the attending police officers, maps, photographs, measurement of skid marks by police, statements of vehicle examiners, interviews and witnesses, which provide rich information in reconstruction of the entire incident from the information available in the policy record.

In the study area, 8036 crashes out of the valid 15,426 records found between 2000 and 2010 were selected for this project; the crash data are extracted from the electronic database. In other words, about 52.1% of the crashes involve over-speeding or other speed-related factors. A set of minimum possible explanations for each crash was recorded to obtain the objective facts of each crash location: roadway geometries, class of road, crash severity and crash types, as shown in Table 1. Here for crash severity, four levels are determined: fatal injury (type K), incapacitating injury (type A), non-incapacitating injury (type B) and possible injury (type C). Crash types, in the example Xianfeng Rd., are categorised into seven groups: front end, angled strike, rear end, sideswipes, strike object, ran-over embankment and others. For simplification, we do not consider the fatalities, injuries and property damages beyond the crash amounts.

1.2. Road network message

For this study, road sections, which include both arterials and sub-arterials of Harbin in 2010, are selected to be adjacent to each other on the same road segment to ensure that the information is as nearly matched as possible with the crash data, and the few changes in roadway network since 2005 are also taken into account. Harbin's geometric database is used to identify the segment geometric characteristics within the associated four districts: road type, road length, segment type associated with median, segment length (a road is divided into several segments by different median closings), segment width, number of driveway lanes, number of driveway openings associated with a residential zone, or a named road (the number of segment openings is summed by section length to determine the segment opening density). Table 2 presents the summarised result.

Finally, the road database for the study includes a total of 45 arterials and 82 sub-arterials. In response to median closings, we derive 483 segments derived from the available 127 roads according to lane numbers and median amounts. As presented in Table 2, the four-lane segments without a median account for 35.4% among the total determined segments and the following are two-lane segments without a median and six-lane segments without a median by 26.08% and 13.0%, respectively. This summarised table also indicates that the four-lane segments without a median cover the biggest proportion of the overall road network in

Table 1. Explanatory example of police crash sheet

			Crash count[a]						Crash severity				
ID	Road	Segment	HO	AC	RE	SW	SV[b]	OT[c]	C	B	A	K	Total
1	Xianfeng	Xuanhua – Hongqi	7	13	6	2	1	0	16	8	6	0	30
2	Xianfeng	Hongqi – Nanzhi	9	11	5	1	0	0	19	6	2	0	27

[a]HO, head on collision; AC, angle collision; RE, rear end collision; SW, sideswipe collision; SV, single vehicle collision; OT, other;
[b]Striking object, striking pedestrian, overturn, run-off road, striking parked vehicle, etc.;
[c]Animal, bird, pavement, vehicle – self- or weather-induced crashes, etc.;
Single vehicle alone: collisions with structures, light pole, road sign, central reserve/median strip, guard fence, house and wall, bridge and pier, etc.; collisions with parked vehicles, run-off road, rolling down, turning over, others;
Person to vehicle: while walking facing or parallel to vehicle, on the side walk, on the side strip, on the roadway; while crossing the segment, on the pedestrian crosswalk, in the vicinity of pedestrian bridge; while playing, working of standing on the segment, others;
Vehicle to vehicle: head on collision while passing or overtaking, rear end collision while travelling, parking or stopping; collision while making U-shaped turning, turning right or left, or backing up, collisions while passing each other, collisions while crossing segments, others.

Table 2. Sum of segment classification by geometrics of lane number[a] and median type

Segment type	1[b]	2	4	6	8	10[c]	PST[d] [%]
None median	7	126	171	53	5	5	75.98
One median	0	0	18	9	26	0	10.97
Two medians	0	0	0	32	1	0	6.83
Three medians	0	0	0	9	21	0	6.22
PST[d] [%]	1.45	26.08	39.13	21.34	10.97	1.04	100

[a]Total amounts of lanes in two directions;
[b]Segments limited in single direction traffic;
[c]Freeway segments;
[d]Percentage of segment type.

Harbin city, which significantly supports mixed daily traffic and has witnessed more crashes. Additionally, the proportion of one median segment in service is approximately equal to that of the two median segments by about 9%.

