THE RELATIONSHIP OF ACCIDENT RATE AND OPERATIONAL CHARACTERISTICS ON TWO-LANE HIGHWAYS

Koji URATA, Chief Engineer,
Transportation Research & Planning
Hokkaido Eng. Consultants Co. Ltd.,
Sapporo, Hokkaido, 004-8585 JAPAN
Fax +81-11-8011520
E-mail: ku432@mb.docon.co.jp

Kazuo SAITO, Dr. Eng.., Professor,
Dept. of Civil Eng. & Architecture
Muroran Institute of Technology
Muroran, Hokkaido, 050-8585 JAPAN
Fax: +81-143-465246
E-mail: k-saito@muroran-it.ac.jp

Toru TAMURA, Dr. Eng. Associate Professor
Dept. of Civil Eng. & Architecture
Muroran Institute of Technology
Muroran, Hokkaido, 050-8585 JAPAN

Yuzo MASUYA, Dr. Eng., Professor,
Dept. of Civil Engineering
Hokkaido College of Senshu University
Bibai, Hokkaido, 079-01 JAPAN

Abstract: Traffic operations on two-lane highways are unique: lane changing and passing are only possible in the face of oncoming traffic in the opposite lane. As traffic volume increases, the passing demand increases rapidly. As a result, traffic accidents increase owing to head-on collisions during passing maneuvers as well as collisions with roadside fixed objects. In this paper the characteristics of real safety and vehicle operation and their relationships on two-lane highways in Hokkaido prefecture were analyzed for managing the existing two-lane highways more efficiently and safely. The data used are from the 1994 National Road and Traffic Census. Regression analysis was performed to relate accident rate with some roadway and traffic characteristics using Quantification Theory Type-I and discriminant analysis was performed to identify the hazardous highway sections for safety improvement by using Quantification Theory Type-II.

1. INTRODUCTION

In developed countries it is usual to rebuild two-lane highways into four-lane highways for maintaining capacity and vehicle speed. However, recent widespread recession has led to review of public works, and influence of financial reform has made it difficult to maintain the pace of road construction. The use of existing two-lane highways more efficiently and safely has become an important issue.

In the past, many studies on two-lane highways were done in OECD countries [OECD (1972)] and in the United States [FHWA (1983)]. However, more research is still necessary because a large portion of highway system still consists of two-lane highways in many countries, and Japan is no exception. Two-lane highways carry with them a certain danger of head-on collisions when passing or 'running-off-the-road' accidents, and deserve greater research to increase safety.

Accidents in Hokkaido Prefecture are the object of this analysis. In the northern part of Japan there were a total of 27,606 personal injury accidents (3.6% of Japan's total) in 1995, resulting in 632 deaths (5.9% nationwide) and 33,294 injuries (3.6% nationwide). Although 28.5% of accidents occurred on national highways and 17.7% on regional highways, the number of deaths on national highways comprised 43.4% of the total, compared with 25.5% on regional highways. The fact shows that the national highway accidents are more dangerous than accidents on regional highways. Table 1 shows a comparison of accident rates of selected nations with Hokkaido. The number of traffic deaths per 100,000 peoples in Hokkaido is higher. This is the reason why Hokkaido regional and national highways were selected for the object of analysis in this study.

Table 1 Comparison of Traffic Accident Rates in Selected Countries and Hokkaido

country	Year	per 100,000 vehicl		per 100,000 people		Accidents	Injured	Deaths	Vehicle	Population (10^3)
		Accidents	Deaths	Accidents	Deaths					
USA	1992	1182.6	20.6	882.5	15.4	2251173	3449211	39235	190362228	255078
CANADA	1992	1009.5	20.6	629.1	12.8	171723	249821	3501	17010890	27297
ENGLAND	1993	1002.7	16.7	404.6	6.7	228865	306020	3814	22824000	56559
GERMANY	1993	931.8	24.1	473.8	12.2	385400	505600	9949	41359366	81338
FINLAND	1994	293.2	22.5	122.5	9.4	6245	8080	480	2130042	5099
SWEDEN	1993	385.3	16.3	171.9	7.3	14959	20373	632	3882054	8700
JAPAN	1994	1120.4	16.4	582.8	8.5	728457	881723	10649	65015047	125001
HOKKAIDO	1994	811.2	18.9	468.6	10.9	26553	32479	619	3273232	5666

It was attempted in this study to analyze the safe operational characteristics of two-lane highways which comprise 85% of total highway system in Hokkaido. The data used for analysis are from the 1994 National Road and Traffic Census in Japan. Some statistical analyses were performed for relating the accident rate to selected roadway and traffic characteristics such as congestion rate, roadway width, and travel speed. Regression analysis using the Quantification Theory Type-I was performed to relate the accident rate to roadway and traffic elements, and then discriminant analysis using the Quantification Theory Type-II was performed to identify hazardous highway sections reading safety improvement. The results showed that more attention and effort are needed for enhancing the safety level of two-lane highways.

