UMTRI-2008-1 JANUARY 2008

ROAD SAFETY IN CHINA: CHALLENGES AND OPPORTUNITIES

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Report No. UMTRI-2008-1
January 2008

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-2008-1		

4. Title and Subtitle	5. Report Date
Road Safety in China: Challenges and Opportunities	January 2008
	6. Performing Organization Code 383818
7. Author(s) Zhang, W., Tsimhoni, O., Sivak, M., and Flannagan, M.J.	8. Performing Organization Report No. UMTRI-2008-1
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.	10. Work Unit no. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Strategic Worldwide Transportation 2020	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

The current members of Strategic Worldwide Transportation 2020 include ArvinMeritor, Bosch, Continental Teves, Ford Motor Company, General Motors, Nissan Technical Center North America, Toyota Motor Engineering and Manufacturing North America, and TRW. Information about Strategic Worldwide Transportation 2020 is available at: http://www.umich.edu/~umtriswt

16. Abstract

China has the world's largest population, is the second largest automobile market, and is the third largest world economy. China's economy is booming, resulting in a rapid increase in both the road infrastructure and the access to private vehicles. As a consequence, China faces unprecedented road safety issues.

The present report was designed to analyze the Chinese road safety situation and to identify countermeasures that would address areas in which the total harm caused by crashes can be substantially and readily reduced. The report focuses on two aspects of road safety in China, challenges and opportunities. In the first part, the report provides a comprehensive analysis of the current road safety situation in China and the likely future trends. Based on this analysis, the following four areas were identified as having potential for substantially reducing fatalities in China: pedestrians and other non-motorists, nighttime driving, vehicle passengers, and motorcycles. In the second part, the report discusses several promising countermeasures for each of these four areas.

17. Key Words	18. Distribution Statement
China, road safety, transportation safety, traffic accidents, road fatalities, motorization, driving, countermeasures	Unlimited

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	42	

ACKNOWLEDGMENTS

This research was supported by Strategic Worldwide Transportation 2020 (http://www.umich.edu/~umtriswt). The current members of this research consortium are ArvinMeritor, Bosch, Continental Teves, Ford Motor Company, General Motors, Nissan Technical Center North America, Toyota Motor Engineering and Manufacturing North America, and TRW.

The principal writers of the core chapters were Wei Zhang (Challenges: Road Safety in China) and Omer Tsimhoni (Opportunities: Promising Countermeasures). Wei Zhang's contribution was prepared while he was a visiting research scientist at UMTRI from Tsinghua University in Beijing.

CONTENTS

CHALLENGES: ROAD SAFETY IN CHINA

Introduction

China has the world's largest population (1.3 billion as of 2007) (U.S. Census Bureau, 2007). Thanks to the economic reforms initiated in 1978, China has experienced an average annual growth in its gross domestic product (GDP) of 8.7% over a recent 10-year period (1997-2006). In 2006, the GDP reached 21.1 trillion Chinese Yuan (about $2.8 trillion). Along with the economic growth, the road system has also improved substantially. The length of express highways (limited-access, divided, and toll roads) almost tripled in six years, increasing from about 19,500 km in 2001 to about 53,000 km in 2007.

The number of motorized vehicles in China has also increased dramatically, from 42.2 million in 1997 to 145.2 million in 2006. In 2005, the motorized fleet included the following main types of vehicles: 16.4% passenger vehicles, 7.5% heavy trucks, 9.4% light or slow trucks, and 57.9% motorcycles (CRTAS, 2006). In recent years, the number of passenger vehicles and motorcycles has increased significantly faster than the number of trucks. In 2006, China became the world's second largest automobile market (total sales of 7.2 million trucks and passenger vehicles) and the third largest manufacturing country (about 8.9 million vehicles in 2007) (Auto-Stats, 2008).

However, the cost of the rapid increase in motorization has been high. Road safety has become a major public health problem and has gained attention from both the government and the public. The government has initiated many countermeasures in recent years (such as stronger law enforcement, insurance policy reforms, and use of radar and camera technology), and these measures appear to have positive effects.

A comprehensive report, prepared by the Development and Research Center of the Chinese State Council, reviewed China's current road safety situation and proposed a strategic plan to improve road safety (Development and Research Center of State

Council, 2007). The report compared the situation in China to conditions in the U.S., Japan, and Germany. The report also identified aspects of road crashes characteristic of China, such as high fatality rates for pedestrians and users of non-motorized vehicles; and illustrated the trends in road crashes, overall fatalities, fatalities per vehicle, and fatalities per population. The report identified several major problems that should be addressed, including: poor road-safety awareness among road users; poor stability and safety performance of motor vehicles; lack of safety standards in road construction; deficiencies in the road safety management system and operation mechanism; deficiencies in road safety laws, promotion, and education; poor emergency rescue and treatment; and lack of a comprehensive and reliable road safety database. The report also identified targets for improved road safety in China (short-term, mid-term, and long-term), and outlined a road map for achieving them (designated the Six-E Project).

The goal of the present report was to identify countermeasures that have promise to address specific aspects of the overall road safety problem in China. The first part of this report examines the available crash data and identifies a limited number of important areas that are especially characteristic of the current road safety situation in China, and for which relatively specific countermeasures are available. The second part discusses several promising countermeasures. In this discussion, we have organized the treatment of countermeasures in terms of an analysis that describes the total harm from road crashes as the product of three components: exposure, risk, and consequences (Thulin & Nilsson, 1994), and in terms of the Six-E Project.

Fatality data in this report are taken from the official Chinese road statistics, as published by the Traffic Administration Bureau of China State Security Ministry (CRTAS, 2000, 2001, 2002, 2003, 2004, 2005, 2006), and all unreferenced data in this report are from those publications. Other sources of information have quoted different fatality numbers, sometimes almost twice as high (e.g., Koornstra, 2003).

Comparison with the U.S.

In contrast to the situation in developed countries, traffic fatalities in China are not primarily motor vehicle users. In 2005, for example, drivers of passenger vehicles and trucks accounted for only 9.0% of all road fatalities, compared to 53.4% in the U.S. in 2000 (AUSTST, 2002). However, the same group of drivers were responsible for 59.6% of all road fatalities in China. Pedestrians, users of non-motorized vehicles, motorcycle drivers, and passengers in motor vehicles accounted for 24.8%, 15.5%, 22.2%, and 20.5%, of fatalities, respectively (CRTAS, 2006). The corresponding percentages in the U.S. in 2000 were 11.3%, 1.6%, 6.3%, and 25.5%, respectively (AUSTST, 2002). This comparison indicates that China's road fatalities include higher percentages of pedestrians, motorcycle drivers, and users of non-motorized vehicles (mainly bicyclists). In addition, although passengers in motor vehicles account for a lower percentage of all fatalities in China than in the U.S., they account for a higher percentage of fatalities among motor vehicle occupants (i.e., relative to drivers).

Table 1 lists several key fatality rates in China (CRTAS, 2001-2006) and in the U.S. (FARS, 2006). The results show that although most of the Chinese rates have declined recently they are still much higher than those in the U.S.

Table 1
Comparison of some key fatality indices between China and the U.S.

Country, year	Fatalities per 10,000 motorized vehicles	Fatalities per 10,000 passenger vehicles	Fatalities per 10,000 population	Fatalities per $ billion GDP
China, 2000	15.6	27.15	0.73	59.6
China, 2002	13.7	24.14	0.88	59.2
China, 2004	9.9	17.76	0.82	48.3
China, 2006	6.2	N/A	0.68	31.8
U.S., 2005	1.8	3.19	1.47	3.5

Overall Fatality Trends

Figure 1 shows the trend of traffic fatalities in China from 1997 to 2006.