1.3. Traffic flow involvement

Traffic volume has a significant effect on travelling speed as well as on crash occurrence, as it was proven in many previous reports (Qin, Reyes 2011), and one approach is to determine whether or how it induces crashes. Thus, we have obtained the present traffic volume messages for 305 segments, located within Daoli, Nangang, and most part areas of Xiangfang and Daowai, from the video detectors at segments and intersections. For the other 152 segments, we have carried out two traffic surveys on 12 April 2010 and 25 September 2010. Meanwhile, we have referenced the historical traffic volume in the report of 'Annual Traffic Report of Harbin', in which the traffic conditions have been reflected. Thus, the Annual Average Daily Traffic (AADT) volume at these 457 segments are used to reflect the traffic volume level in statistical mode over the period 2000–2010 and for the remaining 26 segments, their AADT is mainly estimated by the adjusted segments or intersections nearby. Table 3 presents the distribution of traffic flow on roadway network by the type of segment.

Traffic volumes vary according to the time of day, season and weather conditions as well as the existing AADT, PM peak hour traffic (evening commute) and turning movement volume. Unfortunately, the observational values through the original survey could not be used as AADT, because:

(1) AADT or flows in vehicles per peak hour (FPH) could not be obtained for some segments;
(2) some year's data are missing;
(3) flows in vehicles per day (ADT) are not equal to AADT.

Therefore, ADT and FPH need to be converted by Eqns (1a) and (1b). Additionally, ADT derived from different months and years should be converted into the basic year's value:

$$AADT_i = \frac{FPH_i \cdot \beta_{1i} \cdot \beta_{2i}\ 1}{k_i}; \tag{1a}$$

$$FPH_i = ADT_i \cdot \beta_{1i} \cdot \beta_{2i} \cdot k_i, \tag{1b}$$

where: $AADT_i$ – AADT value to be estimated for segment i [pcu]; FPH_i – FPH value by observation or to be estimated for segment i [pcu]; ADT_i – ADT value by observation or to be estimated for segment i [pcu]; β_{1i} – year modification coefficient for segment i, assumed as Eqn (2a) basic year's ADT/ADT of a particular year; β_{2i} – month modification coefficient for segment i, assumed as Eqn (2b); k_i – FPH/AADT for segment i.

$$\beta_{1i} = \frac{ADT_{i0} \text{ of base year for segment } i}{ADT_i \text{ to be estimated for segment } i}; \tag{2a}$$

$$\beta_{2i} = \frac{AADT_i \text{ for a year for segment } i}{ADT_i \text{ to be estimated for a month for segment } i}. \tag{2b}$$

By dividing the total segments into groups by the AADT distribution on the segments of different types in 10,000 pcu (Table 3), where $MAADT_i$ for the AADT on average segment is by:

$$MAADT_i = \frac{\sum_{j=1}^{N_i} L_{ij} \cdot AADT_{ij}}{\sum_{j=1}^{N_i} L_{ij}}, \tag{3}$$

where: $MAADT_i$ – average AADT value for the type i segment, $i = 1, 2, 3, 4$ [pcu]; $AADT_{ij}$ – AADT value of the segment j within the type i category [pcu]; L_{ij} – length of the segment j within the type i category [km]; N_i – number of the type i segments.

From Table 3, AADT on segments with none, one, two and three medians range within 10,000÷20,000 pcu, 30,000÷40,000 pcu, 20,000÷30,000 pcu

Table 3. The AADT featured segment count by geometrics characteristics and 10,000 pcu

AADT	SMT^0 segment						SMT^1 segment			SMT^2 segment		SMT^3 segment	
	1	2	4	6	8	10	4	6	8	6	8	6	8
0÷10000	7	79	34	3	0	0	4	0	0	1	0	0	0
10,001÷20,000	0	24	78	19	3	0	3	0	1	0	0	0	0
20,001÷30,000	0	17	31	13	1	0	5	1	6	17	1	1	2
30,001÷40,000	0	6	8	9	1	0	2	5	12	7	0	2	4
40,001÷50,000	0	0	7	5	0	2	2	2	4	5	0	4	12
50,001÷60,000	0	0	7	3	0	3	1	1	3	2	0	2	1
60,001÷70,000	0	0	6	1	0	0	1	0	0	0	0	0	2
70,001÷∞	0	0	0	0	0	0	0	0	0	0	0	0	0
AADT	4740	8790	17,280	27,830	16,620	53,960	24,530	43,610	35,870	23,120	25,090	47,860	43,850
MLENG	0.357	0.674	0.5308	0.868	0.872	0.614	0.567	0.499	0.773	0.519	0.625	0.993	0.464
MAADT	16601						35649			22839		45769	

AADT – Annual average daily traffic;
Note: original work done in China standard units therefore AADT value of different vehicle types should be converted to pcu by vehicle transfer coefficients;
SMT $^{0–3}$ – segments of median type for none, one, two and three;
MLENG – sum (length of segments)/total amount of segments;
MAADT – sum (AADT of a certain segment × length of this segment)/sum (length of segments).