2. DATA ANALYZED IN THE STUDY

Hokkaido is the northernmost prefecture in Japan, having 5.6 million people. The total length of highway network, 17,994 km, consists of 308 km national expressways, 6,281.5 km of national highways and 11,404 km of local roads. Of this total length, 15,100 km (84.3%) are two-lane highway and 960 km (5.6%) are four-lane highway. Moreover, only 1330 km (7.4%) run through urban and suburban area, the remaining 16,600 km (92.6%) traversing rural areas. The number of vehicles is, at 3.27 million, 4.8% of the total in Japan. Restricting the discussion to two-lane highways, an even greater fraction (95.5%) is rural and only 700 km is urban and suburban. In this study the rural two-lane highways is selected for the object of analysis, representing 80% of trunk roads in Hokkaido.

The road and traffic census is conducted nationally every two or three years in Japan. The census divides all trunk highways into analysis sections, and for each section makes a digital record of traffic volume by vehicle type, lane number, road surface condition, road width, roadside condition, travel speed and traffic accidents. Traffic accident data are described by a four-year average number of accidents, deaths and injuries (in this case, between 1990 to 1993). Road width consists of traveled lanes, shoulders and medians. In this analysis road width is divided into three categories: less than 8 meters for some 5740 km (40.0%) of narrow road, the standard 8 to 10 meters for 8070 km (56.1%), and greater than 10 meters for 560 km (3.9%) of fairly broad highway. Roadside conditions are categorized into DID (Densely Inhabited District), other residential areas with continuous roadside dwellings, level areas, and mountainous areas. Only traffic accidents on trunk roads are recorded. Table 2 shows the trend of traffic accidents on the trunk roads in Hokkaido categorized by type.

Table 2 Traffic Accidents of Trunk Roads Categorized by Type (Hokkaido)

Item	Type of Accident	1985			1994			1994-1985		
		National Roads	Regional Roads	Total	National Roads	Regional Roads	Total	National Roads	Regional Roads	Total
Accidents per year	pedestrian / vehicle	609	509	1118	499	448	947	-110	-61	-171
	bicycle / vehicle	333	326	659	548	485	1033	215	159	374
	vehicle / vehicle	4521	2478	6999	6032	3436	9468	1511	958	2469
	single vehicle	356	306	662	482	334	816	126	28	154
	total	5819	3619	9438	7561	4705	12266	1742	1086	2828
Accidents per year per 100km	pedestrian / vehicle	10.43	4.44	6.46	7.94	3.93	5.35	-2.48	-0.51	-1.11
	bicycle / vehicle	5.7	2.84	3.81	8.72	4.25	5.84	3.02	1.41	2.03
	vehicle / vehicle	77.41	21.62	40.45	96.03	30.13	53.53	18.62	8.51	13.08
	single vehicle	6.1	2.67	3.83	7.67	2.93	4.61	1.58	0.26	0.79
	total	99.64	31.58	54.55	120.37	41.26	69.35	20.73	9.68	14.8

3. CHARACTERISTICS OF TRAFFIC ON TWO-LANE HIGHWAYS

The distribution of traffic on two-lane highways shows a maximum of 29,000 vehicles per day in the most heavily trafficked section, and 93 sections with a traffic flow of over 10,000 vehicles per day (6% of the total length analyzed). Although OECD Repot [OECD, 1972] defines the maximum traffic volume for a two-lane highways to be 15,000 to 17,000 vehicles per day, 21 sections (144.4 km) endured a traffic flow of greater than 17,000 vehicles per day. In accordance with the OECD definition of a low volume road as having fewer than 500 vehicles per day, this study refers to such roads as "low volume roads". Low volume roads account for 16.8% of sections (259 sections) or 2449.7 km as shown in Fig. 1.

