The road safety situation investigation and characteristics analysis of black spots of arterials highways

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Abstract

The generally road safety situation of highway net was evaluated through investigating road safety of some highways and analyzing accident patterns and causes. Some sections with high accident rate were found using road black spot identification technology. Then, accident causes related to highway features and traffic factors were analyzed. The characteristics of typical black spots were analyzed from the aspect of highway features and traffic devices. Running speed of vehicles on highways was measured in order to explain why over-speed driving always was primary accident cause.

Keywords – road safety; highway features; characteristics of black spots

1. Introduction

During the past 20 years, the highway net of China has been fully improved with the development of national economy and transportation industry. Lots of national and provincial arterial highways have been developed or rehabilitated. Meanwhile, the traffic volume has increased rapidly. Unfortunately, road safety situation has been also getting worse and road accident rate has been progressive rise with the construction of highways.

Road safety issue is a complex engineering problem. It is affected by various factors, such as human factor, vehicle performance, road and environment etc. Many countries always pay great attentions to road safety issues. In order to reduce road accident rate, many research works have been carried out and both technical measures and road safety policy have been applied. For improving road safety in the late 80s, UK developed a systematic road safety audit procedure. According to this concept, all safety issues should be examined during the life cycle of a road, including planning, design, construction, maintenance and operation stages. Road safety audit was also applied in Australia, New Zealand, Sweden, and Malaysia etc. AASHTO has issued "highway safety design and operations guide" in 2001. Tongji University developed a road safety audit procedure and black spot identification method for Xin Jiang, China. Road safety audit procedure of highway projects is also under being developed by MOC of China.

Road black spot identification and improvement is another important technical measure of improving road safety. The main objective using this technology is to find the high hazardous locations (HAL) and to improve its safety condition. In order to identify HAL, different methods and criteria have been founded.

2. Road Safety Condition of Arterials highways

2.1 General situation

During the past 20 years, for satisfying the progress of the national economy and facilitating the public travels, both central government and local governments of China have carried out the improvements of highway net on a large scale. Up to the end of 2002, more than 25,000 kilometers of expressways have been constructed and the expressway net development of the relatively developed provinces in East China has been nearly fulfilled. Great achievement has been obtained in the construction of the arterial highway net and so the transportation ability has been enhanced indeed to some extent. However, on the other hand, the increase of traffic volume and the turnover volumes of transportation also caused that the amount of road traffic accidents has been increasing gradually year by year. Figure 1 shows the change of road accidents since 1990. From this data, it can be seen that the road safety situation in China is getting more and more worse.

As being an example, the development of road traffic accidents and the turnover volume of transportation in the recent years in Xin Jiang province are indicated in Table 1 and 2. The data indicates that the road & traffic accident rates had continuous increase. Data in Table 3 can indicated the road safety situation of different classes of roadways in a province.

2.2 Safety Conditions of Some High-classified Roadways

In the research on "The specification on road safety audit of highway projects", the road safety of some highways was investigated. The road safety condition thereof of high-class highways can be realized from the following analysis about accident causes, patterns and amount.

For TaiJiu expressway in mountainous area, 147 accidents were recorded in 1998 and the annual average accident rate is 1.23 accidents per kilometer (minor accidents are not included, the same thereafter). Out of the all accidents, major accidents are up to 20.33%, most serious accidents 2.8%. According to the traffic volumes measure results in 1998, the calculated accident rate is 0.55 accidents per million vehicle-kilometers. Based on the classification and statistic method of Chinese Traffic Police Office, 68.36% of accidents is rear-end collision, 23.37% is hit permanent objects, 16.77% is lane side collision and 6.21% is lane sideswipe. For the aspect of accident causes, there are 4 major causes. Driving tiredly is 17.51%, Over-speed driving is 12.99%, careless driving is 30.52%, and improper driving activity is 10.16%.