Fig. 1. The prototype of traffic volume intensity united 10,000 pcu on road segment networks in Harbin

and 40,000 ÷ 50,000 pcu, respectively, on which MAADT varies from 16,601 pcu and 35,649 pcu to 22,839 pcu and 45,769 pcu.

Figure 1 presents the intensity of traffic flow on road segment network (Dai 2010).

The AADT distributions on the majority of segments, unsurprisingly, comply with the types of road and crash performances. However, one median segment appears to afford more AADT than two median segments, due to more than 80% of one median segment belonging to the ring expressways and urban access roads (i.e., Hachang and Hamu that are marked in red in Fig. 1). Such locations within the segments account for more heavy trucks and passing traffic, especially at night.

2. Findings and results analysis

2.1. Demographic characteristics

The general characteristics of segment crashes vary from country to country. For the period 2000–2010, type of injuries and deaths, sex, age and license status of drivers are shown in Table 4. Obviously, the gender-specific death and injury rate show significant differences between male and female, observed in Harbin. It tells us that a male is more likely to be involved in a segment-induced crash (Villaveces *et al.* 2011). Particularly, passenger car drivers involved in crash deaths and injuries account for more than all other persons combined, and approximate 1.4% of people who die or who are seriously injured are passenger car and truck drivers, especially taxi drivers and truck drivers of long-distance ferries. About one-third of such drivers have invalid licenses or even no licenses.

Table 4. The percentage of population involved in a crash

Variable	%	Variable	%
Gender		*Licensed driver*	
Male	76.3	Yes	65.9
Female	23.7	No	34.1
Age		*Causes out of over-speeding*	
<18	2.6	Vehicle or brake false	23.3
18÷24	13.5	Fatigue/alcohol	19.2
25÷32	25.1	Inattention	10.6
33÷50	35.2	Inclement weather	21.1
51÷60	16.4	Lighting effects	14.6
>60	7.2	Others	11.2
Experience/year		*Type of vehicle*	
<3	8.7	Passenger car	65.1
3÷5	42.9	Bus	9.9
5÷12	34.3	Trucks	16.3
>12	14.1	Semis	8.7

