CONTRIBUTION OF TRUNK HIGHWAY SYSTEM TO ROAD SAFETY IN CHINA IN THE PAST 18 YEARS

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ABSTRACT

At the end of 1980s, the Ministry of Communications of China, formulated a strategic plan to construct a national trunk highway system in 30 years starting from 1990 and ending at 2020, which comprises 12 trunk highways with total length of 35,900 kilometers. As time passed, it became clear that the system completion would be ahead of schedule. In fact, it was finished in 2007. It took only 18 years for China to construct this highway system that was initially projected to take 30 years to build. The mission of this study focus on the following three aspects. They are (*i*)determine the crash rate, fatality rate and injury rate for trunk highways, and the reduced levels of them when compared with those of Class II highways; (*ii*) establish the standard of crash prevented, lives saved, injuries avoided and the corresponding economic gains for operating this trunk highway system; and (*iii*) estimate the total crash prevented, lives saved, injuries avoided and the economic gains for safety improvement during the past 18 years.The results show that the trunk highway system is estimated to have prevented nearly 1,000,000 crashes, spared the lives of at least 100,000, avoided injuries of 580,000, and obtained 12.5 billion Yuan for economic gains on safety.

Keywords: trunk highway system, crash rate, fatalities and injuries avoided, economic gains.

INTRODUCTION

Early Planning of the National Trunk Highway System

At the end of 1980s, the Ministry of Communications formulated a strategic plan to construct a national trunk highway system in 30 years starting from 1990 and ending at 2020. This trunk highway system, also named “Five Longitudinal and Seven Latitudinal Highway System”, comprises 12 trunk highways with the total length of 35,900 kilometers. Among them, about 25,000 kilometers are expressways and other 10,900 kilometers are Class I highways, which are all designed with high technical standards. This system was authorized formally by the State Department of China in 1992. The highways of this system are shown in Figure 1.

Five Longitudinal Trunk Highways

No.	Start	End	Mileage
1	Tongjiang	Sanya	5700km
2	Beijing	Fuzhou	2540km
3	Beijing	Zhuhai	2310km
4	Erenhot	Hekou	3610km
5	Chongqing	Zhanjiang	1430km
	Total		15590km

Seven Latitudinal Trunk Highways

No.	Start	End	Mileage
1	Suifenhe	Manzhouli	1280km
2	Danton	Lhasa	4590km
3	Qingdao	Yinchuan	1610km
4	Lianyungang	Korgas	3980km
5	Shanghai	Chengdu	2770km
6	Shanghai	Wanding	4100km
7	Hengyang	Kunming	1980km
	Total		20310km

Figure 1 National trunk highway system

Construction of the National Trunk Highway System

The state was soon underway with construction of this highway system. As time passed, it became clear that the goal of system completion by 2020 would be ahead of schedule. In the first eight years of construction, the average annually increased mileage of trunk highways was near 1, 000 kilometers. In 1998 the government increased highway infrastructure investment in order to withstand the Asian financial crisis. As a result, the process of constructing the trunk highway system entered a period of rapid development from then on, and every year there were more than 2,500 kilometers of newly-built trunk highways opened to traffic. In 2000, it was estimated that the system completion would be ten years ahead of schedule. However, the fact is that it advanced the deadline by 12 years. It took only 18 years for China to construct this highway system that was initially projected to take 30 years to build.

Figure 2 shows the total mileage and the annually increased mileage of expressways of China from 1988 to 2008. Approximately 40 percent of these expressways are trunk highways which are constructed by the central government, others are expressways constructed by local governments. It can be found that the China has accelerated the expressway construction process since 1998. By 1998, the expressway mileage of China reached 8,733 kilometers, surpassing that of Italy to rank the sixth in the world. One year later, it was 11,600 kilometers, surpassing that of

France to rank the fourth in the world. By 2000, it reached 16,000 kilometers, surpassing that of Germany to rank the third. And at the end of 2002, it was 19,400 kilometers, surpassing Canada to rank the second in expressway mileage. Due to the incredible development of expressways in recent years, especially the years of 2005, 2007 and 2008, it was called the “China’s expressway constructing speed”.