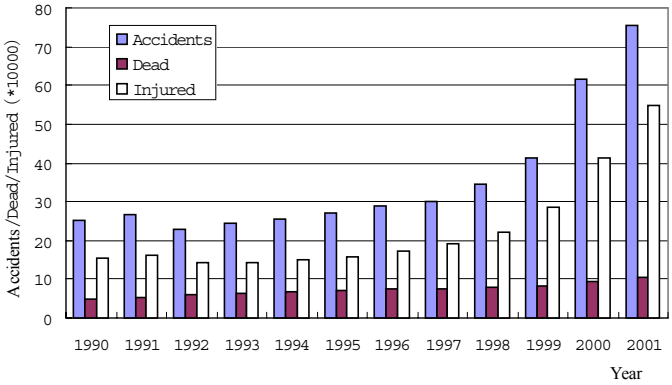

Fig. 1 – Traffic accident increase trend

Tab. 1 – Development of owned vehicles and highway transport in XingJiang province

Item / Year	OMVM	OPVA	OCTA	TVFR	TVPT	Accidents	Fatality	Injured
1995	24.7	9.35	14.33	194.67	115.29	3319	1463	2175
1996	26.53			219.28	126.59	3795	1479	2580
1997	28.52	12.75	15.77	247.00	139.00	4285	1669	3010
1998	30.64			278.22	152.62	4951	1767	3831

OMVM= Owned motor vehicle amount (ten thousand);
OPVA= Owned passenger vehicle amount (ten thousand);
OCTA= Owned Commercial truck amount (ten thousand);
TVFR= Turnover volume of freight transport (million kilometer-tons);
TVPT= Turnover volume of person transport (million person-kilometers).

Tab. 2 – Accident rates in XingJiang province

Period	Items			
	Accident /OMVM	Accident/(TVFR+TVPT)	Fatality/(TVFR+TVPT)	(Fatality+Injured)/(TVFR+TVPT)
1995	134.37	10.71	4.72	11.74
1996	143.03	10.97	4.28	11.74
1997	150.23	11.10	4.32	12.12
1998	161.59	11.49	4.10	12.99
Annual average increasing rate %	6.59	2.43	-4.38	3.55

Tab. 3 – Accident rates of high-classified highways accidents in one province

Period	Accidents	Injuries	Deaths	Accident per billion vehicle-kilometers	Injured per billion vehicle kilometers	Fatality Per billion vehicle kilometers
1996	636	162	58	12.649	3.227	1.155
1997	575	135	34	10.104	2.364	0.648
1998	593	226	108	8.125	3.097	1.480
1999	511	220	142	5.967	2.569	1.658
2000	876	193	102	7.964	1.754	0.982

One section of HuNing expressway with very heavy traffics in the rainy flatland area of South China was also investigated. The annual average accident rate of the year 1998 and 1999 is 1.94 accidents per kilometre, and 21.2% of which occur on the entrance and exit of ramps. The accidents caused 28 fatalities and 17 injuries.

For the aspect of accident pattern, 12.7% of which is lane sideswipe, 36.75% is rear-end collision, 4.5% is turnover, and 24.8% is hit-permanent objects.

For the accident causes, the first one is wrong driving activity is 28.8%. Secondly, insufficient longitudinal space is 17%, and careless driving is 15.8%, over-speed driving is 3.9%.

48 kilometres section of JiQing expressway with heavy traffic in flatland area of North China had the annual average accident rate of 3.8 accidents per kilometre in 1998 and 1999. Out of which there are 8 most serious accidents and 34 major accidents. These accidents caused 26 fatalities, 26 severe injuries, and 68 minor injuries. For the aspect of accident pattern, 32.6% of which is rear-end collision, 8.5% is sides collision, 8.8% is turnover, and 17.3% is hit-permanent objects. For the accident causes, the first one is over-speed driving which is 37.5%. Secondly, tiredly driving is 23.0%, other mechanical failure is 10.13%, and insufficient longitudinal space is 4.7%.

25 kilometres section of YanQing first class highway with heavy traffic in a flatland area of North China had the annual average accident rate of 6.6% accidents per kilometre, 9.1% of which are the most serious accidents. These accidents caused 16 fatalities, 42 severe injuries, and 36 minor injuries in 1998. These accidents have various patterns and no obvious dominant pattern. For the accident causes, over-speed driving is 11.5%, wrong driving activity is 10.3%, other motor error is 24.8%, driving in opposite direction against regulation is 4.8%, and changing lane against regulation is 4.8%.