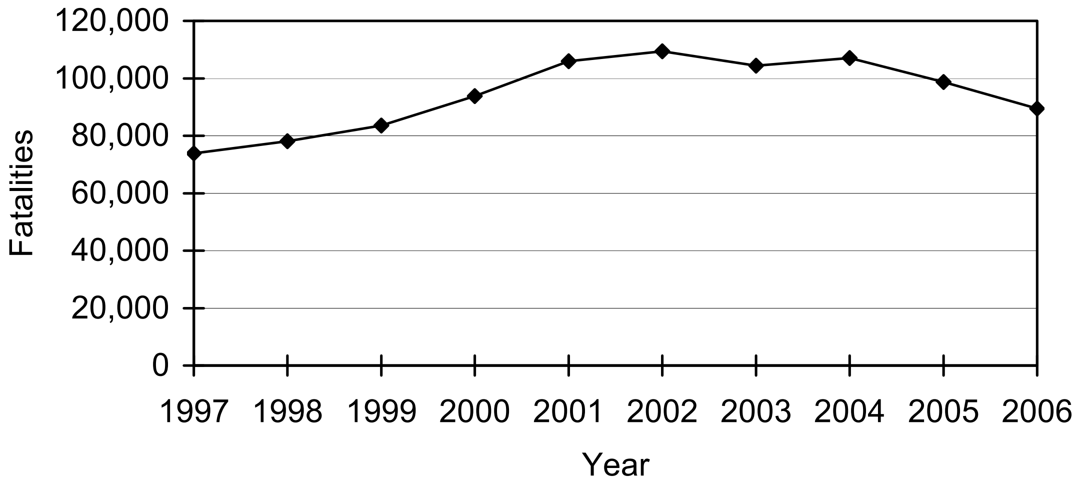

Figure 1. Annual fatalities from 1997 to 2006.

Time of Day

Figure 2 shows fatalities by time of day for 2000 through 2005. The number of fatalities changes substantially throughout the day, following a consistent pattern across years. The fatalities tend to peak in early evening (between 6 p.m. and 9 p.m.) and they tend to be lowest after midnight (1 a.m. to 5 a.m.). Because exposure information by time of day is not available, the risk per distance driven cannot be directly inferred from Figure 2. However, the peak in early evening probably reflects both an increase in risk due to darkness and high exposure.

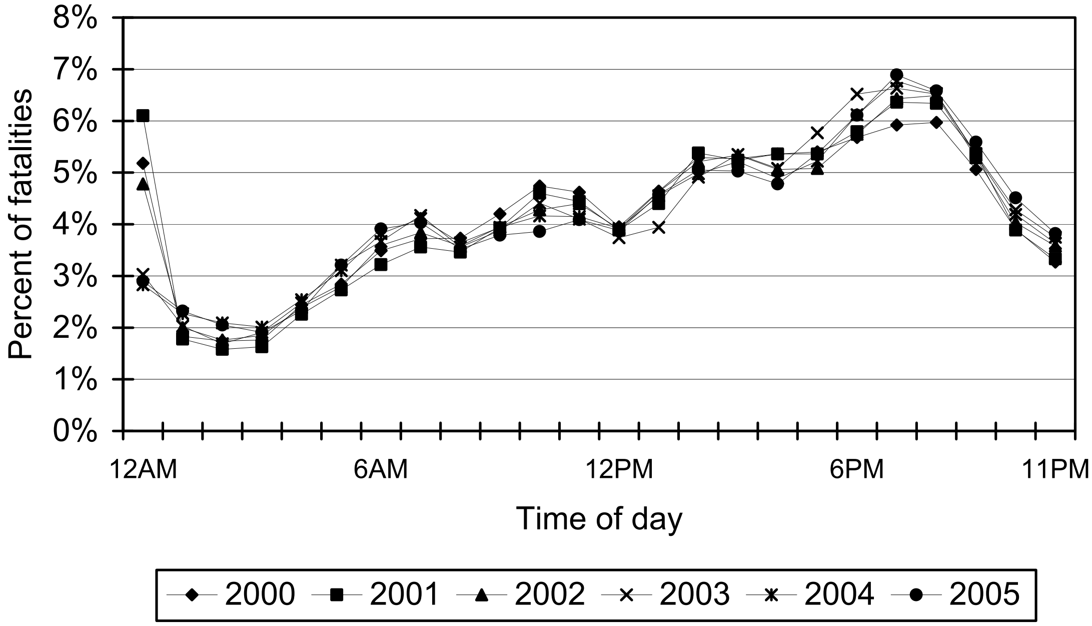

Figure 2. Hourly fatality rates, 2000-2005.

The pattern for express highways is different from the overall hourly pattern (see Figure 3). Express highways in China are limited-access, divided, and toll roads with speed limits of 100 km/h to 120 km/h. Here, the fatalities during late night and early morning are greatly elevated. It is possible that many of these crashes involve trucks, which are not allowed to enter big cities during daytime. A relatively high number of vehicles on the road, and the risks associated with fatigue, are likely causes for this pattern.

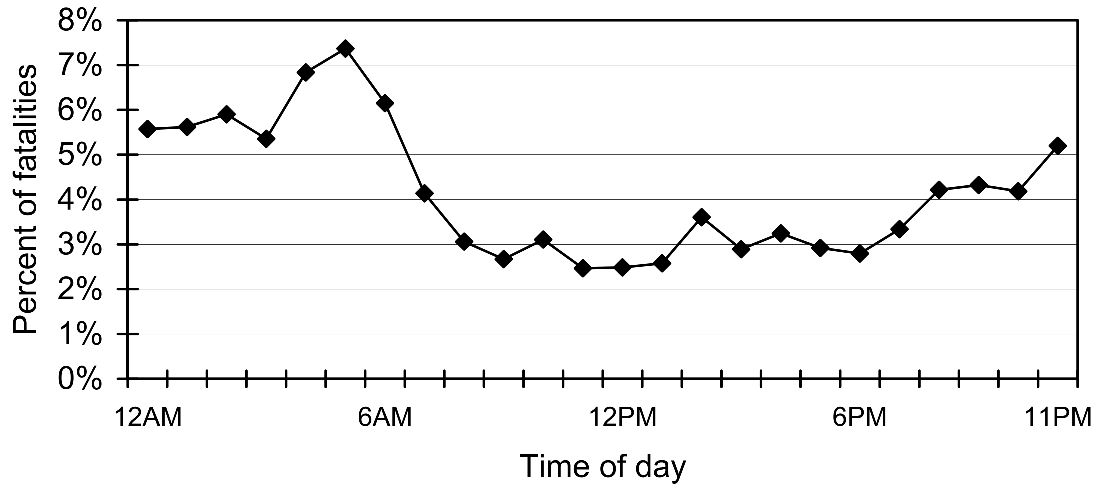

Figure 3. Hourly fatalities in 2005 on express highways.

Adverse Weather

Table 2 shows numbers of fatalities and the corresponding percentages for adverse weather driving (clouds, rain, snow, or fog).

Table 2
Road fatalities in adverse weather.

Year	N	Percentage of all fatalities
2000	21,924	23.4
2001	23,570	22.3
2002	24,261	22.2
2004	22,786	20.5
2005	23,872	24.2

Driver Age

Table 3 presents road fatalities by age. Children (15 years and younger) and the oldest group in the table (56-65 years of age) each represent about 2% of fatalities. Middle-age persons (26-46 years of age) represent the largest percentage (66%), followed by young adults (16 to 25 years of age) with 20%. Young adults are likely to account for some of the increase in passenger vehicles in the near future, and thus this group is likely to increase in importance.

Table 3
Fatalities by age.

Year	0-15		16-25		26-45		46-55		56-65	
	N	%	N	%	N	%	N	%	N	%
2000	3,501	3.7	19,634	20.9	59,116	63.0	7,450	7.9	2,095	2.2
2001	1,723	1.6	21,349	20.2	67,251	63.5	8,711	8.2	2,301	2.2
2002	1,609	1.5	21,384	19.6	70,737	64.7	9,582	8.8	2,231	2.0
2004	1,035	1.0	20,980	19.6	72,219	67.4	9,552	8.9	2,388	2.2
2005	703	0.7	18,438	18.7	67,929	68.8	8,966	9.1	1,620	1.6
Mean		1.7		19.8		65.5		8.6		2.1

Economic Development Level

According to Kopits and Cropper (2005), the road fatality rate per population has an inverted-U shaped relationship with economic development level (GDP per capita). Such a relationship may exist between countries and also possibly within countries. China is a developing country, but great differences exist among its provinces and cities, with the GDP per capita varying by 10:1 between highly developed cities and rural areas (Table 4). Table 4 documents general and traffic data for Chinese regions. It is an expansion of data presented in Table 3 in Development and Research Center of State Council (2007).

Table 4
China provincial data (GDP as of 2006, other data as of 2005).