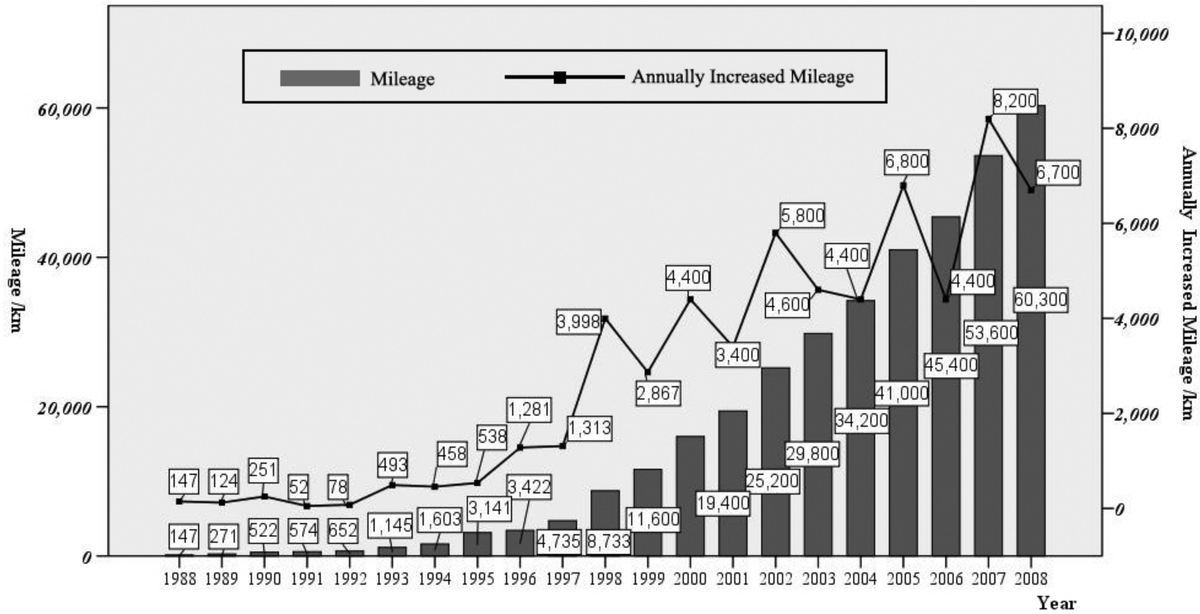

Figure 2 Mileage and annually increased mileage of China expressway

Impact of the National Trunk Highway System

The trunk highway system serves virtually all of the nation’s large cities with population of more than one million and 93 percent cities with population of more than half million. A day trip can be available in this system between cities with the distance of 400 to 500 kilometers. It covers almost all of the provinces and more than 600 million people have benefit from it. Although representing just over 2 percent of the nation’s highway system, it carries nearly one fifth (20 percent) of all highway traffic. The average travel speed is two times that of the rest of the system. As a result, it has generally reduced travel time by 50 percent or more. It was estimated that this system has returned more than 3.3 Yuan in economic productivity for each 1 Yuan it cost (the total cost of the system is 700 billion Yuan), and created annually more than one million job opportunities (Transport Planning and Research Institute, Ministry of Transport, and School of Transportation Science and Engineering, Harbin Institute of Technology, 2007).

The Dwight D. Eisenhower System of Interstate and Defense Highways of the U.S. had saved the lives of at least 187,000 people and prevented injuries to nearly 12 million people from 1956 to 1996 (Wendell and Jean, 1996). The following questions are then introduced on what’s the safety situation of the China’s trunk highway system has and how does it effect on the nation’s road safety?

Mission of This Study

The study aims at solving some problems on safety situations of the trunk highway system which are highly concerned by all circles of the society. The objectives are given as follows:

(*i*) Determine the crash rate, fatality rate and injury rate for trunk highways, and the reduced levels of them when compared with those of Class II highways.

(*ii*) Establish the standard of crash prevented, lives saved, injuries avoided and the corresponding economic gains per unit exposure.

(*iii*) Estimate the total crash prevented, lives saved, injuries avoided and the economic gains for the opreation of this national trunk highway system during the past 18 years in China.

HIGHWAY TYPE AND HIGHWAY SELECTION

Highway Type

Two kinds of highways are discussed and compared with respect to their safety situations. The first one is the trunk highways which are the higher class highways covering most of the *Expressways* and *Class I highways*. The second is the *Class II highway*s which were served as the trunk highways before 1980s when there were no expressways and Class I highways in China. The others, such as *Class III* and *Class IV* highways, are lower class highways which connect small towns and villages. Their main function is land access, so there is no need to take them into account.

Obviously, without the trunk highway system, the increasingly vehicle travel needs would be satisfied by the Class II highway system, and in this case the safety situations would be far different.

According to the "*Technical Standard of Highway Engineering*"(The Ministry of Communications, P.R.C., 2003), *Expressways* are divided, dual carriageway, high-speed trunk highways with full access control.Four-lane expressways are generally capable of accommodating an Annual Average Daily Traffic (*i.e.*, AADT) of 25,000 to 55,000 passenger cars, while six-lane and eight-lane expressways can accommodate AADTs of 45,000 to 80,000 and 60,000 to 100,000 passenger cars, respectively. *Class I Highways* are divided, dual carriageway, four-lane or six-lane highways with patial access control, and generally able to accommodate an AADT of more than15,000 passenger cars. *Class II Highways* are two-lane highways which can accommodate an AADT of 5,000 to 15,000 passenger cars. *Class III* and *Class IV* highways are all two-lane highways which accommodate less than 5,000 passenger cars.

Highway Selection

There are 14 highways containing 7 expressways, 1 Class I highway and 6 Class II highways selected as the study sites. These highways with total length of 6,230 kilometers cover Liaoning Province, Heilongjiang Province, Sichuan Province and Jiangsu Province. Comparative analysises are brought forward between each trunk highway and its correspoding Class II highway, and the two compared highways are nearly paralleled and located in the same traffic corridor. The trunk highways and the compared Class II highways are listed in Table 1.

Table 1 Trunk highways and the corresponding compared Class II highways

No.	Trunk Highways	Class II Highways	Location
1	Shen-Da expressway	No.202 highway	Liaoning province
2	Shen-Dan expressway	No.304 highway	Liaoning province
3	Shen-Shan expressway	No.102 highway[1]	Liaoning province
4	Cheng-Yu expressway	No.108 highway	Sichuan province
5	Hu-Ning expressway	No.312 highway	Jiangsu province
6	Ha-Shuang expressway	No.102 highway[1]	Heilongjiang province
7	Ha-A Class I highway	No.301 highway[2]	Heilongjiang province
8	Ha-Da expressway	No.301 highway[3]	Heilongjiang province

[1] No.102 highway passes through both Liaoning province and Heilongjiang province; [2] the segments of No.301 highway starting from Harbin and ending at Acheng; [3]the segments of No.301 highway starting from Harbin and ending at Daqing.