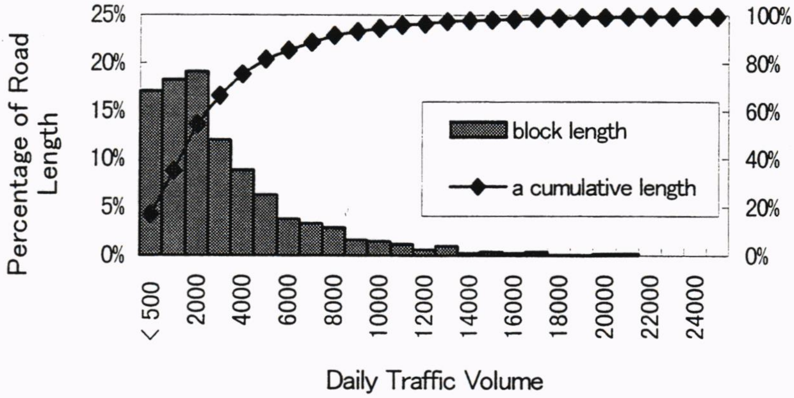

Fig. 1 Distribution of Length of Two-Lane Highways by Traffic Volume

The traffic congestion index is defined as actual traffic volume divided by capacity. An average congestion index on two-lane highways was 0.37, in contrast with the value of 0.68 on four-lane highways. Some 6.6% of the highways (880 km) had a traffic congestion index greater than 1.0 and the highest index was 2.66. The average percentage of heavy goods vehicle was 26.1%.

Speed limits on two-lane highways were 40 km/h for 1147.7 km (8.0% of total length) on which 4.78 million vehicles per year were carried, 50 km/h for 3736.7 km (26.1% of total length) on which 21.43 million vehicles were carried, and 60 km/h for 9445.5 km (65.9% of total length) upon which 21.70 million vehicles were carried. That is, greater than half of the traffic traveled on two-lane highways with a speed limit of less than or equal to 50 km/h.

An average actual travel speed of traffic flow by speed limit and roadside environment is shown in Table 3. The actual average speed for the speed limit 40 km/h was 42.2 km/h, 45.0 km/h for the speed limit of 50 km/h and 48.8 km/h for the speed limit of 60 km/h.

Table 3 Average Actual Travel Speed by Speed Limit and Roadside Environment

Average Travel Speed(km/h)		SPEED LIMIT (S.L) (km/h)			
		40km/h	50km/h	60km/h	total
level terrain	<= S.L	34.3	43.3	48.5	46.0
	> S.L	48.3	52.9	66.4	51.3
	total	42.3	45.1	48.9	46.8
mountainous terrain	<= S.L	33.8	43.0	48.6	46.9
	> S.L	48.3	52.5	65.0	51.1
	total	41.9	44.4	48.7	47.2
total	<= S.L	34.2	43.2	48.6	46.2
	> S.L	48.6	52.8	66.1	51.3
	total	42.2	45.0	48.8	46.9

Fig. 2 shows the percentage of the sections as classified by difference in speed limit and actual average speed of traffic. It is seen that the speeding is common on the highway sections having a speed limit of 40 km/h.

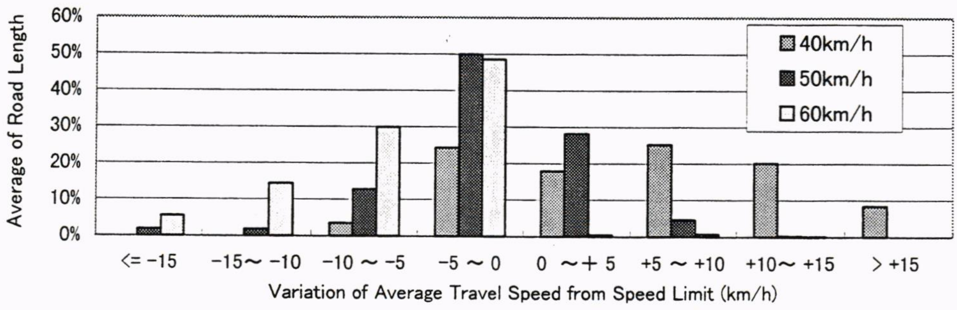

Fig. 2 Distribution of Sections Classified by Difference Between Speed Limit and Actual Travel Speed of Traffic

4. ANALYSIS OF ACCIDENT DATA ON TWO-LANE RURAL HIGHWAYS

4.1 Accidents and Accident Rates

The number of accidents by type was 461 pedestrian accidents (9.7%), 3529 multi-vehicle accidents (74.2%) and 767 single-vehicle accidents (16.1%). Multi-vehicle accidents can be further classified into 755 head-on collisions (21.4%), 1458 rear-end collisions (41.3%), 364 right-angle collisions (10.3%) at intersections, 184 collisions (5.2%) during passing, and 768 other collisions (21.8%).

