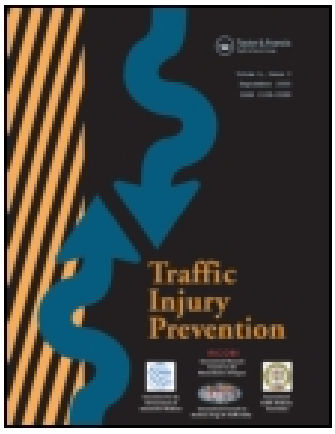

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Traffic Accidents on Expressways: New Threat to China

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Objective: *As China is building one of the largest expressway systems in the world, expressway safety problems have become serious concerns to China. This article analyzed the trends in expressway accidents in China from 1995 to 2010 and examined the characteristics of these accidents.*

Methods: *Expressway accident data were obtained from the Annual Report for Road Traffic Accidents published by the Ministry of Public Security of China. Expressway mileage data were obtained from the National Statistics Yearbook published by the National Bureau of Statistics of China. Descriptive statistical analyses were conducted based on these data.*

Results: *Expressway deaths increased by 10.2-fold from 616 persons in 1995 to 6300 persons in 2010, and the average annual increase was 17.9 percent over the past 15 years, and the overall other road traffic deaths was −0.33 percent. China's expressway mileage accounted for only 1.85 percent of highway mileage driven in 2010, but expressway deaths made up 13.54 percent of highway traffic deaths. The average annual accident lethality rate [accident deaths/(accident deaths + accident injuries)] for China's expressways was 27.76 percent during the period 1995 to 2010, which was 1.33 times higher than the accident lethality rate of highway traffic accidents.*

Conclusions: *China's government should pay attention to expressway construction and safety interventions during the rapid development period of expressways. Related causes, such as geographic patterns, speeding, weather conditions, and traffic flow composition, need to be studied in the near future. An effective and scientific expressway safety management services system, composed of a speed monitoring system, warning system, and emergency rescue system, should be established in developed and underdeveloped provinces in China to improve safety on expressway.*

Keywords Expressway accidents; Time and spatial distributions; Rear-end collision; Speeding; Weather condition; Large vehicles

INTRODUCTION

Road traffic deaths and injuries in China have been the world's top 2 causes for death and injury for more than 20 consecutive years since 50,063 people were killed and 185,785 more were injured in the 295,136 road traffic accidents in 1986 (Ministry of Public Security of China [MPSC] 1987). Although road traffic deaths and injuries began to decrease continually after 2004 (MPSC 2011), there were still 65,225 deaths and 254,075 injuries caused by 219,521 road traffic accidents in 2010 (MPSC 2011). In addition, traffic accidents on expressways associated with deaths and injuries have continued to increase obviously and rapidly since the first expressway opened to vehicular traffic in 1988, and the rapid growth momentum did not show a remission until 2007 (MPSC 2011). As China is building one of the largest expressway systems in the world to meet its dramatically increasing demand for expressway transportation stimulated by the unprecedented economic boom, expressway safety has become a serious concern to China's government.

Expressway accidents always result in enormous costs to society, including excessive delay for expressway users and damage to public property. Early studies have shed light on road traffic accidents in China, but fewer research studies have been carried out on expressway accidents. Compared with research on the predictors of expressway accidents in developed countries, China's researchers have made few in-depth and continuous studies on some specific topics, such as speed limit (Haleem and Gan 2011; Malyshkina and Mannering 2008), multiple-vehicle crashes, and other binary categorizations of expressway accidents (Abdel-Aty et al. 2006). Wang and Jiang (2002) have specially analyzed the epidemiology of road traffic trauma in China in 1998, in which they reported that China's road traffic accidents and casualties would continue to increase in the late 20th century. Since the beginning of the 21st century, China's government has undertaken a series of strong initiatives to improve road traffic safety. Statistics from both the Ministry of Health and the MPSC showed that since 2005, the per capita rate of

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road traffic deaths has decreased. Studies in other countries have shown that the relationship between economic development and road traffic injury and death rates forms an inverted U-shaped curve, with death rate increasing initially with increased motorization and then decreasing (Garg and Hyder 2006; Hu et al. 2008; Soderlund and Zwi 1995; van Beeck et al. 2000). There is no doubt that both road traffic deaths and injuries in China have already shown continued decline since 2004, but the results are quite pessimistic for expressway-related deaths and injuries. The total expressway mileage in China was 74,113 km by the end of 2010 compared to only 20.5 km in 1988. However, efforts made toward expressway safety measures lag far behind expressway construction. As expressway mileage and the number of users have increased rapidly, and this trend is expected to continue, expressway accidents will become a burgeoning public health crisis and a new threat to China if this problem does not receive immediate attention.

Using the publicly available national data released by the MPSC and the National Bureau of Statistics of China, this article has 2 main objectives: to (1) to conduct statistical analyses on the trends in expressway accidents, deaths, and injuries in China from 1995 to 2010 and (2) discuss the influences of some related causes (geographic patterns, speeding, weather condition, traffic flow composition, etc.) on China's expressway accidents. The analysis and discussion are further expected to raise the awareness of China's government in paying more attention on expressway accidents and improving expressway safety at the national level.