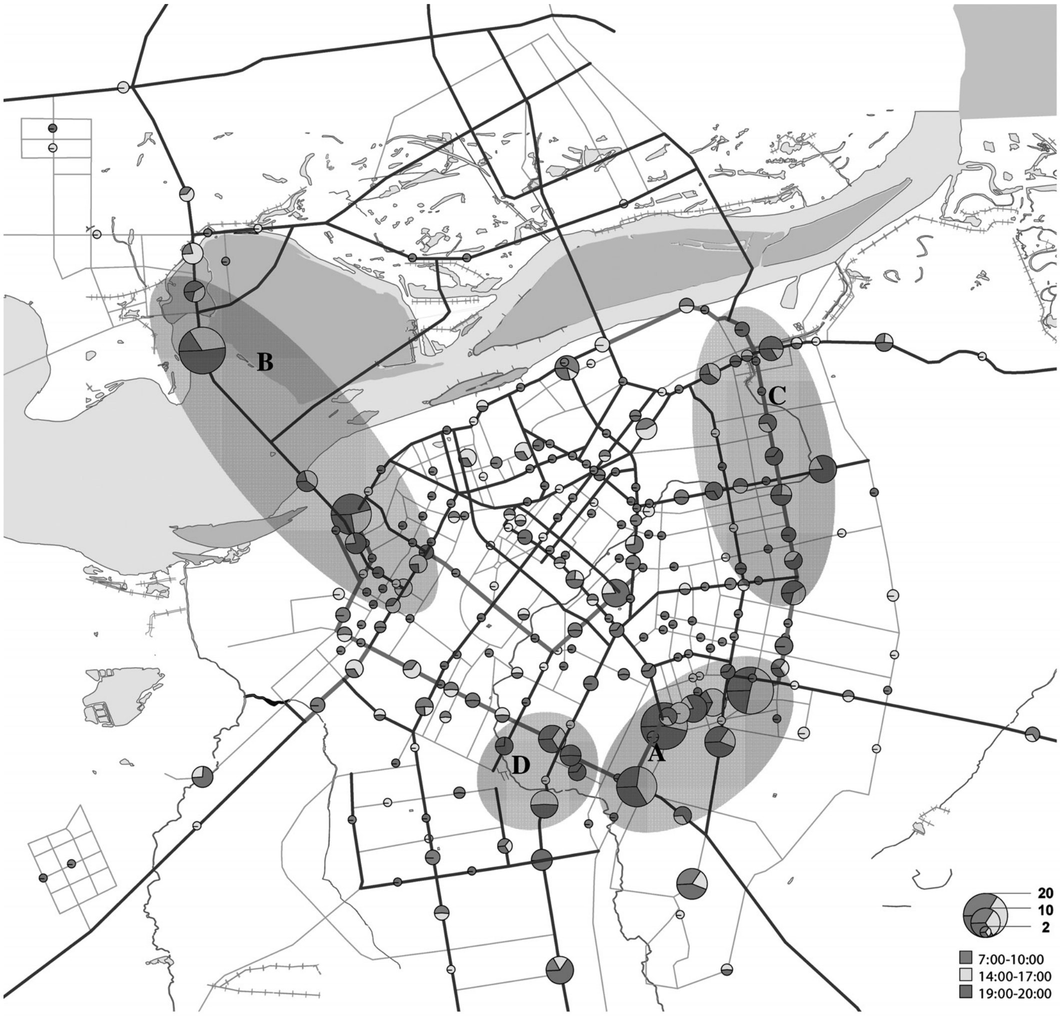

Fig. 2. The temporal prototype of segment crashes on roadway networks

In fact in Harbin, persons being involved in crashes demonstrate a big proportion in mortality of the most vulnerable age groups: less than 24, 51÷60 and more than 61 years. This is consistent with the findings that in high developing countries, adults aged between 15 and 29 years are the most dangerous for both sexes (Dell'Acqua 2011). Although young drivers have good reaction times, disproportionately more crashes related to young male drivers are observed during the period 2000–2010 in Harbin, due to the contribution of excess or inappropriate speed, accompanying with unfamiliarity of vehicles, braking failure, over-confidence, fatigue or alcohol use, and effects of inclement weather, etc. Overall, elderly people are more likely to be killed or seriously disabled than younger people due to the poor ability of vision and reaction resilience.

2.2. Temporal characteristics

We use the selected segment- involved crashes to produce a prototype of crash distribution on the GIS map for decision-making in the safety improvement act (Castro *et al*. 2008). Figure 2 presents the distribution of crashes on each segment according to the time and space, in which the majority of crashes have occurred on urban in/out roads and 10-lane expressways (Dai 2010). As might be expected, we have identified four areas with higher crash frequencies: 2207 cases or approximately 27.5% of the total crashes reviewed with higher proportions of truck flow and over-speeding are at least partially to blame, which also confirms the traffic flow distribution shown in Figure 1.

Furthermore, the plots of A and B show the first two areas of high crash density and they are much more likely to witness the occurrence of crashes as the two main bottlenecks linking the outside flows from Mudanjiang, Jiamusi, and Daqing and Qiqihar, the surrounding cities, into or through Harbin. Unsurprisingly, these two areas are all located in urban driveway gates linking to rural highways, and bigger ratio of heavy trucks in passing traffic flows, higher driving speed and poor safety management level, etc., which are all among the main causes to be blamed. Therefore, various quantitative supports varying from

Table 5. Segment crashes percentage over month in a statistical year

Month	01	02	03	04	05	06	07	08	09	10	11	12
Crash (count)	1093	902	755	667	514	458	498	466	554	506	763	860
Crash (%)	13.6	11.2	9.4	8.3	6.4	5.7	6.2	5.8	6.9	6.3	9.5	10.7
Crash (type)	FE, RE, SW	FE, RE, SW	AS, SW	AS, SW	SW, OS	SW, OS	AS, OT	OT	AS, SW	SW, OS	RE, AS, SW	FE, RE, SW

risk warning systems, truck driving monitoring and facility improvements to speed limit, pedestrian flow management further merit provisions for these crash-associated hot spots. Area B is particularly for the location between the two heads of the Songhua River and the large number and rate of crashes are partially due to the urgent change from four lanes to three lanes on the bridge in one travelling direction. Though there is a huge traffic volume passing through area D to Shenyang and Changchun, crashes in area D do not increase significantly and it at least partially contributes to the effective traffic calming equipment, such as dumps, speed cameras, etc. Different from the other three in/out roads is area C, which mainly covers the Nanzhi Rd. and this arterial lies in the old Daoli district with six-lane segments, narrow sub-arterials and branches, with a heavy volume of about 50,000 pcu per day; these have induced more serious congestion problems and increased the likelihood of over-speeding induced rear-end or sideswipe crashes.