Each of these 8 trunk highways is utilized to characterize the safety situations of a specific area as well as a specific terrain condition (shown in Table 2), and then a set of safety evaluation criterion can be established.

Table 2 Trunk highway attribute

Economic Condition	Terrain Condition		
	Level	Rolling	Mountainous
Economy developed area	Hu-Ning expressway	Shen-Da expressway	Shen-Dan expressway
Moderately developed area	Ha-Shuang expressway	Shen-Shan expressway	--
Economy developing area	Ha-Da expressway	Ha-A Class I highway	Cheng-Yu expressway

DATA DESCRIPTION

Crash Data

The crash data are collected from highway administration management departments of corresponding highways. Totally, 15,620 traffic crashes occurred on the 8 trunk highways and 6 Class II highways are analyzed, which caused 2,043 people killed and 6,151people injured. Each crash with the relevant information of the location, the time of occurrence, and the severity (fatal, injury and property damage only), is recorded.

Safety Indexes

In order to meet the requirements of the study, six safety indexes of total crash rate (TCR), fatal crash rate (FCR), injury crash rate (ICR), direct economic loss per crash (ELC), economic loss per fatality (ELF) and economic loss per injury (ELI) are employed. The former three indexes are defined as the number of crashes, the number of fatalities and the number of injuries per 100 million vehicle kilometers of travel, respectively. They can be obtained by:

$$TCR = \frac{C \times 100,000,000}{VKT} \tag{1}$$

$$FCR = \frac{F \times 100,000,000}{VKT} \tag{2}$$

$$ICR = \frac{I \times 100,000,000}{VKT} \tag{3}$$

where:

C: number of crashes during the given year

F: number of fatalities during the given year

I: number of injuries during the given year

VKT: vehicle kilometers of travel during the given year, calculated by AADT×365(366 for leap years)×length of highway segment

The latter three indexes can be obtained from statistic analysis on the crashes occurred on trunk highways and calculated by the following equations:

ELC=Total economic loss of property damage only crashes/ the number of property damage only crashes (4)

ELF=Total economic loss of fatality/the number of people killed (5)

ELI =Total economic loss of injury/the number of people injured (6)

Furthermore, it is necessary to determine the crash rates reduced (or increased) on trunk highways when their crash rates are compared with those of Class II highways. The crash rates reduced can be described by the crash rate reduced (CRR), the fatality rate reduced (FRR), the injury rate reduced (IRR). They are given by:

CRR= crash rate of a Class II highway–crash rate of the compared trunk highway (7)

FRR= fatality rate of a Class II highway–fatality rate of the compared trunk highway (8)

IRR= injury rate of a Class II highway–injury rate of the compared trunk highway (9)

Traffic Volume

As the most important exposure, the AADTs of trunk highways are obtained from the "*Handbook of national trunk highway volume*" reported annually by Transport Planning and Research Institute, Ministry of Communications (1990-2008). Those for Class II highways are collected and summarized from the data of continuous volume count stations which are operated by local transportation management bureaus.

Generally, the traffic volumes on both trunk highways and Class II highways have the tendencies of increase annually, but the increasing rates of the trunk highways are all greater than those of Class II highways. The traffic volume growth rate for each segment of Cheng-Yu expressway during the years of 2003 to 2007 changes from 14.3 percent to 15.8 percent, and it is 15.1 percent for all segments of Shen-Da expressway. The traffic volumes of Cheng-Yu expressway and Shen-Da expressway are shown in Figure 3 and Figure 4. It can also be found that the volumes on segments very near the big cities are obviously larger than those of segments far away from it. Figure 5 is an example to illustrate the effect of big city on traffic volume.

