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Statistical Analyses on the Collisions with Roadside Obstacles and Development of Roadside Hazard Model

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Abstract

Single-vehicle accidents, especially collisions with roadside hazards are a major highway safety problem in many countries. Accident statistics indicate that the probability of occupant fatality in these accidents is significantly higher than most other accident types. However, this problem has been paid little attention in the highway safety research in Japan.

In this paper, therefore, some attempts are made to idenify the magnitude and nature of the problem by reviewing the findings of recent studies in many countries, to perform some statistical analyses on the collisions with roadside objects in Hokkaido, and to develop a simple roadside hazard model for estimating the hazard for particular roadside object.

A limit study on the roadside accidents in Hokkaido reveals that nearly two-third of the fatalities are caused by a striking a utility pole and a longitudinal guardrail. The effects of alignment on roadside accidents and deperture location are defined. In discriminant analysis, it is found that the most important factor contributed to the fatal accident potential is an impact speed, and the second contributor is the kind of vehicle. Based on the results, logit model is developed for estimating the probability of fatal accident in roadside impacts.

The simple roadside hazard model is developed for the conditions that vehicles will encroach to the left-side and collide with particular object on a tangent section of two-lane highway. This model consists of accident model, encroachment model and fatal probability model. This model is applied for the simulation in case of electric pole and the results suggest that an estimated accident rate is almost similar to an actual one in National highway system in Hokkaido.

1. Introduction

Single-vehicle accidents, especially collisions with roadside hazards involving "man-made" objects, are a major highway safety problem in many countries. The typical roadside contains many features that are potentially hazardous to encroaching vehicles and their occupants. The problem increases with growing traffic volumes and increasing man-made or planted objects such as fences, lighting standards, utility poles, bridge abutments and trees.

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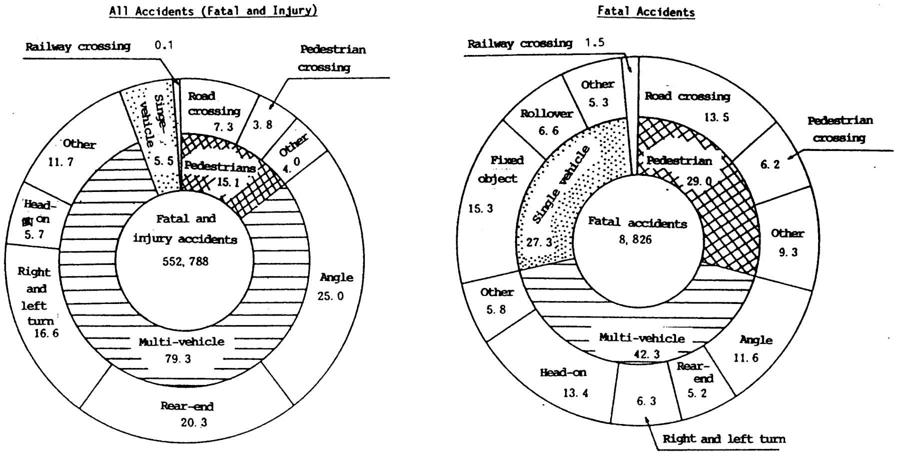
Highways, however, cannot expect to exist in a vacuum. They are an integral part of any highways and many roadside objects are needed for the control, management and aesthetic enhancement of the highway and its traffic. On the other hand, it is desirable to provide a roadside clear zone for stopping of encroached vehicle. The run-off-the-road type accident resulting in a collision with a fixed object is an expression of the conflict of problem which results from this conflicting requirements.

Accidents involving fixed roadside objects, as compared with other types of traffic accidents, involve not only the responsibility of the driver, but also that of the highway and traffic engineer. Despite the importance of the problem, this type of accidents has been paid little attention in the highway safety research and has not been studied on their highway-related aspects in Japan. The lack of the study is probably attributable in part of traditional beliefs that single-vehicle are the fault of the driver rather than the roadway. As a consequence, engineers have remained complacent with respect to their responsibilities for this type of accident, and have justified their inaction on the assumption that appropriate remedial action is beyond their control.

In this study, therefore, it was attempted to make a comprehensive study on the collisions with roadside objects in Hokkaido Prefecture, Japan. Based on the findings of the study, it was also attempted to develop a simple roadside hazard model for evaluating the risk of roadside objects.