Particularly, according to Figure 1, expressways linking areas A, D and B (marked in red) also show more crash counts on Hexing Rd. and Zhongshan Rd. Significantly increased fatal crashes in rear-end and sideswipe types could be caused during the five-month-lasting winter due to the effect of snowfall and iced pavements on these expressways and arterials (Table 5). By further exploring this statistical crash plot, it is found that the majority of crashes have appeared during the night – 19:00–00:00 hours, 12:00–16:00 hours and 09:00–12:00 hours – due to driver fatigue, a less sensitive perception of driving risk at night, lack of effective night lighting, speed management facilities, etc., which is especially true during the winter nights.

To provide a broad overview, work zone locations present a hazardous environment to drivers due to the presence of workers, construction machinery, construction barriers, sudden disrupt of traffic flow, etc. Thus, conflicts, between vehicular traffic and work activity, bottleneck, caused by the closure of one or more lanes of a highway section, are likely to reduce the capacity in the work zone and increase the crash probability for all involved. The review of crash records during these 10 years shows that the work zone-related crashes account for about 8÷10% of the total observations, and over-speeding or the flashing warning sign is identified as the main cause. The severity of the crash injuries is more serious than average. Nevertheless, night-time – 22:00–03:00 hours – is a dangerous time for work zone safety due to dozing, driver fatigue, weak lighting conditions, etc., and the review shows that more than one-third of the work zone-involved crashes are concentrated during these hours. The flashing warning signs, the markers on pavement, and the anti-collision bucket as well as ITS measures are all important factors in assisting a driver to avoid work zone crashes and are therefore highly recommended.

2.3. Crash severity

The type of segment divider has a significant effect on the occurrence of segment-involved crashes (Table 6). For a certain roadway type i, the mean E_i and

Table 6. The segment crash records, severity and frequency by geometric types

Segment in divider			Crash count										Crashes in severity			
No.	Sample	Total	FE	AS	RE	SW	OS	RO	OT	E_i	σ_i	C	B	A	K
None	367	5472	987	2352	873	612	103	235	310	14.91	473.93	2132	1463	1088	789
One	42	1221	371	394	152	149	43	67	45	29.07	302.41	459	337	253	172
Two	44	942	306	388	124	17	12	39	56	21.41	254.72	361	247	189	145
Three	30	401	125	143	67	31	16	8	11	13.37	225.90	163	95	102	41
Sum	483	8036	1789	3277	1216	809	174	349	422	–	–	3115	2142	1632	1147

Table 7. The average crash rate for each kind of segments

Segment	Single roadway				Triple roadway			Dual roadway		Quadri roadway		Expressway
No. of lanes	2	4	6	8	4	6	8	4	6	6	8	10
Crash count[a]	46.61	290.61	95.64	21.05	24.61	35.86	61.62	71.44	22.76	23.64	16.46	93.3
Length (km)	0.682	0.535	0.873	0.829	0.556	0.481	0.779	0.637	0.521	1.128	0.471	0.612
Width[b] (m)	9.78	15.83	22.67	31.16	18.86	32.07	36.38	16.84	23.53	24.0	23.8	63.5
AADT (1000 pcu)	8.76	17.28	27.59	16.74	24.66	43.75	36.28	22.37	30.15	48.13	44.08	42.91
Opening number[c]	3.41	2.44	3.72	4.25	3.73	2.61	3.52	3.31	2.45	6.33	2.47	1.85
CMVK	16.70	49.21	18.44	31.97	22.35	31.12	17.57	36.15	44.11	7.95	7.49	64.89

[a]The total number of crashes over study period;
[b]Average section width of segment;
[c]Opening number – sum of openings with each segment/the number of total segments.

standard deviation σ_i of the total number of crashes are determined by:

$$E_i = \frac{\sum_{k=1}^{j} N_{ik}}{j}; \quad (4a)$$

$$\sigma_i = \sqrt{\frac{\sum_{k=1}^{j} (N_{ik} - E_i)^2}{j-1}}, \quad (4b)$$

where: N_{ik} – crashes of segment k in roadway type i and j – number of segment in roadway type i.