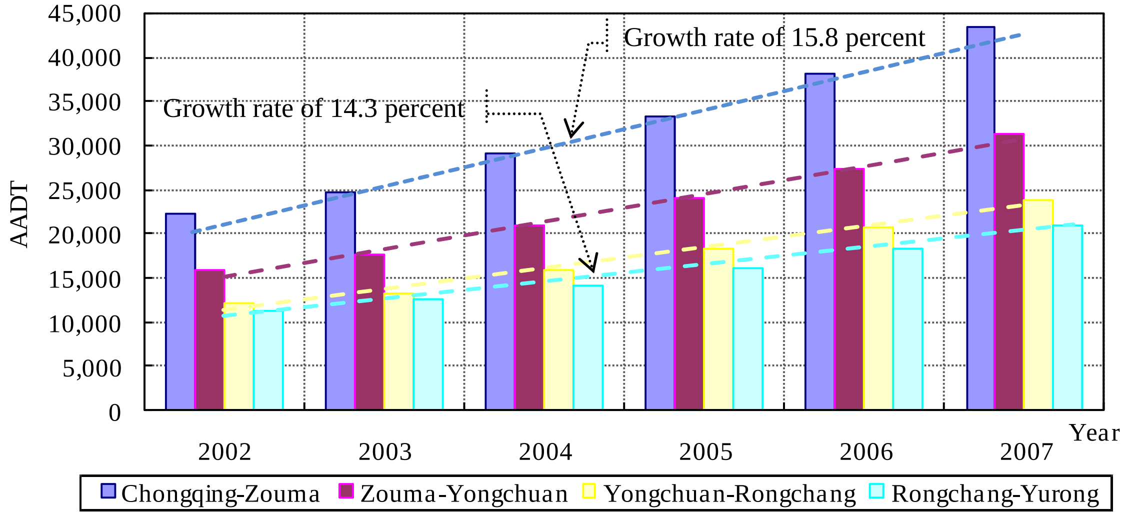

Figure 3 Development of traffic volume on Cheng-Yu expressway

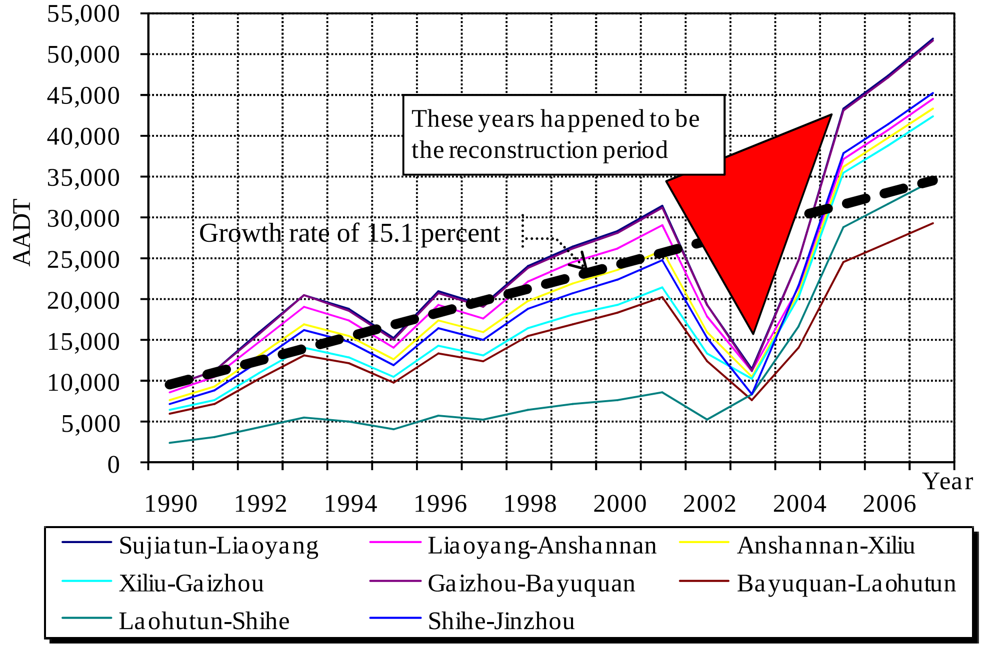

Figure 4 Development of traffic volume on Shen-Da expressway

Storage and Retrieval of Data

The databank based on Geographic Information System (GIS), which is developed by School of Transportation Science and Engineering, Harbin Institute of Technology, is employed to store and retrieve the data collected above. Figure 5 which is summarized by this databank is an example to show the occurrence of crashes and the traffic volume on Cheng-Yu expressway.