2. An Overview of The Problems

The fact that collisions with fixed roadside hazards are more severe than most other accident types has been a well-established finding of accident reserch and investigation in many countries. For example, a report of OECD Road Research Group in 1975 showed an accident statistics of OECD Member countries that approxmately 10–20 percent of all persons killed in traffic accidents are victims of roadside obstacles, and synthesized the research on roadside obstacles [1]. A "Fixed Roadside Hazards Symposium" was held in 1977 in Australia to emphasize the problems and suggest possible means of overcoming the increasing trend in the number and severity of run-off-the-road type accidents [2]. More recently, Mc Carthy [3] indicated the importance of the problem by examination of the traffic fatality distribution in the United States for 1984 by most harmful event that on all highways, over 36 percent of the fatalities were caused by striking roadside objects such as trees, poles, and embankments. Similarly, a roadside object was judged to be most harmful event in 47 percent of the fatalities on the Interstate System. Similar problem in Japan is illustrated in Fig. 1, which shows the distributions of all personal–injury accidents and fatal accidents in 1985 [4]. The serious consequences of single-vehicle accidents is shown in this figure



Numbers are expressed as percentage

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Fig. 1 Percentage Distribution of Accidents by Type

that over 27 percent of fatal accidents were caused by single vehicle accidents which were only in 5.5 percent of all personal-injury accidents. Furthermore, an examination of fatal single-vehicle accident reveals that 56 percent were caused by collisions with fixed objects and 24 percent were caused by vehicle rollover. Clearly, single-vehicle accidents represent a major highway safety problem with massive social costs.

A number of studies have sought to investigate the characteristics of roadside accident. Pioneering studies of roadside encroachments and accidents were conducted by General Motors [5]. A study conducted by Wright and Robertson [6, 7] analyzed more than 300 fatal accidents in Georgia which involved roadside objects to determine correlating conditions within 528 feet of the collision site. It was found that over one-half of the collisions with roadside objects occurred at or near horizontal curves greater than six degrees. Hall et al. [8] also studied the nature of single-vehicle accidents involving fixed objects along the roadside and found that these accidents occurred most frequently during darkness and / or on horizontal curves. Hutchinson and Kennedy [9] studied the problem of roadway departures; they investigated vehicle enchroachment into median areas and developed distributions for angular deperture from the roadway. Perchonok et al. [10] reviewed accidents on divided and undivided roadways according to many aspects of alignment. They found there was a pronounced tendency for vehicles to depart the right side of the road. A reasonable explanation is that if a vehicle leaves the travel lane to the left, the adjacent lane often provides room for recovery. Many findings of these and another studies are summarized by Tignor et al. [11].

The most desirable roadside is one that is relatively flat and free of obstacles. If ample recovery room is provided, the errant vehicle driver may be able to return to the travelway or stop safely. Therefore, eliminating all roadside hazards is the most desirable alternative. If it is impossible to eliminate, next would be to move objects further from travelway. If it is unable to be removed or relocated, then it may be necessary to make objects breakway or to shield them [12]. Idealy, every altenative engineering solution to every fixed roadside hazard should be evaluated in order to determine the best solution. Glennon [13] suggested an evaluation procedure based on a detailed inventory of every roadside hazard along a particular route and evaluation of a number of engineering solutions relating to that hazard. Koike [14] reported the development and application of the Roadside Hazard Simulation Model (RHMS) which was developed in Canada for comparing roadside designs and obstacles.

Cost-effective treatment for roadside hazards require warranting criteria based upon accident and/or encroachment models and an effectiveness estimate of the palnned countermeasure. That is, to quantify the expected benefits of a safety improvement, estimates are needed as to the expected number and type of vehicle impacts with the roadside object. To develop warrants for the roadside object, the encroachment or run-off-the-road accident rate and type must be defined as a function of highway geometry and traffic distribution. As a minimum, these data should include vehicle speed, vehicle departure angle, and the lateral distance traveled from the edge of the roadway [3].

Based on an overview of the problems described here, it is emphasized that there has been an intensive effort to make the roadside of highways more safely, but much is still to be done both in design concepts and implentations. It is also emphasized that more information on the road user, vehicular and highway enviromental factors contributed to roadside accidents would be internationally provided. Another emphasized is a need for development of roadside hazard model to evaluate the risk of roadside objects and to estimate an expected benefit of a safety improvement.