Province	Area (1000 km^2)	Pop. (M)	GDP (B$)	Pass. veh. (1000)	Trucks (1000)	Motor-cycles (1000)	Car/truck drivers (1000)	High-way (km)	1st Class roads (km)	2nd Class roads (km)	Fatal-ities
Beijing*	16.8	15.8	104.9	1,871	178	266	3,692	548	554	2,368	1,515
Tianjin*	11.3	10.8	57.8	543	120	342	1,477	593	497	1,729	970
Hebei	190.0	68.5	155.5	1,200	709	4,699	6,355	2,135	2,645	12,547	4,075
Shanxi	156.0	33.4	63.3	678	476	929	2,041	1,686	1,011	11,586	3,819
Neimonggu	1,183.0	23.8	63.9	385	250	1,139	1,729	1,001	2,139	8,359	2,106
Liaoning	145.7	42.2	123.4	993	483	1,190	3,701	1,773	1,556	13,440	2,919
Jilin	187.4	27.1	56.7	458	199	1,359	2,201	542	1,529	7,335	2,428
Heilongjiang	454.0	38.2	82.9	577	263	549	2,221	958	1,118	7,140	2,164
Shanghai*	6.3	13.5	137.3	724	181	1,111	2,091	560	302	2,306	1,393
Jiangsu	102.6	74.3	287.3	1,446	433	7,100	5,028	2,886	4,214	13,998	7,603
Zhejiang	101.8	47.2	208.7	1,435	559	4,804	4,202	1,866	2,955	6,569	6,881
Anhui	139.6	62.3	81.9	436	332	2,465	2,467	1,501	338	9,633	4,355
Fujian	121.4	35.1	100.0	450	231	3,426	1,712	1,208	358	6,262	4,125
Jiangxi	166.9	42.8	61.6	272	199	2,424	2,120	1,559	565	8,555	2,428
Shandong	157.1	93.1	291.3	1,665	735	9,073	6,241	3,163	4,855	21,949	7,050
Henan	167.0	97.2	166.2	934	468	4,379	6,545	2,678	106	21,684	4,587
Hubei	185.9	60.2	100.0	534	310	2,898	3,581	1,649	1,093	15,225	2,417
Hunan	211.9	67.0	99.9	508	293	2,202	2,364	1,403	530	5,563	3,832
Guangdong	179.8	83.0	346.3	2,474	1,188	10,893	7,816	3,140	7,301	17,147	9,959
Guangxi	236.3	48.9	64.0	380	195	4,338	1,878	1,411	546	6,299	3,489
Hainan	35.0	8.2	14.0	105	56	873	582	625	180	1,255	497
Chongqing*	82.4	27.7	46.5	266	202	589	1,212	748	306	4,676	1,484
Sichuan	485.0	87.3	115.2	971	394	3,247	3,914	1,758	1,599	10,123	4,415
Guizhou	176.1	39.0	30.1	262	176	543	1,283	577	92	2,629	1,647
Yunnan	394.0	44.2	53.4	625	404	1,856	2,475	1,421	248	3,325	2,901
Xizang	1,228.4	2.7	3.9	51	34	36	116	0	0	807	540
Shaanxi	205.6	37.1	58.5	428	188	1,226	2,022	1,226	359	5,858	2,698
Gansu	455.0	26.2	30.0	193	136	311	875	1,006	141	4,969	1,799
Qinghai	722.0	5.4	8.6	71	48	92	307	171	144	4,002	736
Ningxia	66.4	5.9	9.4	72	72	376	354	670	219	2,109	796
Xinjiang	1,660.0	19.6	40.8	335	205	828	1,398	541	883	6,993	3,110
Total	*9,630*	*1,287*	*3,063*	*21,341*	*9,716*	*75,565*	*83,997*	*41,003*	*38,383*	*246,440*	*98,738*

* Direct-controlled municipalities

Alcohol, Fatigue, and Speeding

China enforces a zero alcohol tolerance policy, in contrast to content-limit tolerance policies in most developed countries. The percentage of traffic fatalities in China associated with alcohol was less than 5% in the past few years (CRTAS, 2006), compared to about 40% in the U.S. (FARS, 2006). However, there has been a trend toward more alcohol-related fatalities in China. If, in the future, alcohol content-limit policies are used instead of the current zero tolerance policy, the situation could rapidly worsen. Compared to the overall rate of alcohol-related fatalities (4.8%), alcohol-related fatalities on express highways are much lower (1.4%).

In China, long-distance travel in a personal vehicle is less common than in the U.S. However, in recent years, with the improvement of road infrastructure and more privately owned motor vehicles, such travel has been increasing. At the same time, with the growth of the economy, truck transportation is likely to increase. Because of restrictions in many big cities (such as Beijing), trucks are not allowed to enter the city during daytime. Consequently, truck driving at night is common, and fatigue has been a major problem for long-distance night driving in China, especially for truck drivers. As shown in Table 5, fatigue is also an increasing cause of fatalities, and fatalities due to fatigue on express highways are more frequent than on all roads in general (13.4% versus 2.6% in 2005, respectively).

In China, the speed limit generally is 110-120 km/h for rural express highways, and 80-100 km/h for urban express highways. In 2005, speeding was identified in more traffic fatalities than alcohol or fatigue (16.2% versus 2.6% and 4.8%, respectively). However, on express highways, fatalities due to speeding were lower than those due to fatigue (11.3% vs. 13.4%). In the past few years, widely installed anti-speeding radar and cameras in most cities and express highways proved to be effective in reducing speeding. Law enforcement incidents for speeding increased from 12.8 million incidents in 2004 to 15.3 million in 2005. Furthermore, the total fines for speeding increased from $75.6 million in 2004 to $155.2 million in 2005 (CRTAS, 2005, 2006).

Table 5
Fatality percentages associated with alcohol, fatigue, and speeding.

Factor	Road type	Percent of total fatalities					
		2000	2001	2002	2003	2004	2005
Alcohol	All roads	2.3	3.1	3.1	3.8	4.3	4.8
	Express	N/A	N/A	0.4	N/A	N/A	1.4
Fatigue	All roads	1.9	1.7	1.7	2.1	2.8	2.6
	Express	N/A	N/A	11.6	N/A	N/A	13.4
Speeding	All roads	8.5	8.7	8.8	11.6	17.2	16.2
	Express	N/A	N/A	8.2	N/A	N/A	11.3

Road User Categories

Fatalities for various categories of road users are shown in Table 6 for 2000 through 2006. Pedestrian and non-motorized vehicle users (40% in 2005) account for substantially more fatalities than in developed countries. Passenger fatalities are substantially more numerous (20%) than driver fatalities (9%, combining drivers of passenger vehicles and trucks). Motorcycle drivers represent a substantial share of the fatalities (22%).

Table 6
Fatalities by road users.

Year	Pedestrians & non-motorized vehicle users		Passengers		Motorcycle drivers		Truck drivers		Passenger vehicle drivers	
	N	%	N	%	N	%	N	%	N	%
2000	42,243	45.0	22,393	23.9	17,194	18.3	3,773	4.0	3,247	3.5
2001	47,520	44.9	24,658	23.3	20,244	19.1	4,071	3.8	4,091	3.9
2002	47,034	43.0	26,044	23.8	21,909	20.0	4,419	4.0	4,605	4.2
2004	43,991	41.1	22,460	21.0	22,835	21.3	4,453	4.2	5,002	4.7
2005	39,701	40.2	20,216	20.5	21,895	22.2	4,015	4.1	4,868	4.9

In 2005, there were more than twice as many passenger vehicles (cars, small vans, and small buses) than trucks (21.3 million vs. 9.7 million). However, truck drivers were responsible for approximately as many fatalities as drivers of passenger vehicles (about 30% each), highlighting the problems caused by truck crashes. Motorcyclists were responsible for about 21% of fatalities, although motorcycles dominate all motor vehicles (75.6 million out of the total of 130 million). Recent fatality trends by the responsible party are shown in Figure 4. Over the past six years, there have been steady increases in fatalities due to drivers of passenger vehicles and motorcycles, while the relative contribution of truck drivers remained approximately the same. These trends most likely reflect the fact that passenger vehicles and motorcycles have recently increased in number more rapidly than trucks.