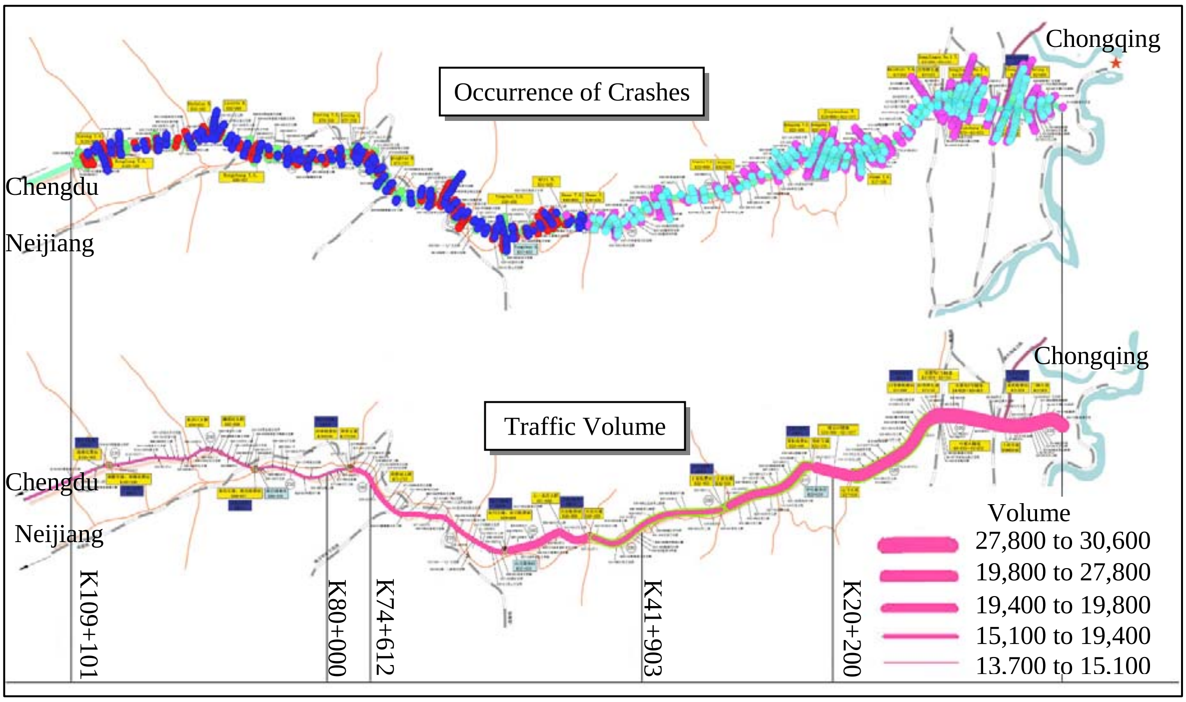

Figure 5 Crashes and traffic volume on Cheng-Yu expressway

CRITERIA AND METHODOLOGIES

Crash Rates

According to Equations 1 to 3, the crash rates of TCR, FCR and ICR can be obtained. Table 3 is an example to show these crash rates of each segment on Hu-Ning expressway from the first year of operation. The average crash rates of all segments for all years are taken as the final crash rates of a highway. For example, the TCR, FCR and ICR are 42.47, 1.64 and 8.73 for Hu-Ning expressway, which are obtained from four segments during a period of 5 years. The determined crash rates of trunk highways and compared Class II highways are listed in Table 4.The average TCR, FCR and ICR of all trunk highways are 28.40, 4.76 and 13.01, and those for all Class II highways are 50.01, 17.32 and 48.16.

Table 3 Crash rates of Hu-Ning expressway

Year	No.	Segment	TCR	FCR	ICR	Year	No.	Segment	TCR	FCR	ICR
2003	1	Zhenjiang	30.70	1.14	6.47	2006	1	Zhenjiang	20.04	0.70	6.55
	2	Changzhou	51.66	2.47	18.53		2	Changzhou	52.51	4.07	11.35
	3	Wuxi	21.26	0.00	0.00		3	Wuxi	14.68	0.00	0.00
	4	Suzhou	8.58	0.82	2.27		4	Suzhou	25.04	1.43	1.22
2004	1	Zhenjiang	52.90	0.81	9.85	2007	1	Zhenjiang	32.08	1.05	6.57
	2	Changzhou	86.66	6.27	32.78		2	Changzhou	63.75	3.69	26.61
	3	Wuxi	33.85	0.00	0.00		3	Wuxi	44.37	0.00	0.00
	4	Suzhou	27.37	1.92	5.35		4	Suzhou	38.08	0.48	3.81
2005	1	Zhenjiang	44.84	0.95	12.40	*Average of all segments and for all operation years*			*42.47*	*1.64*	*8.73*
	2	Changzhou	129.82	4.27	26.95						
	3	Wuxi	32.27	0.00	0.00						
	4	Suzhou	38.87	2.73	3.80						

Table 4 Crash rates of trunk highways and Class II highways

Group	Trunk Highway Versus Class II highway	Crash Rate		
		TCR	FCR	ICR
1	Shen-Da expressway	21.11	4.61	5.68
	No.202 highway	31.10	13.32	24.35
2	Shen-Dan expressway	11.36	7.19	9.13
	No.304 highway	16.30	8.01	12.31
3	Shen-Shan expressway	9.91	2.30	8.28
	No.102highway[1]	11.72	10.33	11.25
4	Cheng-Yu expressway	69.47	5.08	25.59
	No.108 highway	75.73	12.54	105.93
5	Hu-Ning expressway	42.47	1.64	8.73
	No.312 highway	74.35	9.76	24.38
6	Ha-Shuang expressway	42.89	9.33	23.28
	No.102 highway[2]	97.56	15.83	96.45
7	Ha-A Class I highway	17.37	3.67	14.37
	No.301 highway[3]	55.44	40.28	68.24
8	Ha-Da expressway	12.59	4.25	9.04
	No.301 highway[4]	37.86	28.45	42.37
	Average of all trunk highways	*28.40*	*4.76*	*13.01*
	Average of all Class II highways	*50.01*	*17.32*	*48.16*

[1] segments located in Liaoning province; [2] segments located in Heilongjiang province; [3] segments of Harbin to Acheng; [4] segments of Harbin to Daqing.

Crash Rates Reduced on Trunk Highways

From the figures shown in Table 4, it can be found that all the three crash rates of each trunk highway are all lower than those of compared Class II highway. This reveals the fact that the trunk highway system is much safer than Class II highway system. The average TCR, FCR and ICR of trunk highways take only 56.8 percent, 27.4 percent and 27.0 percent of those on Class II highways, and the reduced values of them are 21.61, 12.56 and 35.15, respectively. The reduced crash rates (i.e., CRR, FRR and IRR) on trunk highways are listed in Table 5.

Table 5 Crash rates reduced on trunk highways

No.	Trunk Highway	Crash Rates Reduced		
		CRR	FRR	IRR
1	Shen-Da expressway	9.99	8.71	18.67
2	Shen-Dan expressway	4.94	0.82	3.18
3	Shen-Shan expressway	1.81	8.03	2.97
4	Cheng-Yu expressway	6.26	7.46	80.34
5	Hu-Ning expressway	31.88	8.12	15.65
6	Ha-Shuang expressway	54.67	6.50	73.17
7	Ha-A Class I highway	38.07	36.61	53.87
8	Ha-Da expressway	25.27	24.20	33.33
	Average	*21.61*	*12.56*	*35.15*

Direct Economic Loss of Crashes on Trunk Highways

According to equations 4 to 6, the economic loss indexes of ELC, ELF and ELI for each trunk highway can be calculated, then a set of economic loss criteria shown in Table 6 is establisehd.