3. Analysis of The Characteristics of Roadside Accidents

In order to determine characteristics of personal-injury roadside accidents, the study was designd to compare fixed object accident and rollover accident in Hokkaido for 1983 and 1985. A number of accidents analyzed and their severity are illustrated in

Table 1 A Number of Accidents Analyzed and Their Severity

	Fixed Object Accident		Rollover Accident	
Severity	Accidents	Persons	Accidents	Persons
Fatal	182	202	133	139
Serious	263	367	249	350
Light	472	918	452	977
Total	917	1487	834	1359

Table 1. The percentage of fatal accident is 19.8 for fixed object accidents and 15.9 for rollover accidents. Table 2 shows distribution of accidents killed persons by type of objects. It reveals that nearly one-third of the fatalities were caused by a vehicle striking a utility pole and another one-third were caused by a vehicle striking a longitudinal gurdrail.

The effect of alignment on accident occurrence was also studied. The result is illustrated in Table 3, which shows higher percentage of right curve accidents than left curve accidents and also shows higher percentage of downgrade accidents than upgrade accidents. Because it can be assumed that right and left curves experience equal vehicular travel, this implies 43 percent higher accident rates for right curves than for left curves.

Table 2 The Distribution of Accident and Persons Killed by Type of Fixed Objects

Type of Object	Accidents	Persons Killed
Electric Pole	318	63
Guard Rail	225	63
Bridge/Bridge Rail	97	22
Wall/House	62	6
Sign Pole	32	5
Median/Safety Island	24	7
Other	159	36
Total	917	202

Similarly, because upgrades should have as much vehicular travel as downgrades, the accidents rate for downgrades is almost 100 percent higher than for upgrades. Fig. 2 shows the departure locations by horizontal alignment. It can be found in this figure a pronounced tendency for vehicles to depart the left side of the road (vehicle travels left side in Japan).

Table 3 Accident Frequencies for Vertical and Horizontal Alignment

Vertical Alignment	Horizontal Alignment	Fixed Object Accident		Rollover Accidents	
		Accidents	Percent	Accidents	Percent
Upgrade	Right Curve	18	2.0	30	3.6
	Left Curve	13	1.4	15	1.8
	Tangent	29	3.2	18	2.2
Downgrade	Right Curve	57	6.2	61	7.3
	Left Curve	32	3.5	39	4.7
	Tangent	32	3.5	31	3.7
Level	Right Curve	165	18.0	165	19.8
	Left Curve	112	12.2	135	16.2
	Tangent	475	49.8	341	40.8
Other		2	0.2		
Total		917	100.0	834	100.0

An impact speed would be a major factor for determining the severity of an accident. Therefore, it is attempted to compare an estimated impact speed and fatality rate which is defined as a number of killed persons per 100–accident. Table 4

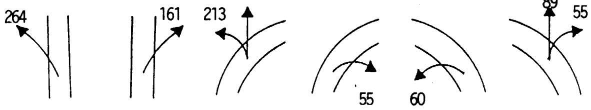


Fig. 2 Deperture Location and Accident Frequencies by Horizontal Alignment

shows a distribution of fatality rate by two types of accident, fixed object accidents and rollover accidents. It can be seen from this table that the fatality rate increases rapidly as an impact speed increases and tendency pronounces for fixed object accidens, especially for gurdrail and median impacts.

Table 4 The Distribution of Fatality Rate by Type of Accidents and Impact Speed

Estimated Impact Speed	Fatality Rate (Persons Killed/100-Accident)	
	Fixed Object Accident	Pollover Accident
Under 40 km/h	6.7	11.8
40 - 60 km/h	9.6	8.0
60 - 80 km/h	23.6	16.1
80 - 100 km/h	53.5	28.9
Over 100 km/h	87.2	54.3

4. Development of Model for Estimating The Probability of Fatal Accident

The purpose of the analysis in this section is to develop a model for estimating of the probability of driver fatality as a function of contributing factors in fixed object accidents. For this purpose, two kind of analyses were attempted, one was a discriminant analysis and the other was logistic regression analysis.

4.1 Discriminant Analysis of Roadside Accidents

A discriminant analysis is a statistical procedure and is used when statistically distinguishing among two or more populations which are (1) defined as being different in some manner; and (2) described by a multitude of independent variables. In concept, a road safety researcher applying discriminant analysis wants to know what it is that makes the accident–ralated populations different [15, 16].