Clearly, segments with one divider have severe crash problems than those without dividers as well as the other two types. Of course, a relatively large proportion of crashes and severity of injuries occurs on undivided segments due to huge undivided samples.

The combination of crash frequency (crashes per year) and vehicle exposure (traffic volumes or kilometres travelled) for a particular location influences the crash rate. This crash rate analysis provides an effective tool when comparing the safety performance of a certain location with the average of those contained in the database. If, during a safety audit study, a subject location is identified to have a higher than average crash rate, the technicians should make a detailed study combining crash records review and site visit to determine the key causes and should attempt to develop safety improvement measures. Therefore, the crash rate is expressed as 'Crashes per Million Vehicle Kilometres (CMVK) travelled' that could be determined by Eqn (5) and the result is listed in Table 7:

$$CMVK_i = \frac{\text{Average crashes for segment } i}{365 \cdot AADT_i \cdot N_i \cdot (L_i/1000)} \cdot 10^8, \quad (5)$$

where: N_i – the total number of segments of type i and L_i – the average length of segments of type i (km).

Table 7 clearly shows the important influence of roadway geometric factors on crash occurrence and safety performance. The bigger width of the lane has a relative level of safety due to the less probability of conflicts. More openings among segments also mean more risks induced by the amounts of merging and diversion traffic flows. Recently, the National Highway Traffic Safety Administration (NHTSA) has recommended several specific enforcements and measures concerning the segment openings. The audit of crash samples in 2009 shows that the geometric and environmental factors contributed to 26.8% and are considered as the third factors contributing to fatal collisions and fatalities among which abrupt change of lane width and lane number contributed to 37.3%, poor sight distance by roadside or median greenings to 27.1%, segment openings to 20.9%, and the sudden of pedestrians, bicyclists and motorists to 11.9%. During this 10-year period, more than 88.1% of all the crashes were not able to be geographically located to a point or an area, which means the geometric- and environmental-induced crashes are spread over the roadway network in Harbin. It is strongly recommended that the current urban road design's standard and safety facilities should be raised to provide sufficient protection for daily traffic.

2.4. Traffic flow and incidence of crashes

Illegal or unsafe speed contributes to the involvement of fatal crashes. During 2009–2010 in Harbin, illegal or unsafe speed was a contributing factor to 529 fatal crashes resulting in 253 deaths. Over-speeding accounted for 27% of the leading contributory factors in the reviewed fatal crashes for drivers under the age of 25, compared to only 5% of the factors for drivers aged 55 or older. Moreover, about 40% of the recorded fatal crashes due to over-speeding occurred under

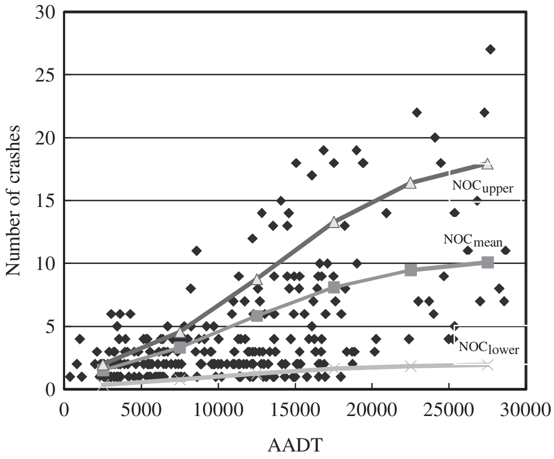

Fig. 3. The relation of crashes and AADT

adverse weather conditions (rain, fog, strong wind, etc.).

Generally, drivers need to maintain a safe speed under the roadway, pavement and weather conditions, as well as at or below the proposed speed limit. In many previous researches, a U-shaped curve with a minimum mean speed was found to illustrate the relationship between vehicle speed and crash incidence (Cirillo 1968; Michaels, Schneider 1976; Almquist *et al*. 1991; Aarts, Van Schagen 2006; Hauer 2009). Crash-involvement rates decreased with increasing speeds up to the mean speed, and increased with greater deviations above and below the mean speed of free-flowing traffic. The U-shaped relationship between deviation from mean traffic speed and crash involvement was also found while examining the crash data from expressways in Harbin. The data from these principle arterials, secondary/sub-arterial roads, branch and minor streets could draw a similar U-shaped relation.

In actuality, traffic Safety Performance Function (SPF) has a statistical relation with a flow state (El-Basyouny, Sayed 2010), such as traffic volume, volume to capacity ratio (*v*/*c*), etc. The crash rate changes with traffic flow and SPF reflects how these changes take place: higher rates within equal SPF mean lower safety level.