Table 6 Direct economic loss of crashes on trunk highway

No.	Trunk Highway	Economic Loss/Yuan		
		ELC	ELF	ELI
1	Shen-Da expressway	30,030	34,500	25,809
2	Shen-Dan expressway	15,979	28,522	19,174
3	Shen-Shan expressway	7,623	22,011	10,360
4	Cheng-Yu expressway	7,381	28,064	8,115
5	Hu-Ning expressway	5,293	38,500	7,699
6	Ha-Shuang expressway	19,174	23,173	12,965
7	Ha-A Class I highway	8,575	26,374	17,518
8	Ha-Da expressway	7,747	29,009	23,173

Methodologies to Estimate the Crashes and Casualties Reduced

Under the conditions of carrying out the same traffic volume, the use of trunk highways will provide much safer travels than those of Class II highways. The crashes prevented annually (CPA), lives saved annually (LSA), and injuries avoided annually (IAA) by the use of trunk highways can be calculated by the following three equations:

$$CPA = 365 \times \sum_{i=1}^{n} AADT_i \times L_i \times CRR \tag{10}$$

$$LSA = 365 \times \sum_{i=1}^{n} AADT_i \times L_i \times FRR \tag{11}$$

$$IAA = 365 \times \sum_{i=1}^{n} AADT_i \times L_i \times IRR \tag{12}$$

where:

$AADT_i$: the average daily traffic of the ith segment

n: the number of segments

L_i: the length of the ith segment

Methodologies to Estimate the Economic Gains of Safety Improvement

The lower trunk highway crash rate will produce a significant economic benefit in direct economic gains. The reduced economic loss attribute to the use of trunk highway system can be described by the economic gains of crashes prevented(EGCP), the economic gains of lives saved (EGLS) and the economic gains of injuries avoided(EGIA). These three economic indexes can be calculated by the following equations:

$$EGCP = CPA \times ELC \tag{13}$$

$$EGLS = LSA \times ELF \tag{14}$$

$$EGLA = IAA \times ELI \tag{15}$$

Methodologies to Estimate the Contribution of Trunk Highway System to Road Safety

In order to estimate the contribution of the whole trunk highway system to road safety, a cluster anaysis is needed, which can group them or parts of them into 8 groups based on the 8 trunk highways analyzed in this research work, and then the corresponding evaluation indexes can be specified. Once these indexes are determined for each trunk highway or part of them, the calculation process would be straightforward.

CASE STUDY OF TWO TRUNK HIGHWAYS

Shen-Da expressway, which starts from Shenyang, ends at Dalian and is known as “the No.1 expressway in China”, is the first and once the longest expressway in Chinese mainland. It is 375 kilometers long and opened to traffic in 1990. It crosses the economically developed Liaodong Peninsula, from level regions to rolling areas. Chen-yu expressway starting from Chengdu and ending at Chongqing, which passes through rugged and steep mountains, is a typical expressway in mountainous area of west China. These two highways are chose as case to illustrate how to estimate the construction they did for the road safety from the date of being opened to traffic.

The contribution of Shen-Da expressway to road safety is evaluated based on the criteria of crash rates reduced and economic loss indexes established above, and on the methodologies to calculate the crashes prevented, the casualties saved and the economic gains. The results are all shown in Table 7 and illustrated in Figure 6. It can be found that Shen-Da expressway do did great contribution to road safety in the past 18 years from 1990 to 2007. It is estimated to prevent at least 4,135 crashes, saved 3,605 lives, avoided 7,727 injuries, and obtained a total of 199 million Yuan economic gains. The contribution of Cheng-Yu expressway to road safety is also evaluated, and the results are listed in Table 8 and shown in Figure 7. The use of Cheng-Yu expressway from the year 2003 to 2007 is estimated to have prevented 228 crashes, saved 324 lives and avoided 3,479 injuries.

Table 7 Contribution of Shen-Da expressway to road safety from 1990 to 2007

Year	Crashes Prevented	Lives Saved	Injuries Avoided	EGCP(10^4Yuan)	EGLS(10^4Yuan)	EGIA(10^4Yuan)
1990	85	74	159	256	256	411
1991	104	90	193	311	311	499
1992	146	127	273	438	439	704
1993	189	165	353	567	568	911
1994	172	150	322	517	518	831
1995	139	122	261	419	420	673
1996	192	167	358	576	577	925
1997	176	154	329	529	530	850
1998	221	192	412	662	663	1,064
1999	243	212	454	729	730	1,171
2000	260	227	487	782	783	1,256
2001	289	252	540	867	868	1,393
2002	178	155	333	534	535	858
2003	119	104	223	359	359	576
2004	241	210	450	723	724	1,161
2005	420	366	785	1,261	1,263	2,025
2006	459	400	858	1,379	1,381	2,214
2007	502	438	938	1,508	1,510	2,421
Total	*4,135*	*3,605*	*7,727*	*12,417*	*12,437*	*19,944*