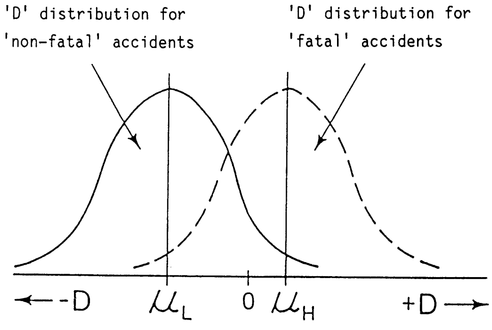
Discriminant function used in this analysis was a quantification theory type II which was developed for use of categorized data (qualitative data) in the factor analysis as following:

$$D = b_1x_1 + b_2x_2 + \cdots\cdots b_nx_n$$

where; D = a non-dimensional "discriminant score"

b' s = weighting constant (category score) for each category of a given variable

x's = categorized values (to be assign 1



μ_L and μ_H are the mean 'D' scores for the distributions of non-fatal and fatal accidents

Fig. 3 Conceptual Discriminant Score Relationship for Non-Fatal and Fatal Accident Populations or 0 for each category) of the variables selected in the analysis

Two populations, fatal injury accidents and non-fatal injury accidents, were used to know which of the many driver-related, vehicular, geometric and environmental variables best described propensity to be a fatal injury accident or non-fatal injury accident. Fig. 3 shows, in concept, D scores for fatal injury accidents would be similar, and significantly different from the D scores for the non-fatal injury accidents. In the analysis, the weighting coefficients of discriminant function are statistically determined as such a manner that the discrimination of two populations would be maximized. The results of an analysis are illustrated in Table 5 which summarizes the absolute values of partial correlation coefficient for each variable. Evaluation of the results shows that estimated impact speed is the most important factor to be contributed to the fatal accident potential in fixed object crashes. The second contributor to the fatal accident potential is kind of vehicle which may relate to vehicle weight, the third contributor is driver's age.

Table 5 The Absolute Values of Partial Correlation Coefficient for Each Variable

Variable	Partial Correlation Coeff.
Month of Year	0.050
Time of the Day	0.136
Weather	0.028
Type of Road	0.076
Age of Driver	0.176
Road Surface Conditions	0.005
Geographical Features	0.073
Alignment	0.071
Width of Travelway	0.066
Kind of Vehicle	0.288
Type of Accident	0.058
Estimated Impact Speed	0.437
Driving Experience	0.143
Departure Location	0.117

4.2 Logistic Model of the Probability of Fatal Accident

Based on the results of this analysis, it was attempted to develop a model to estimate the probability of fatal accident as a function of impact speed and vehicle weight (more precisely, exhaust capacity of engine as an alternative of vehicle weight). In this analysis, the driver injury was treated as a discrete, binary variable; fatal injury (=1) and non-fatal injury (=0). Impact speed and exhaust capacity were treated as a continuous variable. In order to obtain the probability of driver fatality as a function of impact speed and exhaust capacity, standard logistic regression procedures were used [17]. Equations of the following form were then generated:

$$P = \exp(a + b_1 x_1 + b_2 x_2) / [1 + \exp(a + b_1 x_1 + b_2 x_2)]$$

where : P = probability of driver fatality

x_1 = impact speed

x_2 = exhaust capacity of vehicle engine

a and b's = regression coefficients

Maximum likelihood estimates of a, b_1 and b_2 were obtained for rollover accidents and three types of roadside objects; electorical poles, guard rails, and bridges rails, as shown in Table 6. Except the case of bridges and bridge rails, b_1 and b_2 are positive and this imply that the probability of driver fatality becomes higher as the impact speed and exhaust capacity of vehicle engine increase, as shown in Fig. 4 for rollover accidents, in Fig.5 for electrical poles, and in Fig. 6 for guard rails. In case of bridge and bridge rails, however, the coefficient of b_2 is negative and then the curve of probability

Table 6 The coefficients of Logit Model Determined

Type of Accident	Coefficients of Logit Model		
	a	b_1	b_2
Fixed Object			
Electric Pole	-3.32535	0.04157	0.00008
Gurd Rail	-4.84979	0.05419	0.00025
Bridge	-1.65547	0.03014	-0.00018
Rollover	-1.67348	0.01404	0.00032