Accident rates on two-lane rural national highways in Hokkaido are shown in Table 4. In the table accident rates for each section of highway were calculated as the number of accidents, fatalities and casualties divided by 100 million vehicle-kilometers of travel, respectively. The distribution of cumulative highway length ranked by descending order from the section with the highest accident rate is shown in Fig. 3. This figure shows that, for example, the length of highway having an accident rate greater than 40 was about 10% of total length of highways analyzed.

4.2 The Relationships of Accident Rates and Some Operational Variables

Based on the Table 4, the simple relationships between accident rates and each operational variable are discussed in this section.

Table 4 Accident Rates on Two-Lane Rural Highways Analyzed (1994)

item	rank	accidents rate			fatality rate			casuality rate		
		level terrai	mountainous terrain	total	level terrain	mountainous terrain	total	level terrain	mountainous terrain	total
congestion index	<= 1. 0	27.8	26.2	27.5	4.7	3.4	4.4	43.6	45.2	43.9
	> 1. 0	37.7	27.3	33.8	2.4	2.6	2.5	59.3	48.8	55.3
road width	< 10m	28.3	26.1	27.7	4.6	3.2	4.2	44.8	43.3	44.4
	>= 10m	36.2	34.4	35.9	3.1	3.7	3.1	53.1	99.6	59.4
speed limit	40km/h	52.1	13.1	34.4	0.0	1.4	0.6	73.7	18.5	48.6
	50km/h	31.6	29.0	31.0	4.2	3.2	4.0	49.7	56.4	51.4
	60km/h	26.7	25.8	26.5	4.7	3.4	4.4	42.0	41.0	41.7
total		29.1	26.5	28.4	4.4	3.2	4.1	45.6	46.1	45.7

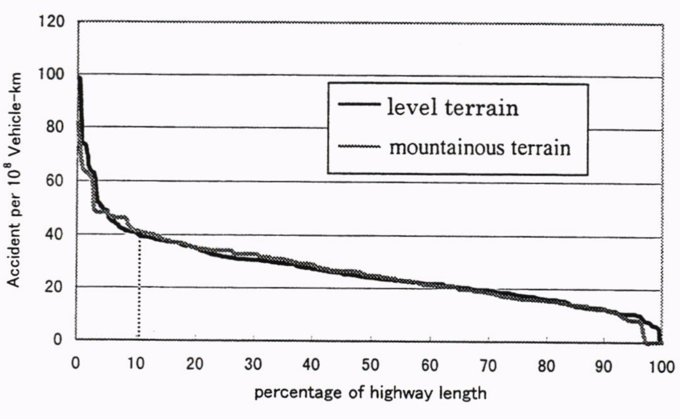

Fig. 3 Distribution of Cumulative Highway Length Ranked by Accident Rates (Descending Order From the Highest)

The relationship between accident rate and congestion index is shown in detail in Fig. 4. It can be seen that an accident rate tends to increase as congestion index increases. Fig. 5 is shown in case of road width. An accident rate is 29.3 for narrow roads of less than 8 meters and is 35.9 for wider roads of over 10 meters in width. The accident rate for roads of 9 to 10 meters in width was 28.3 and the lowest accident rate of 27.1 was found on the standard road of 8 to 9 meters in width. As the two-lane highways are classified into one of three categories; narrow (less than 8 meters in width), standard (8 to 10 meters in width), and broad (more than 10 meters in width), it is recommended to design the cross section of two-lane rural highways according to a standard safety standard. Fig. 6 shows the relationship between an accident rate and intersection density (the number of intersections per kilometer). The accident rate was 25 for the sections with intersection density less than 2, and is 33 for the sections with density greater than 2.

The relation between accident rates and the travel speed and/or speed limit have been studied by many researchers. The average travel speed and speeding within the three kinds of speed limit are already shown in Table 3 and Fig. 2, respectively.