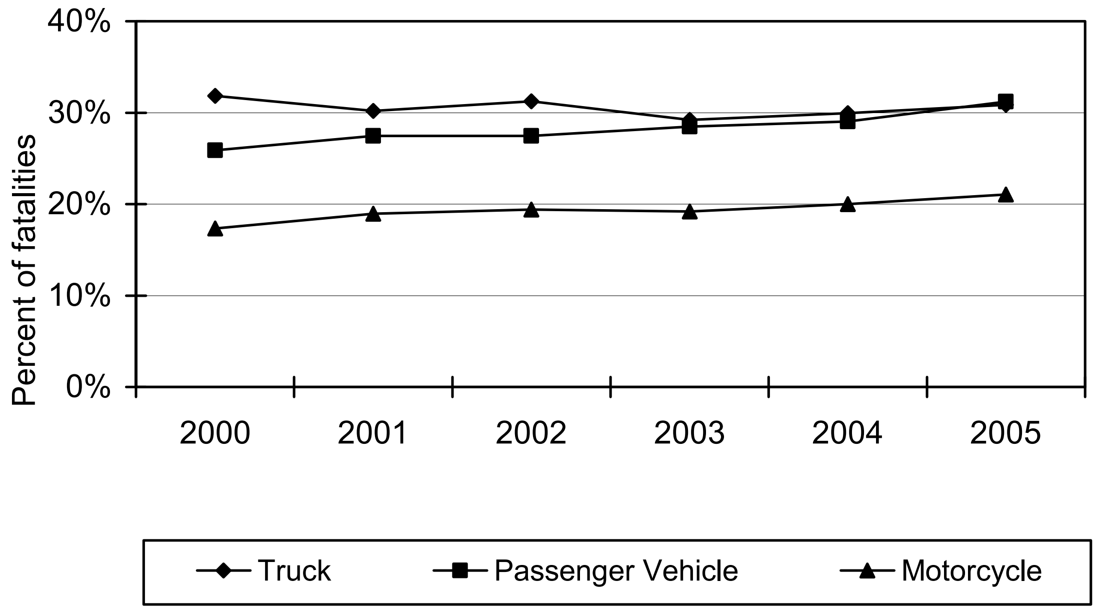

Figure 4. Fatality percentages due to trucks, passenger vehicles, and motorcycles, 2000-2005.

Express Highways

Figure 5 shows the fatalities on express highways versus the length of the express highway network from 1994 to 2005. (Each point in Figure 5 corresponds to the network length and number of fatalities for one specific year.) According to the best-fitting regression equation, the fatality rate is approximately one fatality per year for each 6 km of the express highway network.

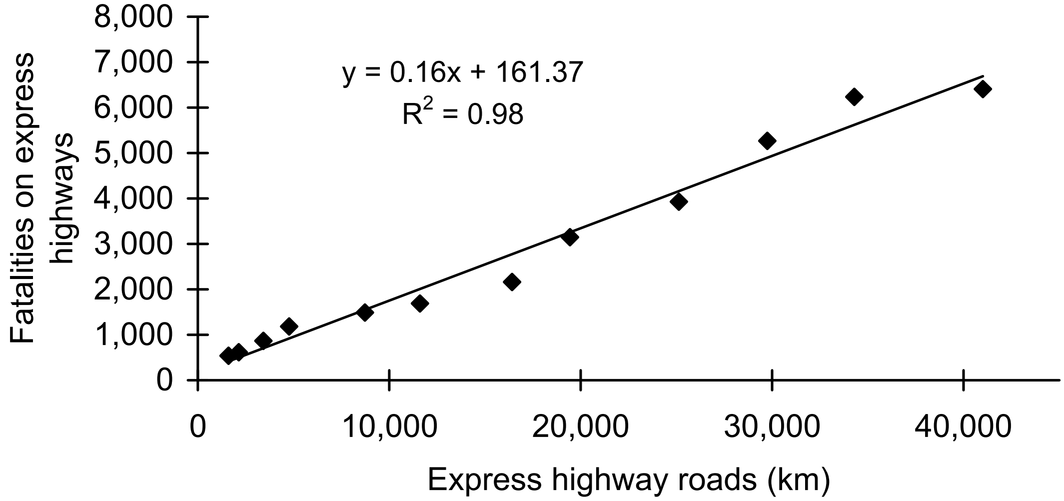

Figure 5. Fatalities and express highway network available 1994 through 2005. Each point corresponds to the network length and number of fatalities for one specific year

Figure 6 shows fatalities on express highways versus the length of the express highway network in 31 provinces (including five minority autonomous administration regions and four direct-controlled municipalities). Each point corresponds to the network length and number of fatalities for one province in 2005. This figure illustrates a strong linear relationship, with about one annual fatality per 6 km of express highway.

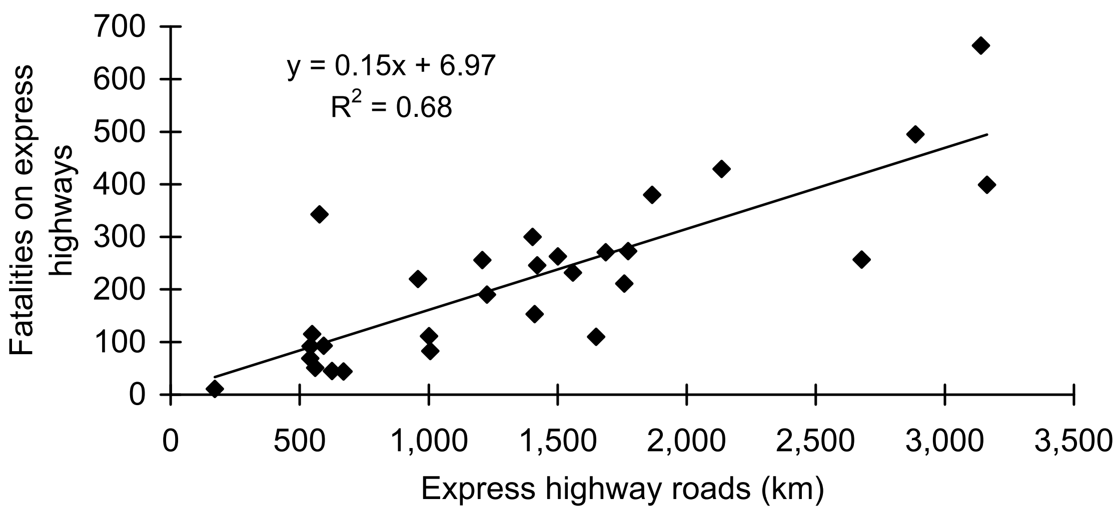

Figure 6. Fatalities per express highway network available in 31 provinces in 2005. Each point corresponds to the network length and number of fatalities for one province.

Geometric Aspects of Crashes

In combination, three crash types account for 70% of all fatalities: head-on collisions, lateral collisions, and rear collisions. In addition to these major types of fatal crashes, three other types of fatal crashes comprise 12% of all fatalities: rollovers (6.3%), running into stationary objects (3.6%), and road departures (2.2%).

Rear collisions occurred much more frequently on express highways than on all roads, while head-on and lateral collisions occurred less frequently. Interestingly, head-on collision fatalities accounted for about 10% of the fatalities on express highways, despite the fact that these are divided and limited access roadways.

Use of Headlights and Seatbelts

China has a primary enforcement seat-belt use law. Nevertheless, the seat-belt use rate in China is much lower than in developed countries. Li, Li, Stevenson, Ivers, & Zhou (2006) found that the average seat-belt use rate was 50% in the city of Guangzhou and 64% in Nanning. Zhang, Huang, Roetting, Wang, & Wei (2006) found that the rate varied from 47% to 93% in Beijing, and from 0% to 38% in Tianjin (a central administration city with similar population, GDP per capita, and land area as Beijing), with the rate in both cities depending on the observation location (seat-belt use is higher in central districts and lower in suburbs). In Enshi, Hubei province, a smaller city (population of 0.77 million), the seat-belt use rate is virtually zero (three drivers out of 3,054 were observed using seat belts). Furthermore, the seat-belt use rates mentioned here are for drivers. Passengers have substantially lower rates. The rates are higher on highways than on suburban roads, but lower than on central district roads.

The above information suggests that many drivers do not view seat belts as essential for safe driving, and that the use rate tends to be influenced by enforcement factors (such as stricter enforcement in central districts and looser enforcement on highways). Passengers may be even less aware of the importance of seat belts. For passenger vehicle fatalities (4,868 drivers and 20,216 passengers in 2005), seat-belt use would be an effective countermeasure.

China currently does not require operation of daytime running lights. The law does require drivers to turn on headlights either when it is dark or when road illumination lights are on. Zhang et al. (2006) conducted roadside observations and illumination measurements at two sites in Beijing and, Rolla, Missouri. Observations and measurements were made on major roads with no traffic lights and on expressways, and they were conducted every three minutes from 30 minutes prior to sunset to 15 minutes after sunset. The results are shown in Figure 7.