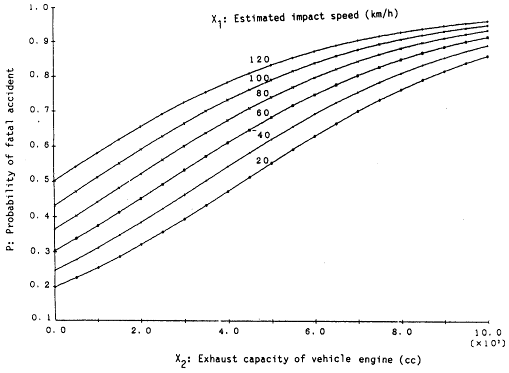


Fig. 4 Probability of Fatal Accident in Rollover Accidents

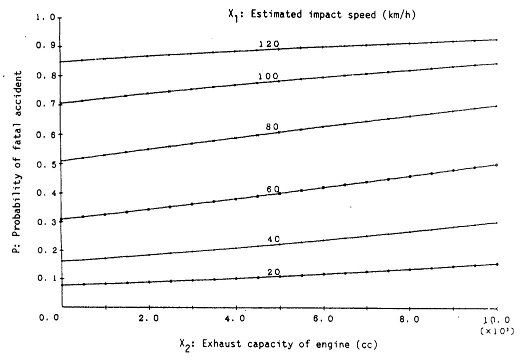


Fig. 5 Probability of Fatal Accident in Collisions with Electric Poles

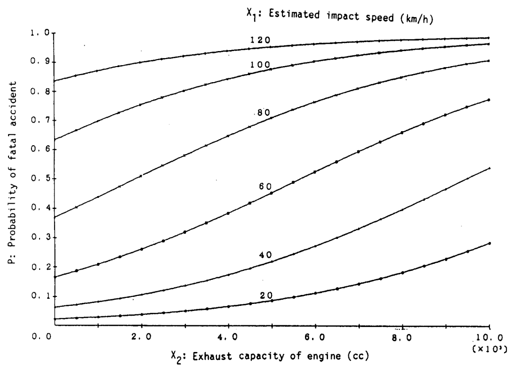


Fig. 6 Probability of Fatal Accident in Collisions with Gurd Rails

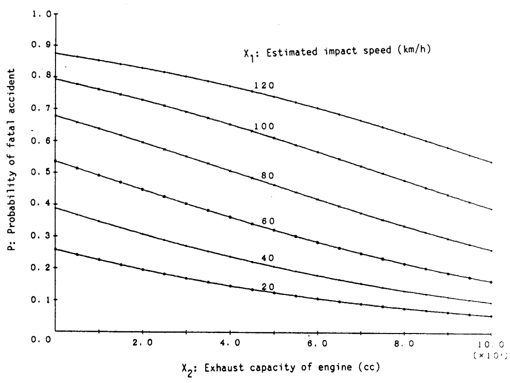


Fig. 7 Probability of Fatal Accident in Collisions with Bridge / Bridge rails

of driver fatality have negative slope as shown in Fig. 7. Since this depends partially on the small sample size of this accident type, it seems that much work is required to better define the model for this type of accidents.

5. Development of Roadside Hazard Model

The cost-effectiveness model developed by Glennon [13] provides a basic analysis for comparision of roadside improvements. The model depends on the concept that an injury-producing roadside impact is a result of a sequence of four conditional events. First, the vehicle must be within the descrete increment of roadway associated with a potential collisions with the roadside objects. Then, roadside encroachment must occur. Next, the lateral displacement of the vehicle must be great enough for collision with the roadside object. And finally, the collision must be of sufficient magnitude to produce an injury.

This sequence of events suggests a conceptual approach for evaluating the degree of hazard for roadside objects. Although the model is conceptually attractive and presents the most advanced analysis technology, it is somewhat complex to use, especially for practicing engineers. In this study, therefore, it was attempted to develop a more simple roadside hazard model for tangent section of two-lane highway.

5.1 Roadside Hazard Modeling

The modeling approach considers the conditions which vehicles will encroach to the left-side and collide with certain object on a one-kilometer length of tangent section of two-lane highway. Fig. 8 is a schimatic illustration of unit highway length associated with a particular roadside object. The degree of hazard for roadside object is evaluated a number of fatal accidents per 100 millions of vehicle-kilometer traveled.