METHODS

Data

Data on road traffic accidents and expressway accidents were obtained from The Annual Report for Road Traffic Accidents (1995–2010) released by the Bureau of Traffic Management at the Ministry of Public Security of China (2011). Data on national and provincial expressway mileage were obtained from the National Bureau of Statistics of China, which can be found from its official publications: *National Statistics Yearbook* (1995–2010) (National Bureau of Statistics of China 2011).

Analysis

According to the statistical standard of the Ministry of Public Security of China and the National Bureau of Statistics of China as well as the function and the average annual daily traffic (AADT), China's roads are classified into urban road and highway, and highways are classified into expressway (lanes [dual carriageway]: 4–8, AADT: 25,000–100,000), first-class highway (lanes: 4–6, AADT: 15,000–55,000), second-class highway (lanes: 2, AADT: 5000–15,000), third-class highway (lanes: 2, AADT: 2000–6000), fourth-class highway (lanes: 2, AADT $\leq$ 2000; or one–lane, AADT $\leq$ 400), and substandard highway. Expressways are divided and limited access roads, whereas others are not.

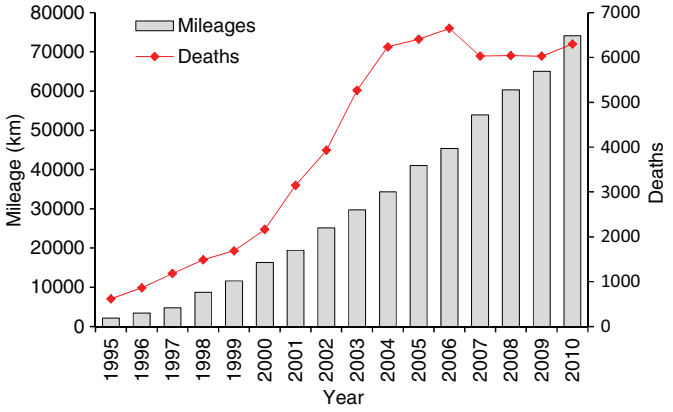

Figure 1 Expressway mileage and deaths (China, 1995–2010) (MPSC 2011) (color figure available online).

Different approaches for calculating traffic deaths have different results. The Ministry of Public Security of China estimated the number of road traffic deaths within 7 days of an accident at 104,372 and 98,738 in 2003 and 2005, respectively, which, when adjusted to the international standard used by the Ministry of Health of China (death within 30 days of an accident) would give 111,678 and 105,650 deaths correspondingly after being multiplied by a factor of 1.07 as used in the UK (World Bank 2008). The Ministry of Public Security of China estimates the number of road traffic deaths considering those that occur within 7 days of an accident, whereas America, Germany, and some other counties estimate the number of road traffic deaths as those that occur within 30 days of an accident. Expressway deaths in China were multiplied by a factor of 1.07 to make international comparisons.

RESULTS

The total mileage of China's expressways increased by 34.62-fold during the past 15 years, from 2141 km in 1995 to 74,113 km in 2010 (Figure 1). By the end of 2010, the total length of China's expressways had become the world's second longest after the United States and slightly longer than European Union. Along with China's great achievements in expressway development, traffic deaths on expressways also experienced a dramatic increase. There were only 616 expressway-related deaths in 1995, but in 2010 this number was 6300, or a 10.23-fold increase. The average annual growth rate of expressway-related deaths was 17.94 percent over the past 15 years, whereas the average annual growth rate of other road traffic deaths was −0.33 percent. Statistics from both the Ministry of Health of China and the Ministry of Public Security of China showed that the total number of road traffic accidents, deaths, and injuries have decreased continually since 2004. However, China's expressway deaths experienced an unstable period, which decreased by 9.28 percent in 2007 but increased by 4.51 percent in 2010. The unstable period is usually a disturbing period, because it is still unknown whether the expressway deaths and nonfatal injuries

Table I Highway categories and highway traffic deaths (China, 2006–2010) MPSC 2011

	Years									
	2006		2007		2008		2009		2010	
Highway category	No.	%	No.	%	No.	%	No.	%	No.	%
Expressway	6647	9.85	6030	10.00	6042	11.25	6028	12.33	6300	13.54
Class 1	8668	12.85	7611	12.63	6877	12.81	6110	12.50	6012	12.92
Class 2	24,251	35.94	21,899	36.33	18,943	35.28	17,605	36.02	16,454	35.36
Class 3	16,379	24.27	14,372	23.85	12,544	23.36	10,817	22.13	9965	21.41
Class 4	6566	9.73	6098	10.12	5563	10.36	4872	9.97	4581	9.84
Substandard	4965	7.36	4261	7.07	3724	6.94	3439	7.04	3222	6.92
Total	67,476	100	60,271	100	53,693	100	48,871	100	46,534	100.00

have reached the inflection point of the U-shaped curve and will show a progressive decline or will continue to increase but, undoubtedly, this period is also the most crucial to take measures to control expressway deaths and nonfatal injuries.