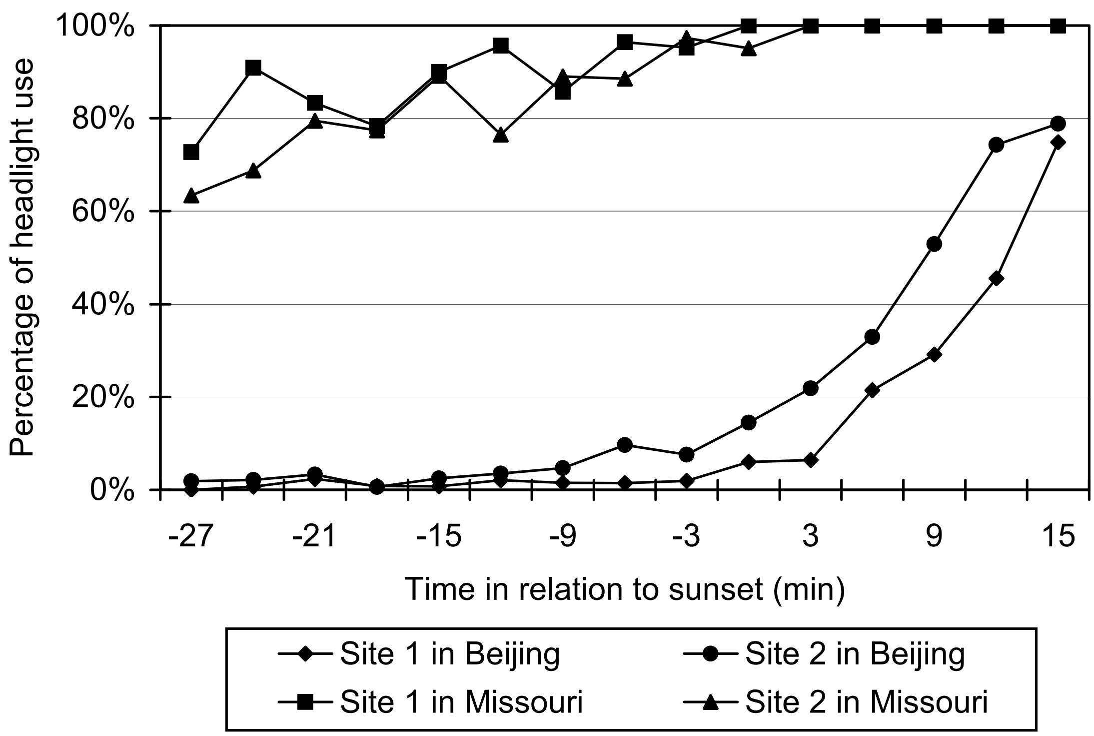

Figure 7. Comparison of headlight/running light use rate in China and the U.S.

As is evident from Figure 7, the headlamp/daytime running lamp use in China prior to sunset is very low (less than 10%). Furthermore, drivers in China wait substantially longer than drivers in the U.S. to turn their headlamps on after sunset. For example, over 20% of drivers did not have their headlamps on 15 minutes after sunset. This delayed headlight use probably reduces road safety by making it much more difficult for drivers to detect other road users (pedestrians, as well as users of motorized and non-motorized vehicles).

Follow-up interviews with drivers indicated that the main reasons for not using headlights earlier were the lack of awareness of the importance of lighting, concerns with wasting energy, and trying to delay glaring other motorists (Zhang et al., 2006).

Expected Future Trends

Road safety is influenced by many factors. Economic development level influences the number of motorized vehicles, travel miles, and road infrastructure. Culture is a long-term factor that influences people's attitudes toward road safety and their behaviors. Enforcement of transportation laws and regulations has immediate and direct influence on people's attitudes and behaviors. Along with enforcement, vehicle safety technologies, convenient public transportation, and education are important for improving road safety.

In order to investigate the influence of economic development on road safety, comparisons can be made between current and historical data. However, it can also be useful to compare current data between countries and even across different regions within countries. For example, by comparing data from different provinces of China, it is possible to see an apparent influence of economic factors. Figure 8 plots values from 2005 for GDP per capita and fatalities per population for China's 31 provinces and the 50 U.S. states. The data in Figure 8 are consistent with a version of the so-called Kuznets curve (Kopits & Cropper, 2005; McManus, 2007), in which fatalities first rise and then fall with economic development, exhibiting an inverted-U shape. Chinese provinces are in the rising portion of the curve, while the U.S. states are in the declining portion.

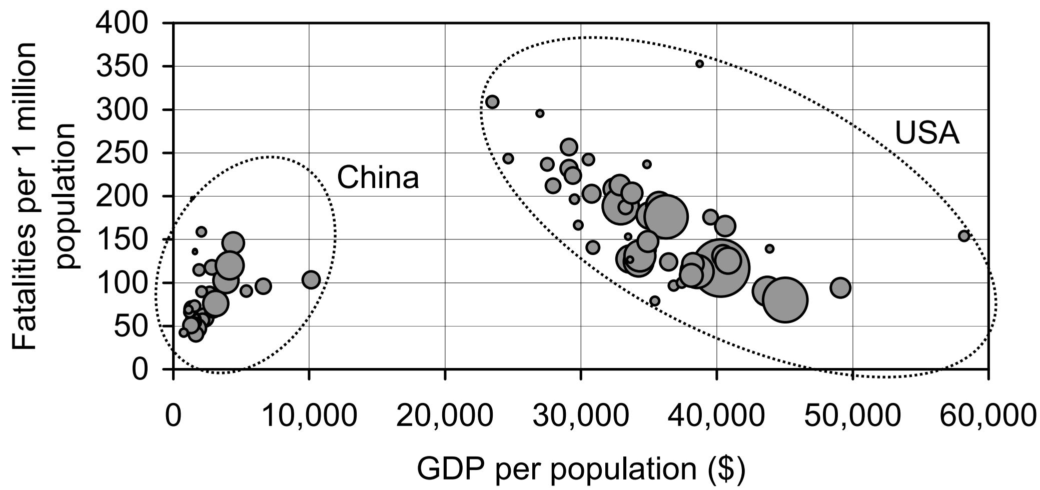

Figure 8. Fatality/GDP relationship: Comparison between Chinese provinces and U.S. states (bubble sizes denote total GDP).

Conclusions

Based on the analysis above, we selected four areas in which to examine countermeasures in the next part of this report. Successfully dealing with these four areas is likely to bring about substantial improvement in road safety in China.

(1) Pedestrians and other non-motorists. This group of road users currently accounts for 40% of all fatalities, substantially more than in most developed countries.

(2) Nighttime driving. Evidence suggests that (a) as is the case in other countries, nighttime driving in China is substantially riskier than daytime driving, and (b) Chinese drivers tend to delay turning on their headlamps.

(3) Vehicle passengers. Vehicle passengers account for over twice as many fatalities as do drivers (20% vs. 9%).

(4) Motorcyclists. Motorcyclists represent a large portion of fatalities (22%).

OPPORTUNITIES: PROMISING COUNTERMEASURES

Introduction

In the first part of this report we identified four areas that, with proper countermeasures, are likely to bring about a substantial improvement in road safety in China: (1) pedestrians and other non-motorists, (2) nighttime driving, (3) vehicle passengers, and (4) motorcyclists. In this part of the report, we will discuss several safety countermeasures for each of these crash categories.

For each of the four areas of road safety problems in China, we present a table of possible countermeasures. Each table consists of a representative set of countermeasures that may be applied to the problem. We highlight a selected number of countermeasures that appear to have a high potential to reduce the total harm for each problem. In highlighting these countermeasures, we have considered factors such as the size of the problem, the potential of the countermeasure to reduce harm, as well as the cost of the countermeasure to society and to the driver, and the likelihood that this countermeasure could be implemented in the next decade.

Approach: Reduction in Total Harm

A comprehensive approach to reducing total harm was used in this report. Total harm is conceptualized here as a product of exposure, risk, and consequence (see Figure 9), and is based on the work of Thulin and Nilsson (1994).