The first step of modeling is to construct accident model by which the single-vehicle accident rate and then vehicular-encroachment rate can be estimated. An accident model used in this study was derived empirically from the data based on 585 sections of two-lane highway in Hokkaido, as following;

$$Y = 625.6x^{-0.62} \qquad (r = 0.702) \qquad (3)$$

where ; Y = single-vehicle accident rate (accidents / 100 millions of vehicle kilometers traveled)

x = traffic volumes (vehicles / 12 hours)

After the estimation of single-vehicle accident rate by using above model, the vehicular-encroachment accident rate to the left can simply be estimated by multiplying the percentage of left side run-off-the-road accidents to the estimated single-vehicle accident rate.

The next step of modeling is to construct a encroachment model by which the probability of encroaching vehicle to colide with roadside hazard can be estimated. This model includes the expected distribution of encroachment angles and the expected distribution of lateral displacements of encroaching vehicles. As shown in Fig. 8, the range of encroachment for a given roadside hazard at a given point can be computed as follow:

$$\tan \theta_1 = a / (Lo + x)$$

$$\tan \theta_2 = (a + Wo + We \cos \theta_2) / (x - We \sin \theta_2)$$

where; x = longitudinal distance from furthest downstream encroachment point (m)

a = lateral placement of roadside hazard (m)

θ = angle of encroachment

Lo = longitudinal length of roadside hazard (m)

Wo = lateral length of roadside hazard (m)

We = width of vehicle (m)

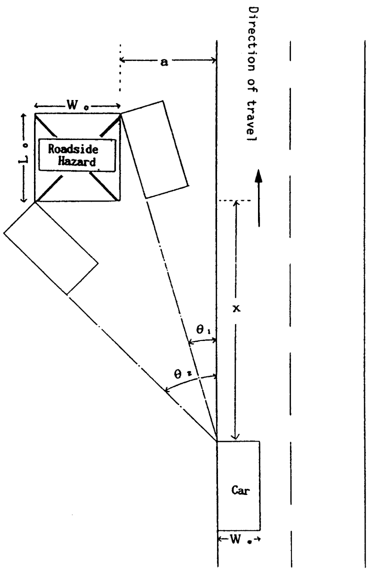


Fig.8 Schimatic Illustration of Roadside Object and Its Relationship to an Encroaching Vehicle

If the expected distribution of encroahment angles and the expected distribution of lateral displacements of encroaching vehicles are known, the probability of impact of encroaching vehicle can be computed. Then, the vehicular-encroachment accident rate multiplied by this probability of impact gives the fixed object accident rate.

The third step modeling is to estimate the severity level of impact. In this modeling approach, the probability model of fatal accident developed in this study is incorporated for particular roadside object. If the impact speed and the exhaust capacity of encroaching vehicle are given, the probability of fatal accident can easily be estimated by using of developed probability model. Finally, the fixed object accident rate, which is estimated in the second step, multiplied by the estimated probability of fatal accident gives the fatal accident rate for paticular object.

5.2 Example of the Model Simulation

An Attempt was made to estimate the accident rate in case of collisions with electric pole in Hokkaido by using of simulation model developed in this study and the estimated accident rate were compared with an actual one for the validation of simulation model. It was assumpted for simulation that the spacing of each electoric pole was 50 meters, the size of pole was 0.5 meter and width of vehicle was 1.7 meter as shown in Fig. 9. Since the expected distributions of encroachment angles and lateral placement of encroaching vehicles have never been developed in Japan, the relationships developed by Hutchinson and Kennedy [9] and Glennon and Walton [17] were adapted respectively in this case study. The simulation was performed for two variables, traffic volume and lateral placement of pole. The results of simulation are shown in Fig. 10 for accident rate. It can be seen from this figure that the accident rate decreases as traffic volume and lateral placement of pole increase. It shoud be noted that the accident rate sharply decreases as a lateral placement of pole increases until 3.0 meters. This suggests that locating or relocting of the electoric pole beyond 3.0 meters may significantly contribute to decrease the accident rate of pole impact.

For the validation of simulation model, it was attempted to compare the simulation results for the average conditions of national highway system in Hokkaido with actual accident rate of electoric pole. The result shows that an accident rate is almost similar to an actual average accident rate of pole impact for 1983 to 1985.