In 2010, expressway mileage in China only accounted for 1.85 percent of highway mileage, but expressway deaths and injuries made up 13.54 and 9.22 percent of highway traffic deaths and injuries, respectively. As shown in Table I, from 2006 to 2010, the expressway death rate (expressway deaths/total highway traffic deaths) continued to increase. Although the traffic deaths on Class 2 highway and Class 3 highway were 2.61 times and 1.58 times higher than expressway deaths in 2010, their total mileage was 4.17 and 5.23 times longer than total expressway mileage. Compared with expressways in developed countries, China's expressways have a higher death rate per hundred kilometers. In 2009, China officially had 3.32 expressway deaths per 100 million vehicle kilometer, which was 4.74 times higher than that for expressways in the United States.

Expressway accidents result in serious deaths and property damage, even though expressway accidents account for a small proportion of road traffic accidents in China. As shown in Figure 2, from 1995 to 2010, the average expressway accident rate (expressway accidents/road traffic accidents) was 3.57 percent, and the average expressway death rate was 4.65 percent, which was 1.3-fold higher than the average expressway accident rate. Since 2008, the safety status of China's expressways has become increasingly serious, and the expressway death rate was more than twice that of the expressway accident rate. From 1995 to 2010, the average annual value of expressway property damage (expressway property damage/road traffic accident property damage) was 5.65- and 4.34-fold higher than the average annual values of expressway accidents and expressway deaths, respectively. In 2010, the property damage caused by expressway accidents was 31.589 million CNY, which accounted for the largest proportion (34.10%) of property damage–only (PDO) crashes.

Traffic accidents on expressways are usually serious and usually result in 3 or more persons killed. Compared with the overall situation of road traffic accidents in China, the expressway accident lethality rate [expressway accident deaths/(expressway accident deaths + expressway accident injuries)] shows a serious trend. As shown in Table II, the average annual expressway lethality rate was 27.76 percent during the past 15 years, which was 1.33-fold higher than the average annual road traffic lethality rate. Expressways should be the safest highways compared to other road types due to their high design standards. Yet for all their advantages, the statistical results from above-mentioned analysis indicate that China's government needs to urgently address the expressway safety problem.

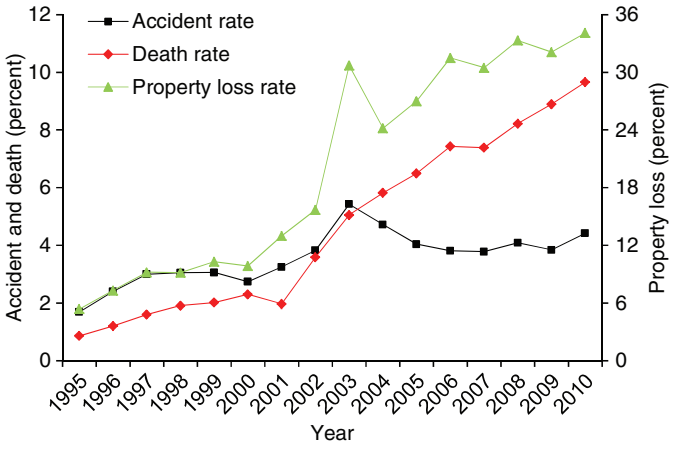

Figure 2 Accident rate, death rate, and property damage rate for expressways (China, 1995–2010) (MPSC 2011) (color figure available online).

DISCUSSION

The distributions of the total number of expressway accidents and deaths within 24 h did not always coincide. From Figure 3, the peak period of expressway deaths (the most dangerous period) usually appeared at nighttime, whereas the daytime had a lower death rate and was relatively safe. From 10 p.m. to 9 a.m. the following day, the time distribution percent of expressway accidents was relatively lower than expressway deaths. Here, the specific value of death percentage/accident percentage was used to represent the degree of seriousness of each time interval in a day. The interval from 2 to 3 o' clock was the most serious time interval with a specific value of 1.24. Furthermore, expressway drivers and safety management personnel should pay special attention to the time interval from 11 p.m. to 5 a.m. the following day, which had a specific value higher than 1.10.

During the 15 years from 1995 to 2010, 31 provinces, with the exception of Xizang, have built expressway networks of

Table II Lethality rates for expressways and all roads (China, 1995–2010)

	Expressways			All roads		
Years	Deaths	Injuries	Lethality rate (%)	Deaths	Injuries	Lethality rate (%)
1995	616	1600	27.80	71, 494	159, 308	30.98
1996	864	2215	28.06	73, 655	174, 447	29.69
1997	1182	3190	27.04	73, 861	190, 128	27.98
1998	1487	4034	26.93	78, 067	222, 721	25.95
1999	1687	4921	25.53	83, 529	286, 080	22.60
2000	2162	6442	25.13	93, 853	418, 721	18.31
2001	3147	9978	23.98	105, 930	546, 485	16.24
2002	3927	12, 253	24.27	109, 381	562, 074	16.29
2003	5269	14, 867	26.17	104, 372	494, 174	17.44
2004	6235	15, 213	29.07	107, 077	480, 864	18.21
2005	6407	15, 681	29.01	98, 738	469, 911	17.36
2006	6647	17, 116	27.97	89, 455	431, 139	17.18
2007	6030	14, 628	29.19	81, 649	380, 442	17.67
2008	6042	13, 768	30.50	73, 484	304, 919	19.42
2009	6028	12, 780	32.05	67, 759	275, 125	19.76
2010	6300	13, 739	31.44	65, 225	254, 075	20.43