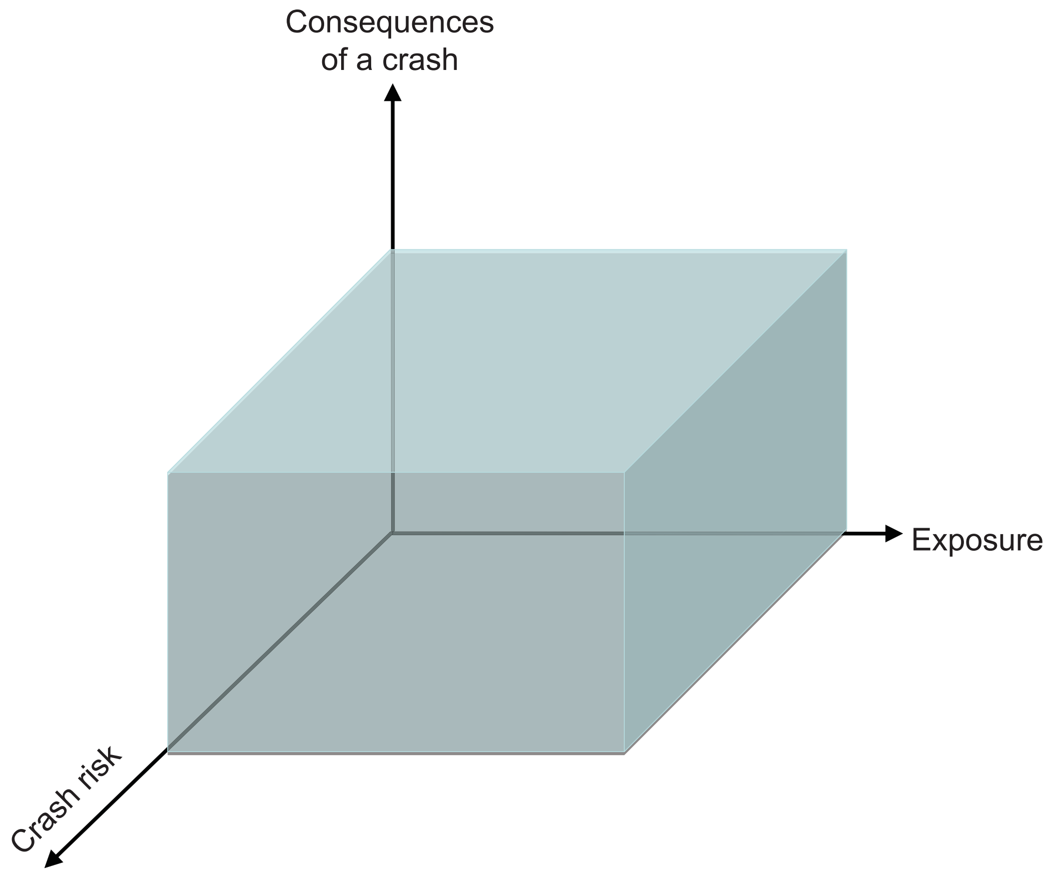

Figure 9. The approach of reducing total harm that formed the foundation of this study.

In this approach, exposure is the probability of a particular event (condition, situation) per distance traveled. Risk is the conditional probability of a crash, given the event in question. Consequence is the conditional probability of a fatality (or an injury), given a crash that was precipitated by the event in question. Consider, as a specific example of an event, making an unprotected left turn (i.e., without a green arrow) across oncoming traffic. In this example, the frequency of making an unprotected left turn per 100,000 km of driving would be the exposure. The frequency of a crash per 10,000 unprotected left turns would be the risk. The frequency of a fatality per 1,000 crashes while making unprotected left turns would be the consequence.

For each event, the values along the three dimensions (exposure, risk, and consequence) define a 3-dimensional space. The volume of this space is the total harm (see Figure 9). The fundamental questions to be addressed are:

(1) In each geographical region of interest (e.g., country), what are the events that lead to the largest 3-dimensional spaces of total harm?

(2) For each region-specific important event, what are the most cost-effective ways of reducing the volume of total harm?

Let us assume that, in a particular region, the above example of making an unprotected left turn leads to a relatively large 3-dimensional space of total harm. The volume of this space could be reduced by effective countermeasures that apply to any of the three dimensions of the space (Figure 10). For example, exposure could be reduced by installing more green arrows or by increasing the frequency of locations where left turns are not allowed. Risk could be lowered by installing collision-warning systems or by reducing the posted speed. Finally, consequence could be minimized by installing side-impact and curtain airbags, or by installing technology that would reduce the likelihood of a rollover. Of interest here is identification of the most promising countermeasures, regardless of which of the three dimensions they affect, while taking into account practical considerations.

In the ideal situation, this type of analysis would be based on quantitative information about both the relative contribution to the total harm of different factors/scenarios, and the likely benefits of different countermeasures in the particular setting. However, available data for China are not detailed enough to allow us to calculate the total harm for different combinations of factors. Furthermore, information about the likely effectiveness of different countermeasures in the Chinese situation is also generally not available. Consequently, the analysis to follow will be more qualitative than we would wish. As relevant data become available, more quantitative versions of the present analysis should follow.

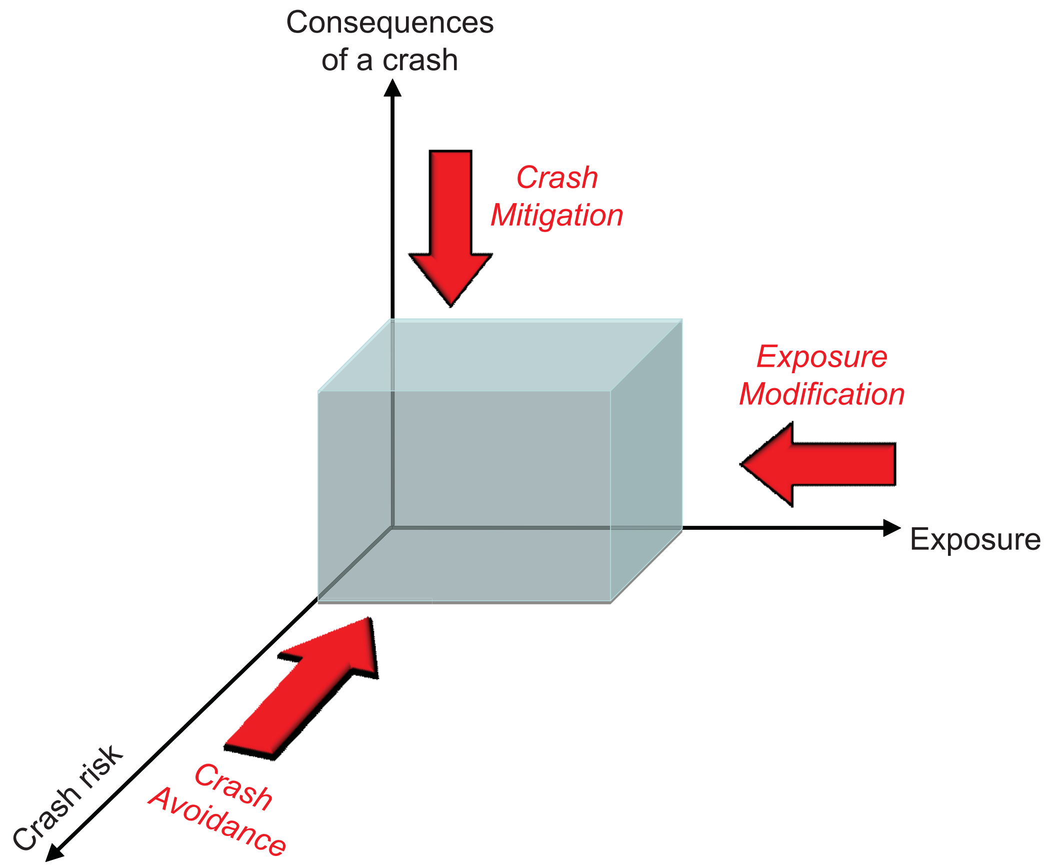

Figure 10. Reducing the total harm by countermeasures that target exposure, risk, or consequences.

Categorization of Countermeasures

We used the reduction-in-total-harm approach to categorize and select possible countermeasures that may reduce total harm. We categorized the countermeasures as reducing either exposure, risk, or consequences of events. Furthermore, we categorized the countermeasures by the type of intervention they represent, following the taxonomy of the Six-E Project that was outlined by the Development and Research Center of State Council (2007). In that report, six categories of countermeasures were described: Enactment (legal regime and legislation), Engineering (vehicles), Environment (roads), Education and publicity, Enforcement (laws), and Emergency (rescue). Our focus in the present report is on Engineering countermeasures, specifically those that are vehicle-centered. Nevertheless, we analyzed and considered countermeasures from other categories, so as to address the road safety problem as a whole.