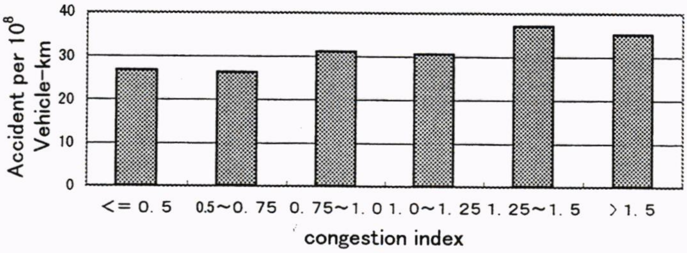

Fig. 4 Accident Rate and Degree of Congestion

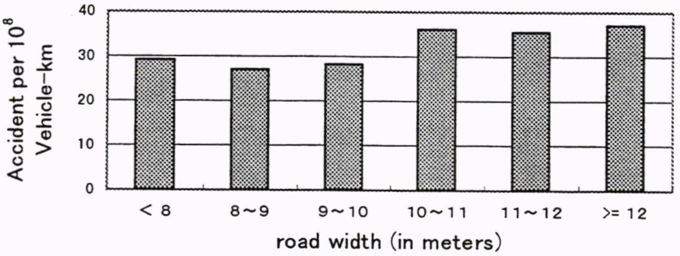

Fig. 5 Accident Rate and Road Width

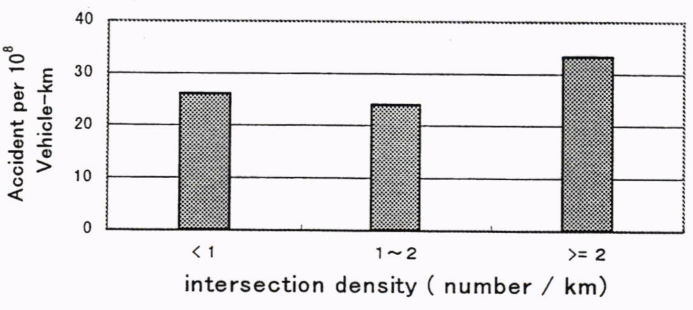

Fig. 6 Accident Rate and Intersection Density

The relationship between an accident rate and speeding within the three speed limits is shown in Fig. 7. The average accident rate within the speed limit of 40 km/h is 34.4, and this drops to 31.0 within the speed limit of 50 km/h and further to 26.5 km/h within the speed limit of 60 km/h. In 40 km/h and 50 km/h speed limit zones, negative speeding is directly related to an increase in an accident rate, whereas this trend is not clear as for the 60 km/h speed limit zone. Solomon [1964] showed that accident rates were highest at very low speeds, lowest at about the average speed and increased again at the very high

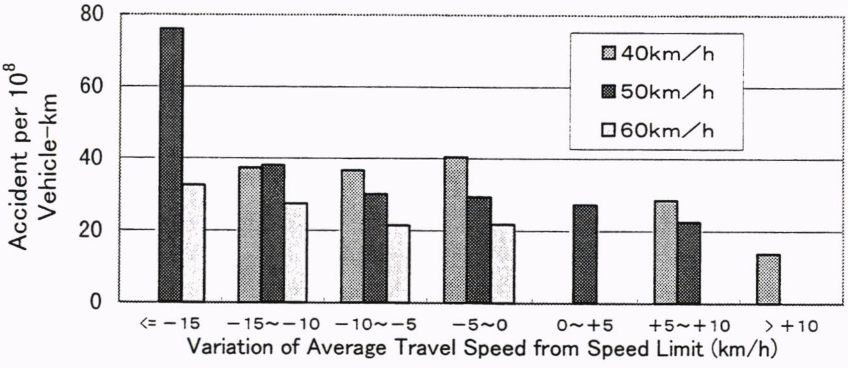

Fig. 7 Accident Rate and Variation of Average Travel Speed from Speed Limit

speeds, forming V-shaped distribution shown in Fig. 8. The results demonstrated in Fig. 7 partially reproduced Solomon's findings in the lower speed range, but the small number of samples at higher speeds led to inconclusive results.

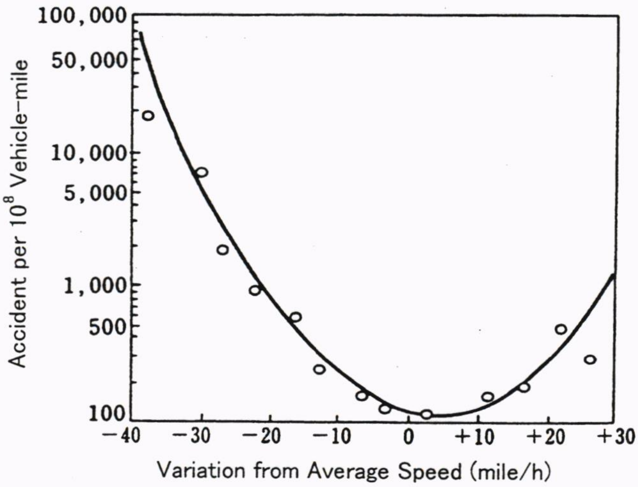

Fig. 8 Accident Rate and Variation from Average Speed (Solomon 1964).