44 kilometres section of G312 secondary highway in Northwest China is a highway constructed in 1970. The pavement width is 8-9m. In this section, 109 accidents of various patterns had happened in two years. The average annual accident rate is 1.24 accidents per kilometre. Out of those, most serious accidents are 9.1%. These accidents caused 11 fatalities, 15 severe injuries, and 9 minor injuries.

In most developed countries, black spots are defined as the locations where there are 12 accidents in each 3 years, per 0.3 kilometres. Based on this definition, it is obvious that the road safety situation in China is very serious. The accident patterns of some highways are shown in Table 4.

3. Distribution characteristics of accidents along highways and identification of black spots

3.1 Distribution characteristics of accidents along highways

Road accidents are real random events. Some road sections are called black spots because the probability that the accidents happen on such sections is obviously higher than other road sections. The accident distribution characteristics of along the investigated highway routes were analysed.

Figure 1 illustrates the distribution conditions of accidents along TaiJiu mountainous expressway. It is easy to find that some sections have more accidents and the hazardous locations exist. The road accidents distributions along other routes shown in Figure 2~6 indicate that most accidents occurred at a few sections. This fact reveals the inevitability of the existing of black spots.

3.2 Identification of black spots

If different sections of a highway have the same condition (alignment, pavement, roadside, etc), the distribution of accident along the road should have no relation with road condition and have uniform distribution. Theoretically, The distribution should be symmetric along highway when statistic samples are sufficient. But in fact, this situation is not possible. Due to the different road features and traffic conditions, some segments will have more accidents than others. Sections

especially with very high accidents frequency are only small part of the highway. The higher accident frequency, the fewer road sections with the accident frequency.

Regarding this fact, highway hazardous locations can be identified through calculating the accumulated frequency of segments with different accident rate.

Accumulated frequency method is developed using statistic theory. In this method, the accident rate at each segment of highway and accumulated frequency can be shown in X-Y Chart, as shown in Figure 7.The relation between accident rate and accumulated frequency is named as the accident-accumulated frequency curve.

With accident statistic results of some highways, it is found that there is an abrupt turning point in the curve when accumulated frequency is about 75% ~ 85%. Over the point, the change of accumulated frequency curve is small. Although this part of a road is small, they have the highest accidents frequency. Contrarily below the point, the change of accumulated frequency curve is steep. That means most of highways sections have low accident rate. Hazardous locations can be defined as those locations over the abrupt point. For example in Figure 7, if defining accident rate of 2 accident per kilometre as the criteria, the sections with accident rate of more than 2 are only 18% of the whole highway. Using this method, black spot identification of some highways in table 5 was carried out. And the results are also shown in the table.