Pedestrians and Other Non-Motorists

Encounters with pedestrians and other non-motorists in the vehicle's path accounted for 40% of traffic fatalities in China in 2005 (CRTAS, 2006). Although this number has been decreasing in the last few years, it is expected to remain a major part of overall fatalities for many years to come. There are several ways in which total harm from these types of crashes can be reduced (Retting, Ferguson, & McCartt, 2003). Reducing exposure can be achieved by pedestrian-vehicle separation. Reducing risk can be achieved by speed control and increasing the visibility and conspicuity of pedestrians. Reducing consequences can be achieved by vehicle modifications that reduce impact forces and by improving post-crash emergency treatment.

The timing of countermeasure implementation is critical. In a recent review of pedestrian protection systems, Gandhi & Trivedi (2007) advocated the development of infrastructure-based solutions as roads are being built in developing countries (mainly China and India) because it would be easier and cheaper to build these systems along with the roads rather than retrofitting them later. Similarly, it is critical to educate pedestrians and drivers early rather than late about crash risks and how to avoid them.

Table 7 lists several countermeasures to reduce the harm to pedestrians and non-motorists. Three particularly promising countermeasures are highlighted: passive safety systems, automatic headlights for nighttime and adverse weather, and an education campaign with emphasis on pedestrians and non-motorists.

Table 7
Countermeasures for crashes that involve pedestrians and other non-motorists.

Category	Exposure	Risk	Consequences
Engineering (primarily vehicle-centered)		**Automatic headlights in the dark**	**Passive safety systems involving vehicle design**
		Retroreflective indicators	Bumper extension or lowering
		Pedestrian/bicycle detection systems	Pop-up hoods
		Pedestrian/bicycle night vision systems	External airbags
Environment and Engineering of Infrastructure	Pedestrian facility design	Road illumination	
	Roadway design and divided traffic	Traffic calming	
	Intersection design	Traffic management	
	Convenient public transportation	Signals and signage	
	Infrastructure-based awareness systems		
Education	**Pedestrian and non-motorist awareness of hazards caused by motor vehicles**	Publicity of traffic rules	
Enforcement and Enactment	Correct lane/road use	Headlight usage	
	Focus on school zones	Turn signal usage	
	Speed monitoring	Mandatory automatic headlights	
	Right of way at crossings	Pedestrians not allowed on limited access freeways	
Emergency			Improved emergency vehicle response time

Passive safety systems involving vehicle design have the potential to reduce total harm by reducing the consequences of vehicle-to-pedestrian crashes (especially head injuries) and vehicle-to-non-motorist crashes (Crandall, Bhalla, & Madeley, 2002). In a study of the geometric details of pedestrian injuries at a hospital in Germany, almost 70% of pedestrian injuries were caused by direct impact with the vehicle before hitting the road, and 80% of serious injuries were head injuries (Kalliske & Friesen, 2001). Compliance with new standards and test specifications for assessing the pedestrian injury potential of vehicle front structures is estimated to reduce pedestrian fatalities by more than 20%, and further improvement may be achieved by improving the windshield structure (Crandall et al., 2002).

Automatic control of headlights for nighttime and adverse weather conditions is designed to increase the use of headlights. The potential of this countermeasure is all the more important in China, given the tendency to delay turning on headlights (Zhang et al., 2006). Automatic control of headlights has the potential to reduce the risk of hitting pedestrians and other non-motorists when visibility is a contributing factor.

An education campaign to increase the awareness of pedestrians and non-motorists of the hazards they face is likely to reduce the exposure of vehicles to pedestrians in their path. Educating the public is not an easy or inexpensive task, especially with a population of 1.3 billion people. Nevertheless, there are clear benefits to educating the public about the risks that pedestrians and other non-motorists face from vehicles.

Nighttime Driving

Nighttime crashes from 8 pm to 4 am, a period which is dark throughout the year for the majority of the population in China, accounted for 35% of traffic fatalities in 2005 (CRTAS, 2006). An additional 16% of crashes occurred between 5 pm and 8 pm, which depending on the geographical position and time of year, is also sometimes dark. Although exact information about exposure (the number of vehicles in China driving at night) is not available, overall nighttime exposure is likely to be substantially lower than that of daytime. The rate of fatalities per hour, however, peaks at 8 pm (7% of all fatalities) and remains high until 11 pm (4.5% of all fatalities) (CRTAS, 2006).

Table 8 lists several countermeasures to reduce the harm associated with nighttime driving. Three countermeasures are highlighted, addressing three underlying reasons for elevated nighttime risk: visibility, fatigue, and alcohol. The first countermeasure, featured earlier in relation to pedestrian crashes, involves installation of automatic headlamps (headlamps connected to sensors of ambient illumination). This is recommended because of the delayed use of headlamps in China and the consequent impaired visibility. The second countermeasure deals with mandatory rest and operation hours for truck drivers, addressing the elevated fatigue component of risk for truck crashes. The third countermeasure involves a continuation of zero alcohol tolerance, minimizing alcohol involvement in nighttime crashes.

Table 8
Countermeasures for nighttime crashes.

Category	Exposure	Risk	Consequences
Engineering (primarily vehicle-centered)		**Automatic headlights in the dark**	Vehicle crash worthiness
		Adaptive lighting	
		Drowsy driver detection	
		Lateral drift warning	
Environment and Engineering of Infrastructure	Convenient public transportation	Road illumination	Wide lane shoulders
		Designated rest areas on highways	Divided lanes
Education	Pedestrian and non-motorist awareness	Effectiveness of headlights when dark	
Enforcement and Enactment		Headlight use during dawn and dusk	
		Continued zero alcohol tolerance	
		Mandatory rest and operation hours for truck drivers	
Emergency			Improved emergency vehicle response time at night

Vehicle Passengers

Passengers in vehicles have been represented among fatalities at a ratio of about 2.4:1 compared to vehicle drivers. In 2005, there were 20,216 passenger fatalities, compared to 8,376 driver fatalities (CRTAS, 2006). There are two important risk factors for passengers:

First, the prevalence of seat-belt use is lower for passengers than for drivers (Stevenson et al., 2007). A recent seat-belt intervention project in the city of Guangzhou (Stevenson et al., 2007) successfully used public education and focused law enforcement to increase seat-belt use for drivers from 50 to 62%, and for front-seat passengers from 40 to 53%.

Second, vehicle crashworthiness, and specifically for side impact, can clearly be improved. In 2002, fatalities associated with side impact crashes constituted about 27.5% of all traffic fatalities and over 30% of all crashes (CRTAS, 2006; Dong, Wang, Zhang, & Huang, 2007). These values are somewhat lower but comparable to those in the U.S. (35% of the fatalities in 2005) (FARS, 2006). Improving vehicle design, especially with respect to side impact as it affects passengers, is of great potential. Countermeasures such as improving vehicle structure and mandating requirements for passenger-side airbags should be considered.

Table 9 lists several countermeasures to reduce the harm for passenger-related crashes. Two countermeasures are highlighted. First, vehicle design for crashworthiness of passengers should be considered. This includes seat-belt warnings for all passengers, front and side airbags, and pre-crash sensing technologies (e.g., seat adjustment, airbag pre-arming). Second, education and enforcement should address the low percentages of seat-belt use, especially that of passengers.

Table 9
Countermeasures for crashes that involve vehicle passenger fatalities.

Category	Exposure	Risk	Consequences
Engineering (primarily vehicle-centered)			**Vehicle crashworthiness**
			Airbags including side airbags for passenger protection
			Occupant position sensing
			Seatbelt warning and interlocks for all passengers
Environment and Engineering of Infrastructure	Convenient public transportation		
Education	Awareness of the risk of riding with a high-risk driver (alcohol, novice driver, etc.)		**Passenger seatbelt use**
Enforcement and Enactment			**Passenger seatbelt use**
			Helmet use
			Mandatory airbag installation
Emergency			Reduced emergency vehicle response time

Motorcyclists

The number of registered motorcycles in China exceeds the number of all other types of vehicles combined. In 2001, registered motorcycles constituted 63.2% of all registered motor vehicles (Zhang et al., 2004). Motorcycle rider fatalities (21,895) comprised 22.2% of all fatalities (CRTAS, 2006). Motorcycles tend to be driven by young drivers, often underage and without a license. Helmet use is not common. For example, in a study of helmet use in the region of Guangxi (Zhang, Zhou, & Chen, 2004), only 18% of motorcycle drivers wore standard helmets, with an additional 38% of drivers wearing non-standard helmets and 44% wearing none. Among the possible countermeasures are education and enforcement of helmet use, especially in rural areas, and regulation of standard helmets. A recent project to promote helmet use in Vietnam used public awareness campaigns and has resulted in a mandatory helmet law with apparent initial success (Craft, 2007). As motorcycles are currently the vehicle of choice for young drivers, educating drivers in traffic rules and traffic risks is critical. Additional engineering interventions such as divided traffic and traffic control are also of great importance.