5. MULTIVARIATE ANALYSIS FOR ESTIMATING THE RISK

Two kinds of analysis were performed; regression analysis and discriminant analysis. Regression analysis was performed to relate accident rate with selected roadway and traffic characteristics using Quantification Theory Type-I. Discriminant analysis was performed using Quantification Theory Type-II, to identify the hazardous highway sections.

5.1 Regression Analysis of Accident Rate on Two-Lane Rural Highways

In regression analysis, Quantification Theory Type-I was employed in determining the influence of explanatory variables on accident rate as a criterion variable. The regression function used in the analysis is as follows;

$$Y = a_1 X_1 + a_2 X_2 + \cdots\cdots + a_n X_n \qquad (1)$$

Where: Y = accident rate

a_i = weighting constant (category score) for each category of a given variable

X_i = categorized value for each variable selected in the analysis

Seven variables were used as explanatory variables (X's) which are categorized as follows:

1. Percentage of heavy vehicles(four categories) : less than 20, 20-30, 30-40, greater than 40
2. Congestion index (four categories): less than 0.75, 0.75-1.00, 1.00-1.25, greater than 1.25
3. Average travel speed (three categories): less than 40, 40-50, greater than 50
4. Speed limit (two categories): 40 & 50, 60
5. Intersection density (three categories): less than 1, 1-2, greater than 2
6. Terrain (two categories): level, elevated

The results of the analysis are shown in Table 5. In this table, the partial correlation coefficient represents the degree of influence upon the accident rate and the sign of a category score shows the tendency of influence. In the case of Table 5, for example, travel speed has the greatest influence among selected variables. A (+) sign means that lower average travel speed contributes to increase the accident rate and a (-) sign acts inversely.

The multiple correlation coefficient of the analysis is 0.407, which is relatively low. The category score of intersection density and road width vary not linearly but rather in a V-shape relation which may indicate less influence on accident rates. However, Table 5 shows that the principal contributor is average travel speed, the second contributor is intersection density, the third is percentage of heavy vehicles and the fourth is the congestion index.

5.2 Discriminant Analysis for Identifying Hazardous Highway Sections

Discriminant analysis is a statistical procedure and is used for distinguishing among two or more groups which are (1) defined as being different in some manner, (2) described by a multitude of explanatory variables. In concept, a road safety researcher applying the discriminant analysis wants to know what it is that makes the hazardous section different [Saito (1979), Saito and Kaku (1979), Newman (1984), Saito and Masuya (1997)].

Table 5. Results of Regression Analysis (Quantification Theory Type-I)

explanatory variable	category	number of sample	category score	partial correlation coefficient
percentage of heavy vehicles (%)	< 20	65	2.2019	0.1079
	20-30	200	0.3803	(3)
	30-40	110	-0.7711	
	>= 40	31	-4.3341	
congestion index	<= 0.75	283	-0.7320	0.0901
	0.75-1.0	58	1.0353	(4)
	1.0-1.25	28	0.2703	
	> 1.25	37	3.7715	
road width (m)	< 8	37	1.3104	0.0728
	8-10	332	-0.4673	(5)
	>= 10	37	2.8828	
travel speed (km/h)	<= 40	36	9.5930	0.2166
	40-50	248	0.3267	(1)
	> 50	122	-3.4948	
speed limit (km/h)	40,50	172	0.7506	0.0440
	60	234	-0.5517	(6)
terrain	level	310	-0.0889	0.0112
	mountainous	96	0.2871	(7)
intersection density (per km)	< 1	92	-0.2454	0.1522
	1-2	143	-2.8182	(2)
	>= 2	171	2.4888	

The discriminant function used in this analysis was the Quantification Theory Type-II ,which was developed for use with categorized data is the following;

$$D = b_1 X_1 + b_2 X_2 + \cdots\cdots + b_n X_n \qquad (2)$$

where: D = non-dimensional "discriminant score"

b_i = weighting constant (category score) for each category of a given variable

X_i = categorized value for each variable selected in the analysis

Two section groups, hazardous sections and normal sections, were used to find which operational variables best identified the hazardous sections of highway. The hazardous sections were selected by applying the accident rate quality-control method [Saito (1978)].