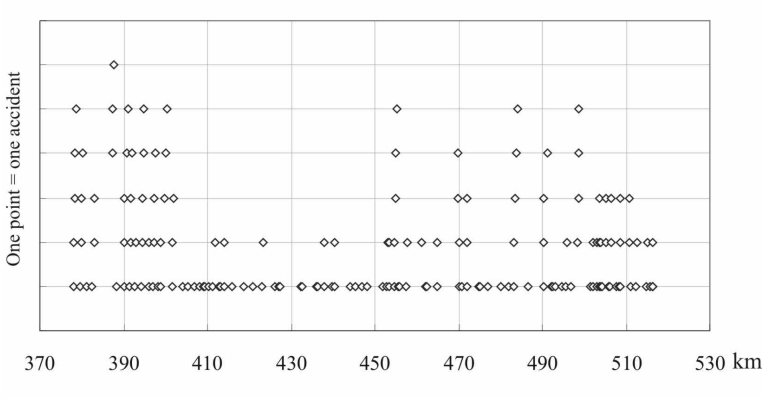

Fig. 2 – Accident distribution along Taijiu expressway

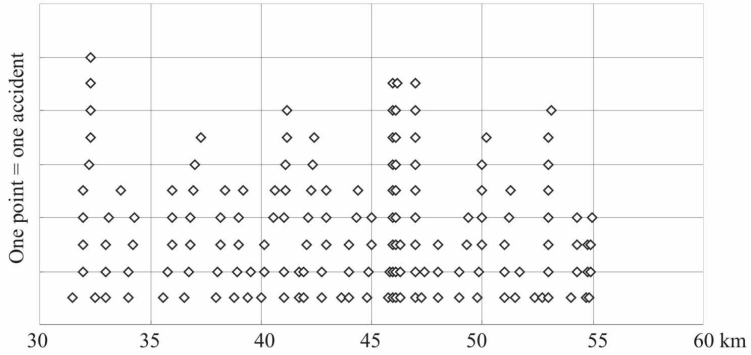

Fig. 3 – Accident distribution along YanOing highway in north China

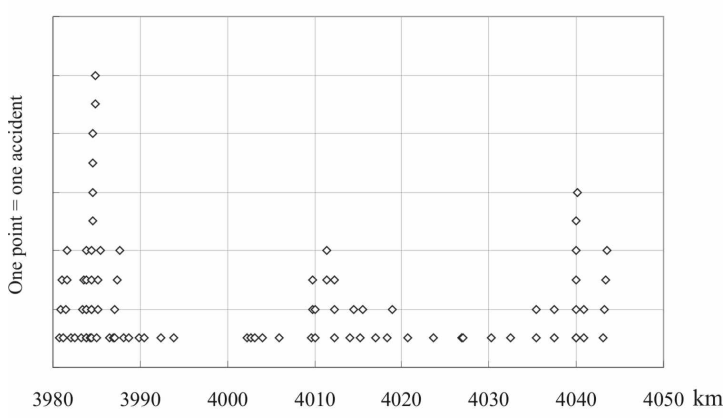

Fig. 4 – Accident distributions along TuWuDa high-classified highway in northwest China