different lengths and densities. The differences in expressway densities, lengths, and deaths among the 31 provinces are shown in Figure 4. Provinces located along the coastal areas of China, such as Shanghai, Tianjin, Beijing, Jiangsu, and Zhejiang, have highly intensive expressway networks, whose expressway densities were higher than 3 km/100 km^2 (expressway length/land area) in 2010. However, their expressway deaths were quite different: more people traveled on longer expressways and more people were killed or injured in expressway accidents on longer expressways. Compared with the provinces located in the southwestern part of China, in particular Guizhou and Hunan, expressway length was not the only factor influencing expressway deaths. Some other factors, such as weather condition or topography, also affect expressway accidents. For example, in Guizhou and Jilin, by the end of 2010 expressway lengths were 1507 and 1850 km, respectively, but the number of expressway deaths in Jilin were 102 compared to 220 in Guizhou, where there are many mountains and hills. Furthermore, from April to October 2010, there were 22 recorded rainstorms in Guizhou, some of which continued for over 5 days. These rainstorms resulted in 644 geological disasters, which brought serious effect to Guizhou's expressways.

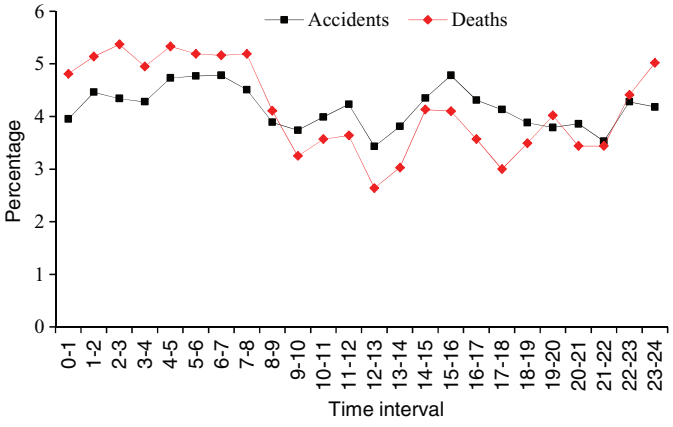

Figure 3 Time distributions of expressway accidents and deaths (MPSC 2011) (color figure available online).

Of all the crash types in expressway accidents, rear-end collisions accounted for the largest proportion. As shown in Figure 5, the Annual Report for Road Traffic Accident of 2010 reported that 42.72 percent of expressway traffic deaths and 43.61 percent of expressway traffic injuries were caused by rear-end collisions. Speeding, wet pavement, and poor visibility easily lead to rear-end collisions. Racing, driving too fast for conditions, and exceeding the posted speed limit were contributing factors in expressway accidents. The MPSC reported that 10.56 percent of expressway-related deaths and 10.59 percent of expressway-related injuries were caused by speeding in 2010. The law of the People's Republic of China on road traffic safety (State Council of China 2004) stipulates that the maximum speed per hour of small cars, motorcycles, and other vehicle types shall not exceed 120, 80, and 100 km/h, respectively, on expressways. However, about 80 percent of small cars exceeded the speed limit, and their actual speeds usually measured up to 140 km/h or higher. About 75 percent of all vehicle drivers did not comply with the constraint that drivers shall turn on the contour, head- and taillights and shall not exceed 60 km/h when the visibility is less than 200 m.

Wet pavement and poor visibility were 2 other important causes of rear-end collisions. Rainy weather and fog result in wet pavement and poor visibility. Table III presents the distributions of expressway-related accidents, deaths, injuries, and property damage under different weather conditions in 2010; 16.02 percent of all expressway-related accidents occurred rainy weather, which resulted in 18.32 percent of total injuries; 3.51 percent of all expressway-related accidents occurred in fog, which resulted in 5.35 percent of total deaths and 4.16 percent of injuries. The inequalities between expressway accidents and injuries or deaths under these poor weather conditions indicated that, compared with expressway accidents that occur in good weather