The quality-control method introduces statistical reliability to determine whether or not the accident rate is significantly abnormal as related to an average accident rate for all sections to be tested. Critical accident rates (control limits) were computed for each section utilizing the following equation:

$$UCL_i = \lambda_0 + k\sqrt{\lambda_0/m_i} + 1/2m_i \quad (4)$$

$$LCL_i = \lambda_0 + k\sqrt{\lambda_0/m_i} - 1/2m_i \quad (5)$$

where: UCL_i = upper control limit for i section

: LCL_i = lower control limit for i section

λ_0 = average accident rate for all sections (in 100 millions vehicle-km of travel)

k = probability constant (1.96 was used in the analysis)

m_i =number of vehicle-kilometer of travel (in 100 millions) for i section

The critical accident rates determine the range of variability that could be expected to result from chance occurrence of accident. If the actual accident rate is greater than UCL, the abnormally high deviation is probably not due to chance but to unfavorable characteristics of the section that require improvement. These sections are defined as the "hazardous section" group. If the actual accident rate falls between the UCL and the LCL, it may be possible that there are no special characteristics contributing to accident hazard. These sections are defined as the "normal section" groups. This concept was applied to two-lane rural highways in Hokkaido. The result is shown in Fig. 9. Some 22 hazardous sections were identified as "hazardous sections" and the remaining sections were identified as "normal sections", using discriminant analysis.

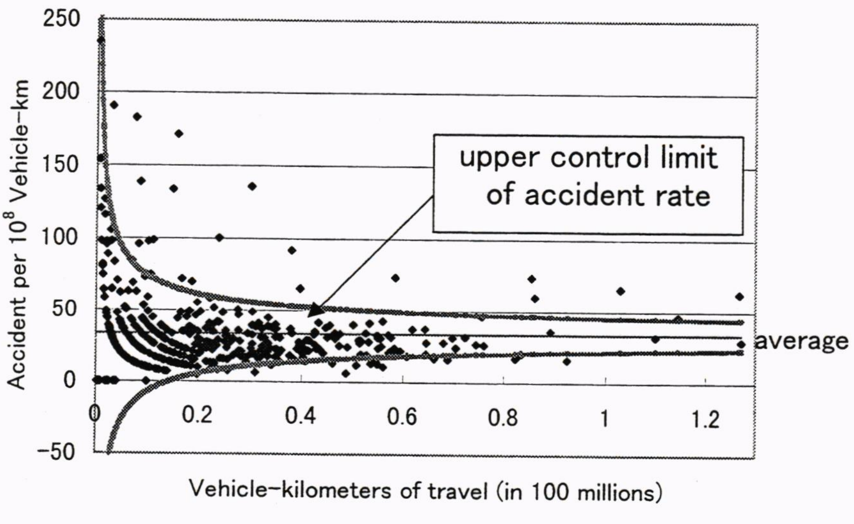

Fig. 9 Comparision of Actual Accident Rate to Critical Rate for Each Sections of Two-Lane Rural Highways in Hokkaido

In this analysis, the weighting coefficients of the discriminant function in Eq (2) were statistically determined as such manner that the discrimination of two groups, hazardous sections and normal sections, would be maximized by using the seven variables. The results of analysis are illustrated in Table 6 in which category score (weighting coefficients, b_i in Eq. (2)) for each category in a given variable are shown. In Table 6 the sign of category score is reversed from Table 5, a (-) sign identifies hazardous sections. Therefore, if a given section has many (-) sign categories, the resulting D score in Eq. (2) tends to be a minus score that means the section is more hazardous.

Table 6 Results of Discriminant Analysis (Quantification Theory Type-II)

explanatory variable	category	number of sample	category score
percentage of heavy vehicle (%)	< 20	72	-0.3966
	20-30	203	0.0339
	30-40	107	0.0842
	>= 40	31	0.4086
congestion index	<= 0.75	290	0.0738
	0.75-1.0	60	0.0570
	1.0-1.25	25	-0.0637
	> 1.25	38	-0.6113
road width (m)	< 8	46	-0.0192
	8-10	328	-0.0088
	>= 10	39	0.0963
travel speed (km/h)	<= 40	47	-0.4283
	40-50	249	0.0628
	> 50	117	0.0383
speed limit (km/h)	40,50	186	0.0003
	60	227	-0.0002
terrain	level	313	0.0371
	mountainous	100	-0.1161
intersection density (per km)	< 1	99	0.0676
	1-2	144	-0.0132
	>= 2	170	-0.0282

The D score was computed using the discriminant function in Eq. (2). Category scores are displayed in Table 6. Fig. 10 shows the distribution of sections according to the D score into two section groups. It is clear that the two section groups were discriminated by the resulting discriminant function (with a probability of success of 75 %) at a point of discriminative D score of - 0.14. As a result, it is possible to estimate the hazardous section of highways by using the developed discriminant function with a fairly high probability of success.