Table 8 Contribution of Cheng-Yu expressway to road safety from 2003 to 2007

Year	Crashes Prevented	Lives Saved	Injury Avoided	EGCP (10^4Yuan)	EGLS (10^4Yuan)	EGIA (10^4Yuan)
2003	34	48	514	25	134	417
2004	39	56	601	29	157	487
2005	45	64	686	33	179	557
2006	51	73	783	38	204	636
2007	59	83	895	43	233	726
Total	*228*	*324*	*3,479*	*168*	*907*	*2,823*

CONTRIBUTION OF TRUNK HIGHWAY SYSTEM TO ROAD SAFETY

Finally, the contribution of trunk highway system to road safety is evaluated, and it is estimated to have prevented nearly 1,000,000 crashes, spared the lives of at least 100,000, avoided injuries of 580,000, and obtained 12.5 billion Yuan for economic gains on safety. The crashes prevented from 1990 to 2007 are shown in Figure 8.

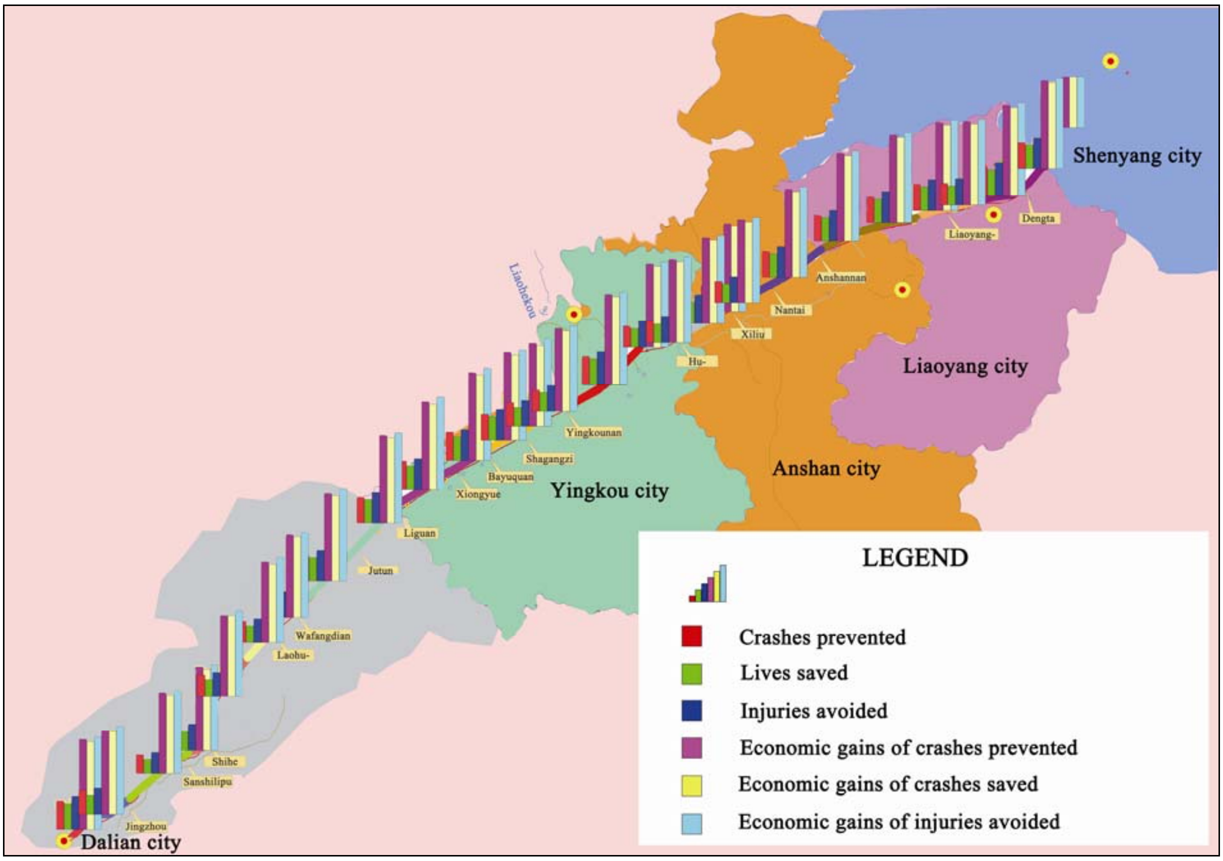

Figure 6 The contribution of Shen-Da expressway to road safety

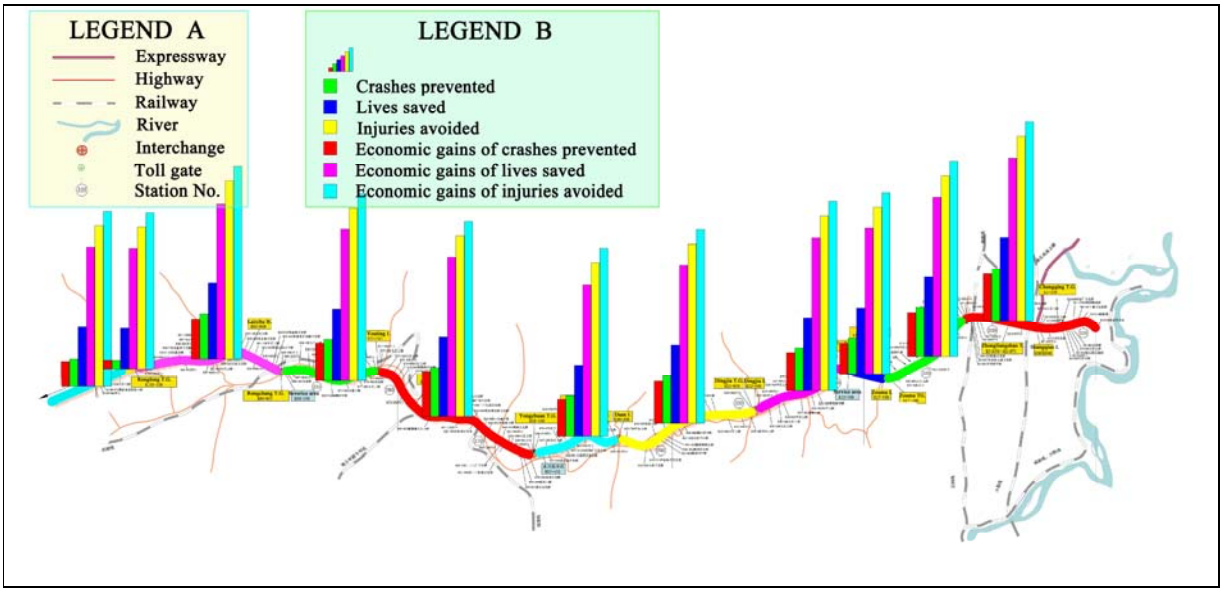

Figure 7 The contribution of Cheng-Yu expresway to road safety

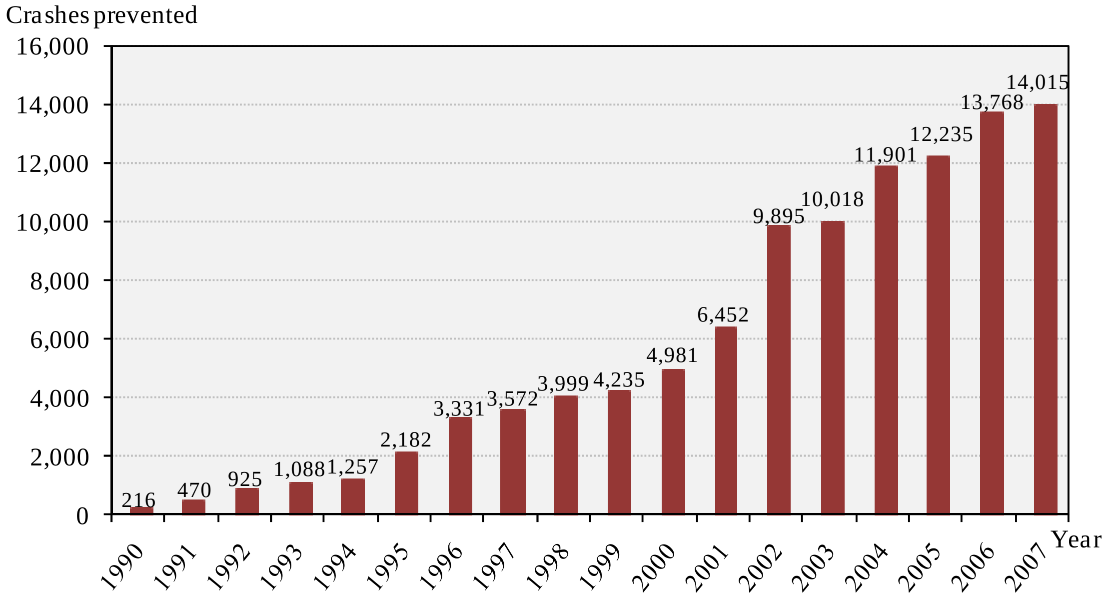

Figure 8 Estimated number of crashes prevented annually with the use of the trunk highway system

CONCLUSIONS

The background of planning and construction of the trunk highway system is introduced briefly. Then 14 highways containing 8 trunk highways and 6 Class II highways are selected as the study sites to perform the field surveys. In this research, the Class II highways, which were once served as trunk highways when there were no expressways and Class I highways, are selected for comparison. These 14 expressways cover three types of areas whose economy are developed, moderately developed and developing. They cover three kinds of terrain including level terrain, rolling terrain and mountainous terrain as well.

In order to meet the requirement of the study, six safety indexes of total crash rate, fatal crash rate, injury crash rate, direct economic loss per crash, economic loss per fatality and economic loss per injury are defined and then they are determined based on crashes and exposure data collected. Furthermore, the crash rate reduced, the fatality rate reduced and the injury rate reduced on trunk highways are given when compared the crash rates with those of Class II highways. Finally, the methodologies to estimate the crashes prevented, the lives saved, the injuries avoided and the economic gains are discussed, and a cluster analysis is applied to estimate the contribution of the whole trunk highway system.

The research results show that the trunk highway system is by far the safest component of the nation's highway system. The crash rate, fatality rate and injury rate take only 56.8%, 27.4%, and 27.0% of those on Class II highway system. The use of trunk highway system during the past 18 years is estimated to have prevented nearly 1,000,000 crashes, spared the lives of at least 100,000, avoided injuries of 580,000, and obtained 12.5 billion Yuan for economic gains on safety improvement. Although this research work does not very analytical, it is believed that it would be useful to decision makers.

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