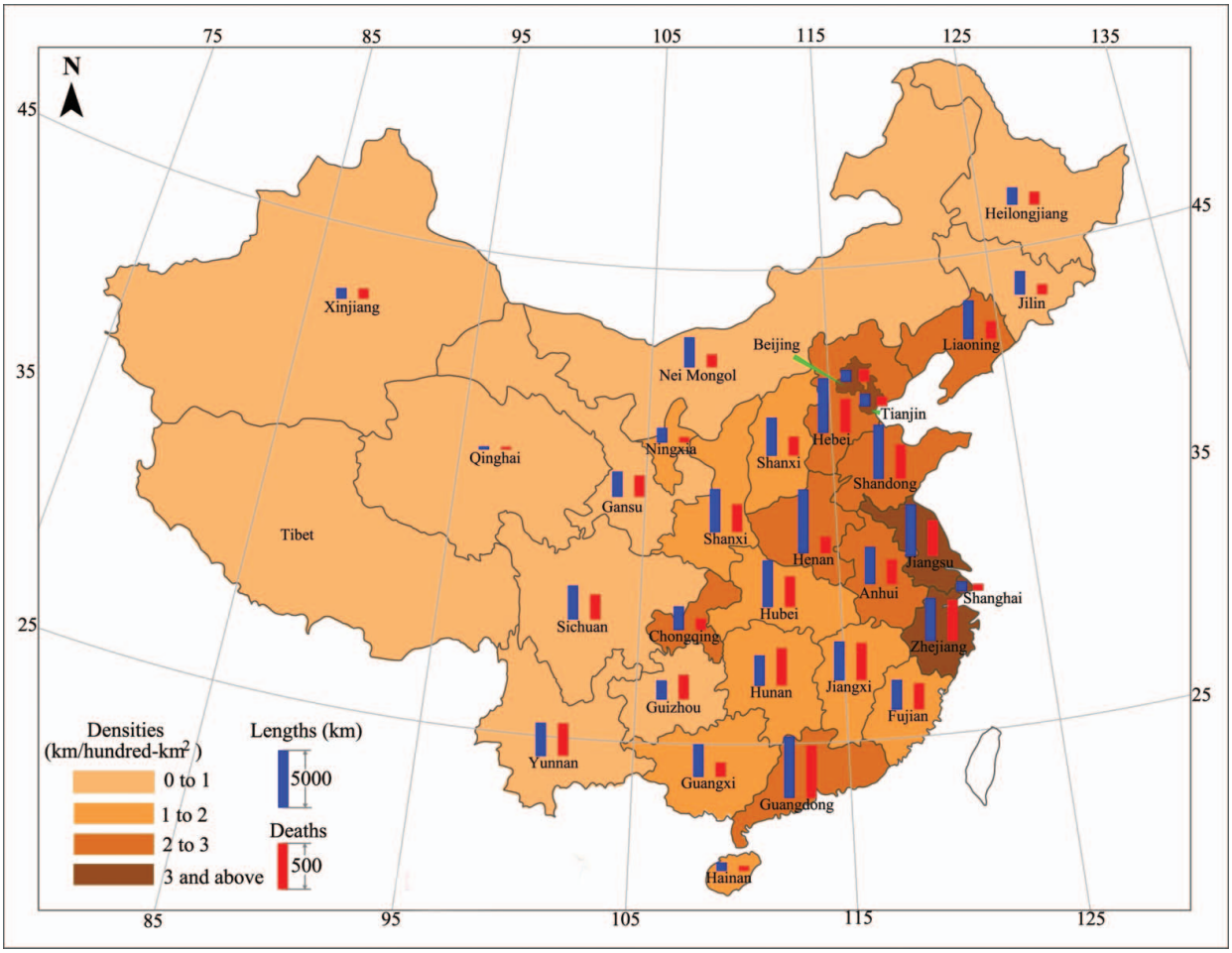

Figure 4 Expressway densities and lengths and deaths in 31 provinces (China, 2010) (MPSC 2011, edited by authors) (color figure available online).

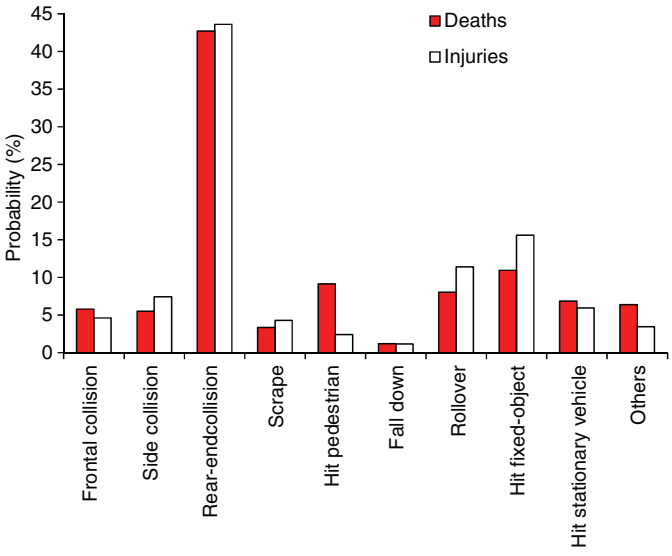

Figure 5 Distributions of expressway deaths and injuries for different crash types (China, 2010) (MPSC 2011) (color figure available online).

condition, accidents that occur in rainy weather and fog result in more deaths and injuries.

Stopping distances are much longer on wet highways than on dry pavement (Cho et al. 2007; Fambro et al. 2007). Based on the 90 km/h data, 90 percent of all drivers without antilock braking systems (ABSs) manifested equivalent constant decelerations of at least 3.4 m/s^2 under wet conditions, whereas 90 percent of all drivers with ABS manifested equivalent constant decelerations of at least 4.7 m/s^2 on dry pavement (Fambro et al. 2007). Cho et al. (2007) simulated the braking distance of patterned tires at 60 km/h and reported that the braking distance on wet roads was longer than that on dry roads by 19.64 percent and the braking time increased by 20.11 percent. The reduction in deceleration and the addition of braking time and distance of vehicles on wet roads caused by rainy weather conditions can result in rear-end collisions if drivers do not comply with speed constraints or respond quickly circumstances ahead.