Table 10 lists several countermeasures to reduce motorcyclist fatalities. One highlighted intervention is increasing standard helmet use by means of education, enforcement, and legislation. The other highlighted countermeasure for motorcyclist crashes is to improve their visibility during day and nighttime.

Table 10
Countermeasures for crashes of motorcyclists.

Category	Exposure	Risk	Consequences
Engineering (primarily vehicle-centered)		**Retroreflective indicators and indicator lights on motorcycles**	
		Daytime running lights	
Environment and Engineering of Infrastructure	Convenient public transportation		
	Divided traffic		
Education	Awareness to the risk of riding motorcycle	Awareness to traffic rules and signaling	**Benefits of helmet use**
Enforcement and Enactment	Licensing policy and formal training		**Enforcement of helmet use**
	Lane/road use enforcement		
Emergency			Reduced emergency vehicle response time

General List of Vehicle-Centered Safety Countermeasures

In the preceding sections we highlighted several vehicle-centered safety countermeasures in the context of addressing four broad classes of crashes (pedestrians and other non-motorists, nighttime driving, vehicle passengers, and motorcyclists). However, there is a wide variety of other vehicle-centered safety countermeasures in production and under development for modern vehicles. A selection of vehicle-centered safety countermeasures and technologies is listed in Table 11. Countermeasures that were included in our preceding analysis are denoted by an asterisk. Some have already been proven effective and are already integrated into many production vehicles in other parts of the world (e.g., antilock braking systems, electronic stability systems), while others are in various stages of development and evaluation. A full examination of the potential benefits of these countermeasures in China is beyond the scope of this report. However, it is likely that some of them are already cost effective for China, while others might prove to be so as they mature with concurrent decrease in cost.

Table 11
Vehicle-centered safety countermeasures.

Crash avoidance warnings (reduce risk and consequences)	Forward collision warning
	Curve speed and rollover warning
	Lateral drift warning*
	Lane change/merge and blind spot warning
	Intersection collision warning
	Traffic sign and one-way warning
	Rear impact warning (high speed)
	Low-speed backing camera and/or warning
	Communication-enabled threat warning (Vehicle to vehicle and vehicle to infrastructure communication)
	Pedestrian and bicycle detection systems (day and night)*
Pre-crash sensing (reduces consequences)	Active braking (forward crash mitigation)
	Active steering (lane change and lateral drift crash mitigation)
	Driver and passenger frontal and side-impact airbags*
	Brake assist
	Seat belt tensioners and airbag pre-arming*
	Pedestrian protection (e.g., Pop-up hoods)*
	Bumper extension or lowering*
	Pedestrian protection (e.g., External airbags*)
	Automatic seat adjustment
	Occupant position sensing (for optimal deployment of airbags)*
Post-crash response (reduces consequences)	Advanced collision notification system
	Passive safety systems involving vehicle design*
	Vehicle crash worthiness*

(continued)

Table 11 (continued)

Advisories and information (reduces exposure and risk)	Congestion ahead advisories (infrastructure communication)
	Road condition and weather advisories (infrastructure communication)
	Hazardous area and crash support warning
	Tire-pressure monitor
Driver assistance and dynamic vehicle handling (reduces risk and consequences)	Intersection support
	Stop-and-go support
	Adaptive cruise control
	Semi-autonomous driving
	Intelligent speed adaptation
	Roll stability / Anti rollover correction
	Lane keeping assist
	Electronic stability control
	Antilock braking system
Support for driver vision (reduces risk)	Daytime running lights* (for motorcycles)
	Automatic headlights in the dark, and low beam to high beam switching*
	Adaptive lighting*
	Adaptive rear signaling
	Retroreflective indicators and indicator lights on motorcycles*
	Retroreflective indicators for pedestrians*
Driver state monitoring (reduces exposure and risk)	Alcohol detection and lock out
	Drowsy driver detection, warning, and lockout*
	Distraction detection, workload management and device lock out
	Seatbelt warning and interlocks*
	Driver medical state monitoring

* Countermeasure is included in the preceding analysis of four areas of road safety problems in China.

Conclusions

Based on the analysis above, we recommend the following countermeasures for dealing with the four areas highlighted in an earlier part of this report.

(1) Pedestrians and other non-motorists. Automatic headlights at night and adverse weather; passive safety systems involving vehicle design to reduce crash impact on pedestrians; and an education effort to improve awareness of pedestrians and non-motorists to the hazards of vehicles.

(2) Nighttime driving. Automatic headlights; mandatory rest and operation hours for truck drivers; and continuation of zero alcohol tolerance laws.

(3) Vehicle passengers. Vehicle design for crashworthiness with focus on passengers; and education and enforcement of seat-belt use.

(4) Motorcyclists. Education, enforcement, and legislation of helmet use; and improving motorcycle visibility during daytime and nighttime.

From recent trends, it is reasonable to assume that exposure will continue to increase and risk and consequences will decrease. Exposure will increase in terms of number of vehicles, drivers, and roads. As the buying power of individuals increases, it is expected that the vehicle fleet will modernize so that risk and consequences will decrease accordingly.

Our choice of countermeasures is based on the analysis of the current road safety situation as reported in official statistics. However, this analysis was limited by the nature of the available data. (See Luoma & Sivak, 2006 for information about the nature and availability of the national database in China and several other key countries). Most notably, the lack of detailed statistics on the interactions among factors of interest has limited this analysis. For example, information on the relationship between time of day (e.g., day/night) and type of road user (e.g., pedestrian/driver) in crash frequencies would allow real quantification of the prevalence of pedestrian fatalities during nighttime in China, a problem that is likely to be very large but for which there are no specific data.

Although accurate local data are necessary to quantify safety problems, it may be possible to some extent to project the effectiveness of countermeasures across countries, thus making use of information from countries with more detailed reporting. For example, a model is under development to represent the effects of safety countermeasures based on detailed crash statistics first in the U.S. (Flannagan & Flannagan, 2007).

The official statistics suggest that the overall number of fatalities in China has decreased recently (CRTAS, 2006). However, other studies have assumed that the peak in fatalities is still ahead of us (e.g., Kopits & Cropper, 2005; McManus, 2007; WBCSD 2004). If these assumptions are correct, the recommended countermeasures should help in bringing about an earlier change in the direction of the fatalities (see McManus, 2007).

In choosing the countermeasures, we have made two additional assumptions. First, we have not focused on older drivers, as it seems that the older driver population in China will remain relatively small for at least the next decade. Second, the concern with younger drivers in China is currently not as high as it is in other countries because of the prevailing cultural and social pressures that keep teens from acquiring driver licenses and from having access to cars, especially for leisure purposes.

Our approach to the choice of countermeasures assumes primarily governmental promotion of safety rather than a strongly market-driven demand. Consequently, the relative importance of policy, legislation, enforcement, and education is high. The zero tolerance alcohol policy is an example that can be extended to a mandatory use of helmets and seat belts, and to the use of headlights as soon as it begins to become dark. By the same token, legislation and standardization of vehicle design to reduce pedestrian impact is important for the reduction of pedestrian and non-motorist fatalities.

SUMMARY

China has the world's largest population, is the second largest automobile market, and is the third largest world economy. China's economy is booming, resulting in a rapid increase in both the road infrastructure and the access to private vehicles. As a consequence, China faces unprecedented road safety issues.

The present report was designed to analyze the Chinese road safety situation and to identify countermeasures that would address areas in which the total harm caused by crashes can be substantially and readily reduced. The report focuses on two aspects of road safety in China, challenges and opportunities. In the first part, the report provides a comprehensive analysis of the current road safety situation in China and the likely future trends. Based on this analysis, the following four areas were identified as having potential for substantially reducing fatalities in China: pedestrians and other non-motorists, nighttime driving, vehicle passengers, and motorcycles. In the second part, the report discusses several promising countermeasures for each of these four areas.

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