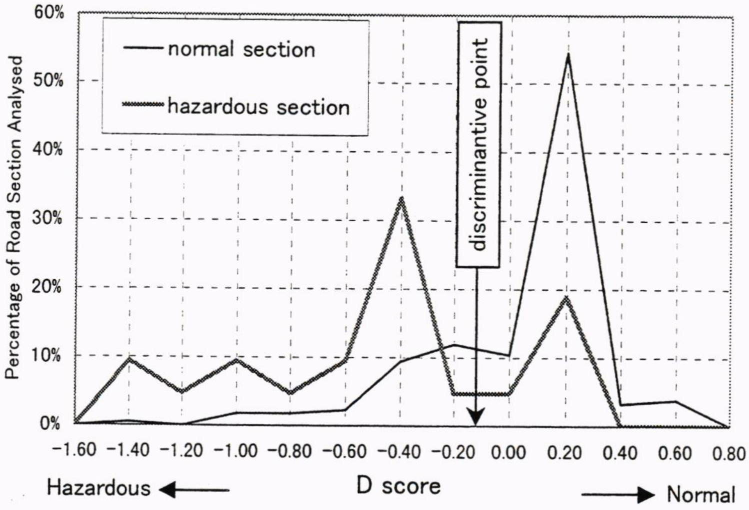

Fig. 10 Distribution of Sections Having the Estimated D scores

6. CONCLUSIONS

In this study, some analyses were made to relate the accident rates with some road and traffic characteristics of two-lane highways in Hokkaido. The following conclusions could be made from the results of the study.

Some relationships between the accident rate and selected operational variables of two-lane rural highways in Hokkaido were developed expressing accident rates in terms of degree of congestion, road width, intersection density, and speed. It was found that the accident rate tended to increases as congestion index increases and the lowest accident rate of 27.1 was found on sections of standard road width (8 to 9 m) and with an intersection density of 1 to 2. It was also found that the accident rate tended to decrease as the speed limit increased.

At speed limits of 40km/h and 50km/h, the negative speeding from the speed limit was related directly to an increase in the accident rate, but at a speed limit of 60km/h, this trend was not clear, possibly because of the small number of samples.

Two kinds of multivariate analysis were performed, regression analysis and discriminant analysis, for estimating the safety risk of sections. Regression analysis for relating accident rate with selected roadway and traffic variables using the Quantification Theory Type-I showed that the principal contributor was average travel speed on the section, the second was intersection density, the third was percentage of heavy vehicles, and the fourth was congestion index. Speed limit was not a significant contributor.

The discriminant function for identifying the hazardous sections was developed by using the Quantification Theory Type-II with a probability of success of 75 %. It is possible to utilize this function to identify hazardous sections.

There is a need for further study to develop the relationship between the accident frequencies by type and detailed geometric design elements such as curvature, up- and down-grade, shoulder width and the roadside hazards.

REFERENCES

FHWA (1984) Identification, Quantification, and Structuring of Two-Lane Rural Highway Safety Problems and Solutions, Volume I and II, Report Nos. ***FHWA/RD-81/021 and –83/022,*** Federal Highway Administration, Washington, D. C. Unpublished reports (General Report by Brinkman, C. P. and Smith S. A. (1984) Two-Lane Rural Highways Safety. ***PUBLIC ROADS, Vol. 48, No. 2***, pp. 48-53).

Newman, T. R. (1984) Discriminant analysis as a tool for improving highway safety relationships. ***ITE Journal, Vol. 54, No. 10***, pp. 16-22.

OECD (1972) Road Research Group. ***Two-Lane Rural Roads: Design and Traffic Flow.*** Paris : OECD.

Saito, K. (1979) A study on the identification of locations having hazardous highway characteristics by statistical methods (in Japanese). ***Proc. of Japan Society of Civil Engineers, Vol. 284***, pp. 73-88.

Saito, K. and Kaku, T. (1979) A Study on the Identification of Locations Having Hazardous Characteristics by Statistical Methods. ***Transaction of Japan Society of Civil Engineers, Vol. 11***, pp. 237-240.

Saito, K., Tamura T. and Masuya Y. (1997) Development of roadside hazard model based on an analysis of fatal accident with fixed objects. ***Journal of the Eastern Asia Society for Transportation Studies, Vol. 2, No. 5***, pp. 1705-1721.

Solomon, D. (1964) ***Accidents on Main Rural Highways Related to Speed, Driver and Vehicle.*** Bureau of Public Roads.