Expressway-related deaths and injuries in poor visibility condition caused by fog also have alarming statistics. As shown in Table III, 337 persons were killed and 572 more were injured in 340 expressway accidents in fog conditions in 2010. Situated on the border of the provinces of Hunan, Jiangxi, Guangdong, and

Table III Expressway accidents, deaths, injuries, and property damage under different weather conditions (China, 2010) MPSC 2011

	Accidents		Deaths		Injuries		Property damage	
Weather condition	No.	%	No.	%	No.	%	No.	%
Sunny	5955	61.39	3890	61.75	7951	57.87	193.48	61.25
Cloudy	1598	16.48	1003	15.92	2301	16.75	50.54	16.00
Rainy	1554	16.02	874	13.87	2517	18.32	50.97	16.13
Snowy	231	2.38	174	2.76	358	2.61	7.15	2.26
Foggy	340	3.51	337	5.35	572	4.16	13.28	4.21
Windy	8	0.08	7	0.11	9	0.07	0.19	0.06
Dusty	3	0.03	1	0.02	3	0.02	0.07	0.02
Hail	1	0.01	2	0.03	3	0.02	0.05	0.02
Others	10	0.10	12	0.19	25	0.18	0.16	0.05

Guangxi, many expressways pass through the Nanling mountainous region, including the G4 expressway (the Beijing–Hong Kong–Macao expressway and the longest expressway in China). Wu et al. (2007) studied the characteristics of fog on the Yunyan section of the G4 expressway. They found that the number of foggy days from November to May occupied over 80 percent of all year-round, resulting in an obvious fog season in this region. As shown in Table IV, each month may have heavy fog with visibility less than 50 m. The cumulative probability of heavy fog with visibility less than 100 m was 12.5 to 22.6 percent from October to April of the following year, and the cumulative probability of heavy fog with visibility less than 500 m was 29.4 to 45.9 percent.

Drivers with good driving visibility are 107.8 percent more likely to take corrective avoidance actions than drivers with adverse sight conditions (Yan et al. 2008). Drivers respond to poor visibility conditions in different ways: some slow down; others do not. Many drivers simply follow the taillights of the vehicle ahead, which can resulted in successive rear-end collisions if drivers do not respond quickly to dangerous situations ahead. Furthermore, there are many large vehicles on the expressways in China, usually forming complex mixed traffic flow with small cars. The difference between the speeds of these 2 different vehicle types leads to rear-end collision in poor visibility conditions. Figure 6 shows 2 serious expressway accidents that occurred on the G4 expressway in China. The first accident (Figure 6a) occurred in Hunan province on January 18, 2010, and resulted in 3 deaths and 9 injuries (Xin Hua Net 2010). The second accident (Figure 6b) occurred in Hubei province on October 16, 2010, and resulted in 8 deaths and 23 injuries (Zhong Guo Net 2010). These 2 accidents occurred in fog conditions and vehicle pileups involving more than 10 vehicles.

Table IV The visibility of Nanling section G4 expressway (%, observed hourly)

	Visibility (m)					
Months	≤50	50–100	100–200	200–500	500–1000	≥1000
Jan.	6.3	16.3	7.6	15.7	4.8	49.3
Feb.	6.2	14.6	9.7	12.7	5.5	51.3
Mar.	4.2	8.9	8.0	17.1	6.5	55.3
Apr.	4.2	8.3	5.6	12.1	7.4	62.4
May.	0.4	1.3	1.0	1.6	2.4	93.3
Jun.	0.3	0.7	0.7	0.9	0.9	96.5
Jul	0.4	0.0	0.0	0.3	0.0	99.3
Aug.	0.7	0.5	0.7	0.7	0.2	97.2
Sep.	3.2	3.2	1.7	2.7	1.0	88.2
Oct.	6.6	10.8	5.0	12.3	6.3	59.0
Nov.	6.2	11.6	7.6	13.2	5.1	56.3
Dec.	5.3	12.0	5.3	6.8	3.5	67.1

Source: Wu et al. (2007).

Compared to experienced drivers, less experienced drivers are more likely to be killed and injured in expressway accidents, partly due to the fact that less experienced drivers cannot deal with emergencies or skillfully prevent a worsening of the situation. As shown in Figure 7, in 2010, drivers with 10 years or less driving experience represented 63.13 percent of all expressway fatalities, compared with only 16.77 percent for drivers with 16 years or more driving experience. Less experienced drivers also had higher rate of involvement in expressway accidents than experienced drivers.

Another serious problem affecting safety on China's expressway is overloading. Although overloading is a common problem on expressways in many countries, this problem is much worse in China because of the huge demand for freight transportation. In China, the movement of goods is generally finished by freight vehicles (light trucks, generally) and combination of vehicles (large trucks). These vehicles usually cannot reach the minimum expressway speed and cause other vehicles to change lanes frequently, increasing crash risks. As shown in Figure 8, in 2010, 51.13 percent of all expressway deaths caused by freight vehicles (39.75 percent) and combination vehicles (11.38 percent). In the United States, a total of 46.5 percent of highway deaths were caused by light and large trucks in 2009, and only 7.1 percent of highway deaths reported involved large trucks (Fatality Analysis Reporting System, General Estimates System [FARS-GES] 2011).