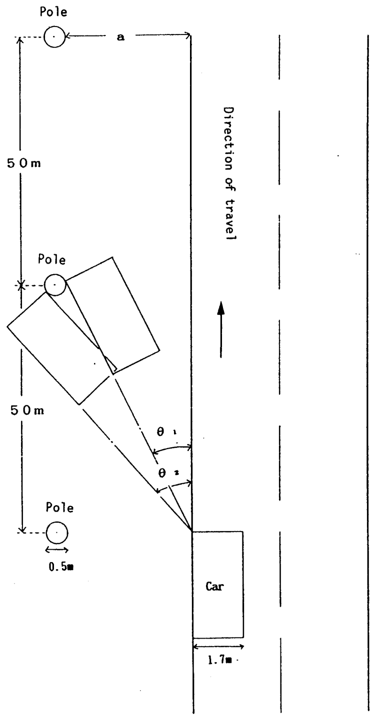


Fig. 9 Schimatic Illustration of Electric Pole and Its Relationship to an Encroaching Vehicle

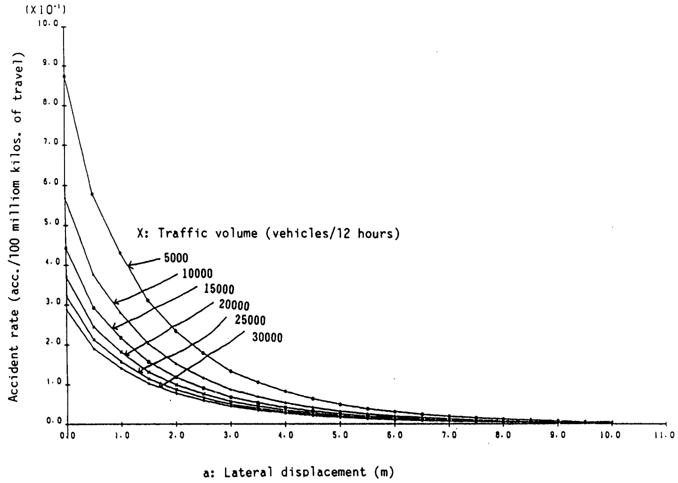


Fig. 10 Relationship Between Accident Rate, Traffic Volume and Lateral Displacement in Case of Collisions with Electric Poles

6. Summary

In this study, some attempts were made to define the magnitude and nature of the problems focused on the run-off-the-road type accident by reviewing the findings of recent studies in many countries, to conduct a comprehensive study on the collisions with roadside hazards, and to develop a roadside hazard model for estimating the accident rate of roadside objects.

In an overview of the problems, it is emphasized that there has been an intensive effort to make the raodside of highways more safely but much is still to be done both in design concepts and implementation by highway and traffic engineers. Another emphasized is that there is a need for development of roadside hazard model to evaluate the degree of hazard of roadside objects and to estimate an expected benefits of a safety improvement.

A limit study on the roadside accidents in Hokkaido reveals that nearly one-third of the fatalities were caused by a striking a utility pole and another one-third were caused by a vehicle striking a longitudinal guardrail. The effect of alignment on roadside accident and the departure location by horizontal alignment were defined in this study. It is found by discriminant analysis that the most important factor to be contributed to the fatal accident potential in fixed object crashes is an estimated impact speed, the second contributor is the kind of vehicle which may relate to vehicle weight, and the third contributor is driver' age. Based on these results, logistic type model for estimating the probability of fatal accident is developed as a function of an impact speed and an exhaust capacity of vehicle engine which is an alternative of vehicle weight.

The simple roadside hazard model (simulation model) is developed for the conditions that vehicles will encroach to the left-side and collide with certain object on a tangent section of two-lane highway. This simulation model consists of accident model, encroachment model and fatal probability model. This model is applied for the simulation in case of electric pole. Except the distributions of encroachment angles and lateral displacement of encroaching vehicles, input relationships used for simulation are developed in this study. The results of simulation suggest that the accident rate of pole impact decreases as traffic volume and lateral placement of pole increase, and locating of the pole beyond 3.0 meters may contribute to decrease the accident rate of pole impact. For the validation of the model, simulation is pferformed for an average conditions of national highway system in Hokkaido and the result shows that an estimated accident rate is almost similar to an actual one.

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