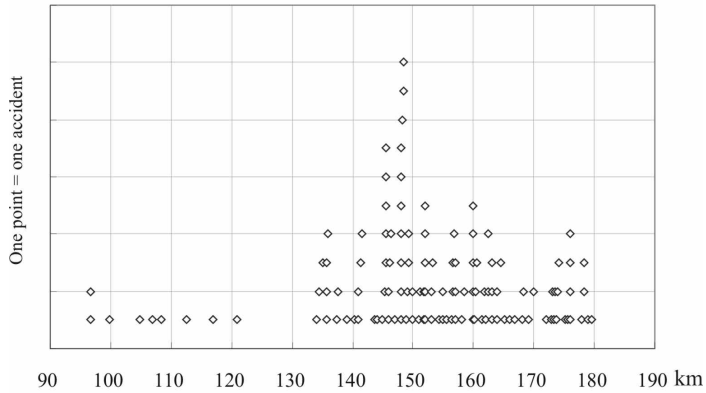

Fig. 5 – Accident distributions along HuNing expressway in south China

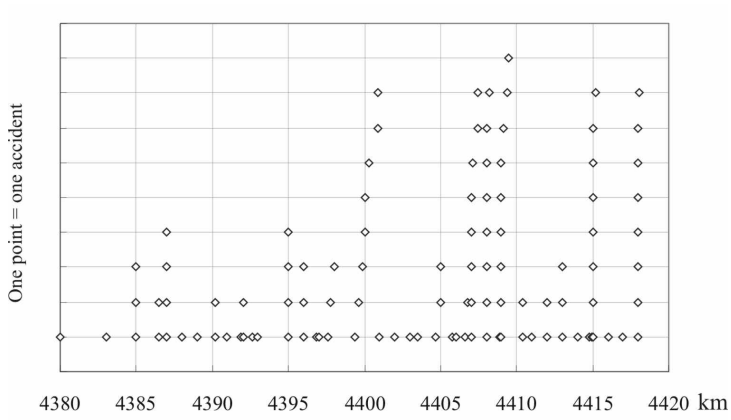

Fig. 6 – Accident distributions along G312 highway in west China

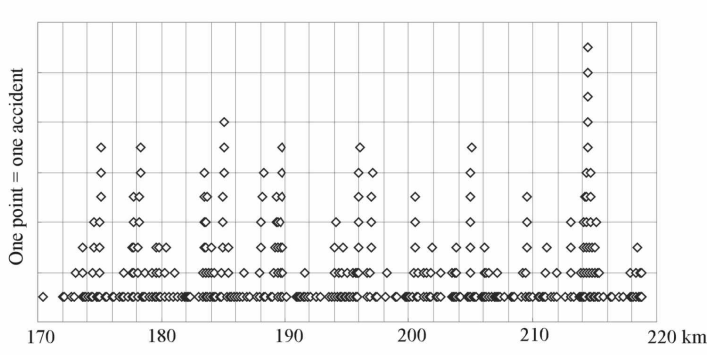

Fig. 7 – Accident distributions along JiQing expressway in north China

4. Analysis of Accident causes and Characteristics of Black Spots

4.1 Typical Segments of Black Spots

The investigation of the accident distribution and the conditions of black spots indicated that Chinese road safety condition is awfully serious and the black spots are extremely evident. In terms of the investigation, it can be concluded that for first and second-class highways, the black spots are mostly at the following position:

(1) Accesses/Exit
(2) Intersections
(3) Pass-by sections
(4) Segments of Poor alignment
(5) Bridges and other constructions

For expressways, black spots often occur at the following sections:

(1) Segments of poor alignment or combined alignment
(2) Bridges, tunnels and other constructions
(3) Interchanges (especially ramps, accesses, exit)
(4) Pass-by sections
(5) Sections of insufficient sight distance

4.2 Accident causes related to highway features

4.2.1 Access, Exit and intersections

Except for expressway, the arterial highways and the low classified highways are normally the roadways with out access/exit control, and the grade intersection is the main type used. For the reasons of higher traffic volume, parking against regulation, insufficient sight distances, etc, road access and exits and intersections always produce hazardous locations. Especially in intersections, the commercial districts, buildings, farmlands, etc, would accumulate gradually around the intersections due to the convenient link. That changed the original environment where the intersections were designed.

Highways	Top four accident Pattern / accident ration % by the total accidents							
	Accident pattern	Accident ratio(%)	Accident pattern	Accident ratio(%)	Accident pattern	Accident ratio(%)	Accident pattern	Accident ratio(%)
ChengYu Expressway	Rear end collision	44.5	Hit permanent objects	16.8	Turn over	7	Lane side collision	6.1
ShenDa Expressway	Rear end collision	41.5	Hit permanent objects	29.1	Turn over	7.1	Lane side collision	
JiQing Expressway	Rear end collision	43.62	Turn over	25.32	Hit permanent objects	16.46	Lane side swipe, Drop	3.95/each
TaiJiu Expressway	Rear end collision	68.36	Hit permanent objects	23.3	Lane side collision	6.77	Lane side swipe	6.21
HuNing Expressway	Rear end collision	35.5	Hit permanent objects	27.0	Lane side collision	12.4		
TuWuDa Expressway	Lane side collision	31.8	Rear end collision	24.5	Turn over	13.2	Other	9.9
104National highway(Tai An)	Rear end collision	21.7	Lane side collision	36.89	Rear end collision	26.23	Head on swipe	0.82
YanQingHighway (laiyang section)	Head on swipe	8.70	Head On collision	47.8	Lane side collision	13.66	other	26.71
YanQinghighway (XiXia section)	Rear end collision	62.5	others	18.75	Lane side collision	12.5	Lane side swipe	6.25