To better understand the influence of some crash variables (percentage of large vehicles, city/rural area, difference in speed between small cars and large vehicles, traffic volume, etc.) on expressway crash severity (fatal, injured, PDO) in China, based on the data collected on 2205 expressway crashes and a crash severity prediction model, Zhong et al. (2009) found that 3

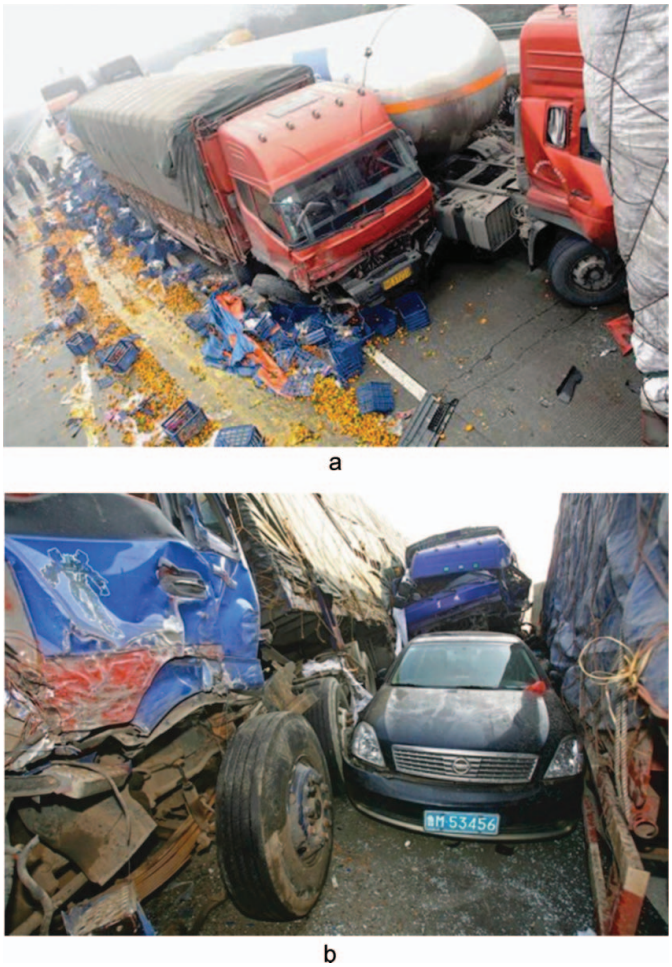

Figure 6 Two serious expressway accidents that occurred in fog conditions: (a) Hunan and (b) Hubei (color figure available online).

variables (city/rural area, difference in speed between small cars and large vehicles, percentage of large vehicles) influenced crash severity, and the percentage of large vehicles significantly affected crash severity and particularly influenced the occurrence of fatal expressway accidents. The statistics, facts, and research results should provide a wake-up call to China's government regarding the need to prevent expressway accidents involving large vehicles.

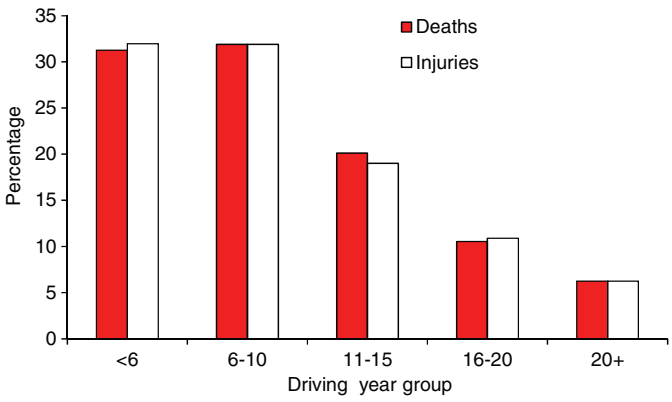

Figure 7 Distributions of expressway deaths and injuries under different driving year group (MPSC 2011) (color figure available online).

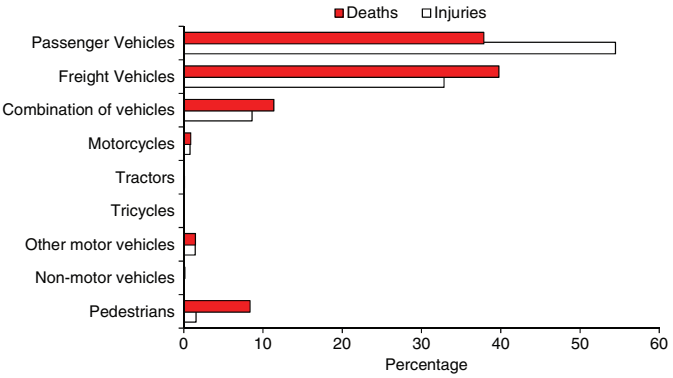

Figure 8 Distributions of expressway deaths and injuries under different travel models MPSC 2011 (color figure available online).

Recommendations

During the "12th Five-Year Plan" (Central Committee of the Communist Party of China 2010) period, China will maintain a rapid, sustainable, and coordinated development in the economic and social sectors. In 2015, China expects to reach a total expressway length of 83,000 km and complete the National Expressway Network (composed by 7 radiative lines, 9 vertical lines, and 18 horizontal lines). However, China still faces a serious expressway safety situation and experiences a high incidence of expressway accidents, and the rates of deaths and nonfatal injuries caused by expressway accidents showed a rapid increase from 1995 to 2010. Expressway accidents are a complex phenomenon, with multiple causes that vary according to specific conditions that are found in any case selected for analysis. The recommendations that follow are intended to gather the most probable causes for the occurrence of expressway accidents in China, with a special focus on man–vehicle–road interactions.