Figure 3 presents the relationship between the number of crashes and AADT.

Rearranging Eqn (4), lets divide AADT (0÷30,000) into six groups with interval 5000 and determine $E_i+\sigma_i$, E_i, and $E_i–\sigma_i$. Then the data series of $E_i+\sigma_i$, E_i, and $E_i–\sigma_i$ could be regressed into the upper function NOC_{upper}, the mean function NOC_{mean} and the lower function NOC_{lower}, respectively, as presented by Eqn (6):

$$NOC_{mean} = \frac{10.47}{1 + 9.6947 \cdot (0.9987)^{AADT}}; R^2 = 0.907; \quad (6a)$$

$$NOC_{upper} = \frac{18.91}{1 + 14.3194 \cdot (0.9987)^{AADT}}; R^2 = 0.833; \quad (6b)$$

$$NOC_{lower} = \frac{2.03}{1 + 7.2706 \cdot (0.9987)^{AADT}}; R^2 = 0.915. \quad (6c)$$

Table 8 gives the distributions of crash variables (mean, E_i, σ_i, min value and max value) of each AADT group. The critical values of each group derived from Eqn (6) are also listed in Table 8.

Figure 4 determines the U-shaped relationship between crash rates CMVK and *v*/*c* ratio and a regression model with quadratic function represents the scatter plots of data pairs quantitatively, as shown in Eqn (7):

$$CMVK = 6.2287 \cdot (v/c)^2 - 7.2465 \cdot (v/c) + 2.7383. \quad (7)$$

Unfortunately, the value of R^2 was 0.538 and it is clear that the quadratic function is not a perfect function due to few valid data. Obviously, the moderate level of traffic congestion ranging from 0.55 to 0.65 has the lowest crash rate with the best safety performance. It yields the lowest CMVK 0.63 with respective to *v*/*c* 0.58 and this also confirms the reported U-shaped relation.

Table 8. Crash cluster by AADT

AADT Group	*N*	Min	Max	E_i	σ_i	Upper	Lower
0÷5000	12	3	34	10.324	8.791	19.114	1.533
5001÷10000	12	2	19	8.019	6.006	14.025	2.013
10001÷15000	46	1	24	7.140	6.292	13.431	0.848
15001÷20000	66	2	18	4.599	4.435	9.035	0.164
20001÷25000	72	1	11	2.694	1.768	4.462	0.927
25001÷30000	51	1	7	2.219	1.628	3.848	0.591

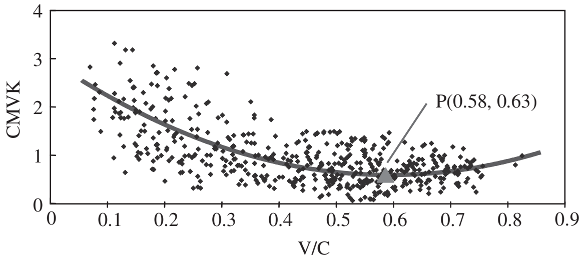

Fig. 4. The relation of crash rate and *v/c* at peak hours

The possible reason that the relationship between *v/c* and CMVK represented in a U-shaped curve is that when *v/c* is small (namely under a low density state), motorists could drive freely and they have enough time to eliminate or avoid a crash, even while encountering danger. Thus, most of the crashes are single-vehicle crashes at this stage. *v/c* increases with the increase of traffic volume, and the travelling speed decrease due to vehicles' interferences, which causes the drivers to operate more carefully than ever and decreases the CMVK value. When *v/c* arrives at a higher value (0.58), the crash rate is the lowest (0.63). While *v/c* increases more than 0.58, the interferences among vehicles are more and more serious, and more drivers are prone to change lanes to overtake and save time, so the probability of a collision also increases, while the CMVK ascends. At this stage, most crashes are sideswipes and rear-end collisions. Moreover, 22:00–06:00 hours witnesses a relatively bigger CMVK, due to poor visual condition, fatigue of drivers, poor performance of heavy vehicles, etc.