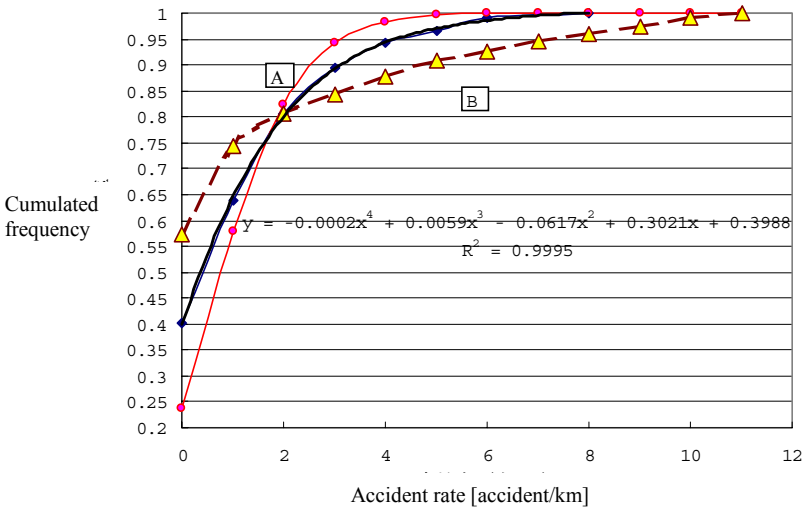

Fig. 7 – Accident accumulated frequency curve

Tab. 5 – Accidents at Black Spots

Highways	Total accident at the investigated section	Identified black spot Number	Accidents at all black spots/percent (%)
ChengYu expressway	1242	16	533/42.9
ShenDa Expressway	3191	35	
JiQing Expressway	1061	28	394/37.1
Taijiu Expressway	177	27	87/49.1
HuNing Expressway	245	10	78/31.8
TuWuDa Expressway	164	13	
104 National highway (TaiAn section, first class)	287	22	185/64.4
YanQing Highway (First class)	323	27	193/59.8

4.2.2 Pass-by sections

Towns progress along highways and peasants immigrate to nearside of highways as well after highways are constructed. Gradually, the road sections linking towns would be developed and the highways become pass-by sections or even streets. Black spots are easily formed in these highways sections due to the disordered traffic, various pedestrians, pavements occupied by peddlers, etc. The vehicles entering the towns without full deceleration and those leaving the towns with acceleration are easily involved in various crashes of high severity under some specified conditions, for example, sideway interference, etc. As result, most of this type sections are hazardous locations.

4.2.3 Interchanges

The results of highway accidents investigations indicated that most of accidents inside or near interchanges happen on ramps, acceleration and deceleration lanes. The critical factors influencing the road safety of ramps include knowablity, readability, visibility and adaptability of the ramp features to various drivers (especially the drivers of large vans, trucks), Road & traffic condition of joint road sections is another key factor.

4.2.4 Highway alignment

There exist normally two extreme features of highway alignments commonly on the first and second-class highways. Except bridges, tunnels and other constructions, one feature of the two is the alignments of large-radii curves, long tangent and small angle of advertence (<7º) combined with short vertical curve in plain areas; The other is that of insufficient sight distance and of poor alignments in mountainous areas. The space of intersections, accesses and exits in the road sections with favourable alignments, combined with high speed and more pedestrians is main accident cause. Low class highways net have been improved to some extent with the progress of economy. However, most of the projects focus on improving the conditions of pavements. So driving conditions were improved and running speed was increased. Therefore, the combination of deficient alignments and improved pavements results in high accident rate. For expressways in mountainous areas, the combined features of horizontal curves and vertical curves are still one of the primary factors causing road accidents.

4.2.5 Bridge and tunnel constructions

For the constructions of bridges and tunnels, the major features affecting road safety are the transition of cross section, horizontal and longitudinal alignment features. For example, the cross sections of bridges in many arterial first and secondary class highways are narrower than that of the conjoint highway sections, and there are even no transition sections between them somewhere. For the arterial first and secondary highways, the unsuitable locations of the constructions of bridges and tunnels are also major factors affecting safety.

4.2.6 Sight distance

It is a common situation that the problem of sight distance exists on both new-built highways and existing ones. The problem of sight distance is more serious due to the changes of highway environment after being opened to traffic. In most cases, the sight distance of the expressways can be ensured. However, the standard of dynamic sight distance is hard to meet safe driving requirements especially in the case of the existence of chaotic traffic at the locations of entrances and exits, horizontal and vertical curves, upgrade and downgrade, ramps of interchanges, etc.

4.3 Accident causes related to traffic devices

For Chinese highway nets, markings, signs and other traffic devices are very imperfect. A lot of highways have no markings and signs indeed. The major problems with traffic and safety devices include too much or less messages, unsuitable font size and locations, indistinct meaning, being rotten or damaged, and being shielded by trees or such as advertisement boards. All of these make the condition of imperfect markings and signs lose the basic function. In some locations with good highway alignments and conditions, great difference in various running speeds makes

the traffic signs near to the black spots less effective. Because of only utilizing warning signs in some hazardous locations, the behaviour of drivers is difficult to be restrained without additional necessary enforcement. The deteriorated pavement markings and delineators commonly cannot be rehabilitated in due time because of the limit of maintenance cost.