One of the major barriers to improving safety on China's expressways is the insufficient awareness of expressway users. Most people see these accidents as the unavoidable cost of development or a result of irresponsible individual behavior. It takes a significant amount of time to improve people's awareness and behavior, and this mission is more arduous in most developing countries, especially in China. On the one hand, the historical experience of hundreds of thousands of expressway deaths has not been able to promote a deep awareness to the problem. On the other hand, the generation of an expressway-oriented environment was not accompanied by proper education and enforcement efforts. To overcome this barrier, China's government should spare no effort to establish a society-based education and enforcement system on expressway safety to improve drivers' behavior in certain areas, such as ignoring or violating formal traffic laws as well as other illegal conduct that severely affects expressway safety.

A high percentage of large vehicles and the difference in speed between small cars and large vehicles are also barriers to resolving this problem. Large vehicles usually cannot reach the minimum expressway speed and many small cars exceed the maximum expressway speed, which results in frequent lane changes. This problem can be resolved preliminarily through technical measures, such as improving vehicle maintenance and quality, strengthening periodic physical and mechanical examinations, etc. This conflict can also be diminishing by restricting some vehicles (in bad conditions, overloaded vehicles, etc.) from entering expressways at the expressway entrance.

The serious imbalance between expressway construction and safety interventions is another corresponding challenge. Emergency management services can further improve response times to those casualties that crucially need emergency services (Lee and Fazio 2005). Expressway safety management is relatively inadequate compared with the rapid development of expressway construction in China. Without a complete emergency rescue mechanism or adequate preplanning, it is not surprising that the death rate on China's expressway is far higher than in developed countries. There is an urgent need to establish an effective and integrated expressway safety management and services system, composed of a speed monitoring system, warning system, emergency rescue system, etc., to improve expressway safety at the national level.

CONCLUSIONS

Analyses involving expressway accidents in China have indicated that the safety situation on China's expressways is grim. Though China's government has achieved much in the field of road traffic injury prevention in the past 5 years, it is time for China's officials and decision makers to take measures to prevent the high rates of deaths, nonfatal injuries, and property damage caused by expressway accidents, even though there are many difficulties and challenges ahead.

In China, economic growth and expressway development are coupled with an increasing rate of expressway accidents. The characteristics of China's expressway accidents have some similarities as well as some distinguishing features compared to those in other countries. Our study suggested that time distribution, geographic areas, speeding, weather conditions, and vehicle composition are closely related to expressway accidents in China. Some existing effective expressway safety interventions that have been developed in developed countries could be effective in reducing the risk of expressway accidents in China. Future research and knowledge of the significance of expressway safety measures are essential for the promotion of expressway safety in China.

Expressway construction is given a priority in China's Western Development Program for the development of western China. More expressways will be extended to the western and central areas of China. There are many mountains and hills throughout these areas, which have many long downhill and other safety black spots. Furthermore, restricted by economic factors, some of the least developed provinces in the western and central areas of China do not have enough money invested in establishing effective safety monitoring systems or emergency management services systems on expressways. Moreover, in many undeveloped areas, injured persons cannot reach hospitals quickly, and medical care may may not be as good as in more developed areas, which results in enormous costs to society. In the development of western China, China's government as well as local authorities should pay special attention to the expressway safety problem in these relatively undeveloped areas.

Limitations

This study has several limitations. Firstly, we did not present the relationships between expressway accidents and vehicle speeds. Research on crash rates and the discrete character of speed has been performed by Pei and Cheng (2004) in China, but studies on the relationship between crash rates and the difference in speed between small cars and large vehicles on expressways are rare. Heavily loaded trucks cannot reach the minimum expressway speed and therefore cause other vehicles to change lanes frequently. Figure 6b shows the seriousness of a crash between small cars and large vehicles. The great different between these 2 vehicle types results in severe consequences to expressway users and enormous costs to public property.

Secondly, expressway accidents that occur at accident black spots, such as long downhill areas and exit and entrance ramp junctions are not reported by the MPSC. Based on data from the US FARS-GES, an estimated 82,609 police-reported crashes occurred at interchanges on interstates in 2001, of which 24,996 crashes resulted in injuries and 544 were fatal. Overall, 18 percent of all interstate crashes, 17 percent of injury crashes, and 11 percent of fatal crashes occurred at interchanges, although such locations constitute less than an estimated 5 percent of total expressway mileage (McCartt et al. 2004). Research on these black spots on expressways in China would be valuable because it could provide the basis for prioritization of preventive measures.

An important measure guaranteeing the operation safety of expressway vehicles, the consistency of expressway design, was not appraised in this study. At the end of 2009, China had finished the renaming and recoding of the expressway network. The Chinese characters on the signs were replaced by English characters with numbers. For example, the Chinese characters ""京港澳高速" " on the original signs were transformed to "G4" in the 2009 program. The new signs before the expressways challenge the perception and comprehension of drivers. Drivers, especially those unfamiliar with the new signs, may not respond quickly enough or correctly after seeing the signs. Although there was no evidence proving the relationship between expressway accidents and the sign changes, the number of expressway deaths and injuries increased in 2010 after China's government finished the renaming and recoding of the expressway network. Analyzing and evaluating the influence of these new signs on expressway users is an important research area to improve safety level on China's expressways in the future.

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