Of course, there are some reasons why the present on-road speed-related crashes are alarming, regarding the direct or potential effect of speed on drivers' perception ability and visual attention (Čičević *et al.* 2011). Through the findings in Section 2.1, it is clear that the number of crashes is related to the driver's individual features, such as age, gender, experience, the perceived level of potential risks, etc. Many situational factors (i.e., weather, road or vehicle characteristics, speed zoning, speed adaptation, impairment, etc.) can influence the speed choice and promote/delay the incidence of crashes that is consistent with the previous reports (Heydecker, Addison 2011; Peer 2011). Moreover, the road width, the type of dividers and the number of lanes also have an influence on the driving behaviour, speed choice and crash occurrence in return. Roadside or median features, especially proximity of tall trees, advertisement signs or other types of objects, can influence the field of view horizon as well as the speeds at which drivers choose to travel appropriately, and this is a subject that should be addressed seriously. Most importantly, a new driver's behaviour during emergencies and their hazard perception is strongly suggested to be added to the driving tests.

Conclusions and suggestions

There is evidence that the occurrence of a traffic crash is the result of multiple contributory factors. As addressed in this study, driver's behaviour, geometrics and environmental conditions all contribute to the traffic crashes and collisions. The study presented in this paper has evaluated the features of crashes occurring in the city of Harbin, using the policy-reported crash data over the period 2000–2010, and checked how the factors (e.g. time, location, number of lane, with or without divided median, mean speed, diversion of speed, etc.) impact the crashes that are expected to provide necessary insight into understanding and coupling with the alarming safety performance of the roadway network effectively.

The findings indicate that driver's behaviour plays a far greater role in the occurrence of crashes than do vehicle, environmental or geometric factors. In terms of preventive strategies, countermeasures or policy initiatives, there is an urgent need to reduce over-speeding while driving and disregarding traffic rules. Moreover, the review of the crash record also reveals that improper overtaking, improper cutting in, improper turning right or left, improper parking or stopping, following too close, drunk driving, careless driving, passing prohibited roads, failure to stop at crossing, failure to use seatbelt, aiding and abetting of violation, etc., always accompany over-speeding in crash occurrence and injuries. Another technical recommendation that is consistent with the ITS function is that real time information about the traffic flow should be provided to help drivers to choose the routes and modify the driving behaviours for the potentially positive safety outcomes.

The review of temporal distribution of crashes over the study region suggests that the linking areas of principal arterials to main access roads witness much more fatal crashes and severe rates of occurrence, due to the presence of more heavy vehicles, particularly at night, and more fatal accidents are to be recorded under some adverse weather conditions. Specific speed limit approaches are strongly implemented for these types of hazardous locations and unsafe weather. Moreover, there are few evidences which suggest that traffic calming measures may work positively all the time. This would suggest that dynamic traffic management techniques (i.e. variable speed limits, automatic speed camera, etc.) that adjust with traffic and environmental conditions could generate potential benefits (Habibian, Kermanshah 2011). For example, various calming measures (e.g. cameras, humps, staggering, transverse signs, narrowing, islands, etc.) have been used in Nanzhi Rd., and has achieved positive effects:

(1) an average of 24.4% reduction in speed at 263 sites covered in crashes;

(2) an average of 5.7 km/h per site decrease in speed at the site of enforcement;

(3) a 60% drop in the number of vehicles violating the speed limit;

(4) an 40% increase in community awareness of speed enforcement, compared with non-camera sites.

But the same measures have little or no effect on minor arterials and branch streets, and the similar findings are also reported in England (Jones *et al.* 2008).

Both lessons in the SLAS project and the review of crash causes indicate that the current safety improvement measures have not completely considered the actual traffic condition of a specific road and final decisions need to be made after a site visit and better understanding of traffic environment and potential causes. Since traffic volume and speed have a primary impact on the occurrence of crashes, we suggest the following speed management and traffic claiming techniques:

(1) variable speed limit signs should be used on the principle arterials with AADT no less than 12,000 pcu or on the segments with sharp curves, limited visibility or limited passing opportunities;

(2) if the traffic volume on the side road accounts for less than 1500 pcu/day or 4000 pcu/day, a dynamic warning sign or a fixed speed limit sign should be suggested, respectively;

(3) if the 85th percentile speed is less than the posted speed limit, speed cameras should be considered.

Since traffic crash is affected by the large number of contributory factors, future emphasis should be placed upon the combination of systematic countermeasures (Ratkevičiūtė 2010). However, this study has considered only the number of crashes due to the lack of records in injuries and deaths. The authors believe that all of them could help researchers and managers to understand why and how the crashes occur as well as how to reduce or prevent them all. The findings suggest that there is an important role in enhancing the traffic safety performance of the roadway network in metropolitan areas through systematic countermeasures and policy initiatives that are not only for Harbin, but other major cities in China.

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