5. Driving behaviours

During the current period of constructions of highways and progress of vehicle industry, the performances of the vehicles running on various highways vary substantially each other. That easily leads too much different running speed, overtaking and over-speed driving. The fast developing of Chinese highways started from 1990's.

At the beginning, the aim of constructing highway was mainly meet the requirements of the economic progress and improvement of living condition of the people. So that, limited resources had to be used to construct comparatively more highways.

In such case, a variety of road sections cannot satisfy the requirement of the future traffic because of irrational combination of road alignments, although the construction quality of these alignments met the original design criteria.

On the basis of investigations and the analysis from two aspects of accident causes and pattern, it can be seen that over-speed driving and overtaking progressively are the primary causes of serious accidents for the first and secondary highways and expressways with long even and straight lines.

With the help of Bureau of Taiga Expressway, running speeds of road sections with different alignments at TaiJiu expressway was measured and summarized in the Table 6. Under the help of Bureau of ShenDa expressway, the running speeds at highway segment, ramps/exits were measure and the results of the running speeds measured are summarized in Table 7.

6. Conclusions

(1) With the development and improvement of highway nets, the road safety should be considered and improved at the same time. Otherwise, road safety situation will get to be worse and accident rate will increase.

(2) Black spots are only small part (about 15-25%) of whole highways, but most accidents (about 40-60%) are caused at black spots. So that, the most beneficial and feasible improvement policy of road safety is to eliminate accident black spots.

(3) Analysis on accident causes and characteristics of black spots indicated that unreasonable highway features and traffic devices are certainly the factors affecting road safety. Typical black spots were found for Chinese highway, which are that with poor highway alignment or with insufficient sight distance, intersections and interchanges, Access/exit, ramps, bridge and tunnel constructions, pass-by section.

(4) Highway safety investigation and accident cause analysis show that over speed driving is primary accident cause for both expressway and other classified highways. The measure results of running speed indicate that there are much different running speed among various vehicles and commercial trucks. So speed control should be enhanced in China.

Tab. 6 – The measured running speed on TaiJiu expressway

Stake	Character of alignment	Average Speed (Km/h)	Standard deviation	V_{85} (Km/h)
K380+100	Ramp combined with horizontal curve(R=400m), i=-4.87%	78.1	22.86	101.79
K378+300	S curves with tangent, R=382m	62.94	30.14	94.17
K397+600	Horizontal curve combined with vertical curve, R=255m, L=182m, ls=75m, i=4.5%	66.64	22.79	90.26
K452+300	Vertical curve fall into the first curve of adverse horizontal curves, R=600m, i=-3.5%	81.92	30.07	112.82
K454+900	Horizontal curve on Downgrade, R=1500m, i=-3.57%	87.50	24.99	113.47
K491+900	Vertex of vertical curve at the end of spiral curve, R=350m, i=-5%	71.82	36.61	109.61
K496+000	Downgrade on horizontal tangent, L=646m, i=-3.25%	75.44	31.64	108.23
K503+500	Vertical curve on horizontal tangent	93.66	42.19	137.38
K508+500	Horizontal curve combined with vertical curve, R=900m	66.34	37.05	104.74
K509+000	Horizontal curve on Downgrade, R=6000m, i=-3%	93.76	27.69	122.76
K515+800	Horizontal curve combined with vertical curve, R_H=5000m, R_V=36000m, i=0.8%	80.48	24.03	105.38

Tab. 7 – The measured running speed on ShenDA expressway

Stake and direction	Average speed(Km/h)	Standard deviation	V_{85}(Km/h)
K146, Shenyang	81.07	24.64	106.61
K135.5, Dalian	87.16	35.52	123.97
K34.5, Shenyang	83.45	23.92	108.24
Anshan ramp, Shenyang	51.99	15.34	67.89
Jintaishan ramp, Dalian	38.64	7.83	46.73
Liaoyang entrance, Shenyang	38.19	14.23	52.94
Liaoyang , Shenyang	38.97	18.27	57.91
Sujiatun exit, Dalian	47.21	12.02	59.66
Yingkou ramp, Shenyang	47.43	16.99	65.04
Yingkou, Dalian	86.41	25.28	112.64

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