INVESTIGATION OF SINGLE VEHICLE RUN-OFFS IN CANADA

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Abstract

In Canada, approximately 30 percent of all roadway fatalities are attributable to single vehicle off-road accidents, the highest of all accident categories. This large proportion of accidents has prompted the Traffic Safety Standards and Research Branch of Transport Canada to research the characteristics of single vehicle accidents (reported by police) and incidents (not reported by police) in an attempt to develop countermeasures aimed at reducing the frequency and numbers of these types of accidents.

Starting with an in-house study in 1973, data for 226 encroachments was collected and analyzed. These preliminary results led to more in-depth studies to try to further identify the contributing roadway/roadside factors. These subsequent research efforts have included the use of infrared false color imagery to better identify those run-offs not reported by police, to the long term surveillance of 4,300 km of roadways in five Canadian provinces by specially trained teams to identify runoffs and measure the roadside and encroachment characteristics associated with each run-off.

Using the data collected in these studies, and the results of it's analysis, a computer simulation model, the Roadside Hazard Simulation Model, has also been developed for use by highway agencies to prioritize their roadside hazard elimination efforts.

The single vehicle accident is a complex problem, and has been the subject of research in many countries. This paper presents the methodologies and salient findings of Canadian research efforts covering the period 1973 to 1981. It also covers a description of the Roadside Hazard Simulation Model and it's application, to contribute to the joint solution of this common problem. The application of this and other single vehicle accident research to future accident reduction methodologies is discussed.

1973-75 Two-Lane Undivided Highways

Up to this time, several research studies had been undertaken in the United States to investigate single vehicle accidents, the most often cited being that of Hutchinson and Kennedy in 1966(1) (see Figure 1). This study and others like it however were primarily concerned with multi-lane divided highways and median encroachments. In Canada, however, the most prevalent type of roadway is 2-lane undivided, making comparisons difficult, and prompting the first phase of the Canadian research.

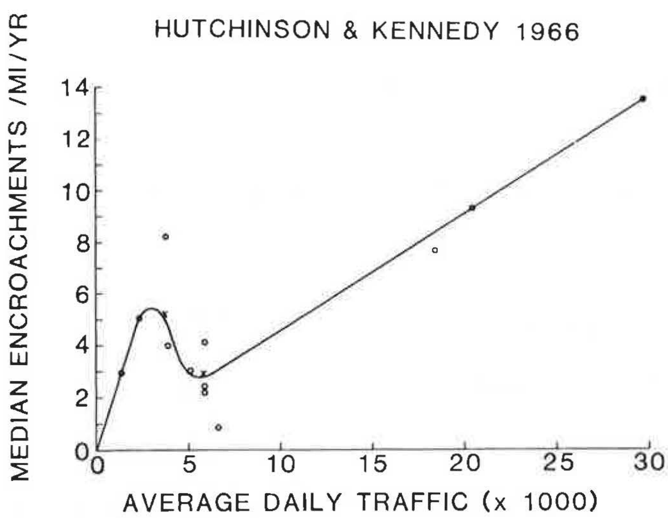

FIGURE 1 - Median Encroachment Rates

The original purpose behind this first study was to collect data for the purpose of developing a cost-benefit mathematical model for assessing and comparing roadside hazard treatments, although, subsequent research by the Organization for Economic Cooperation and Development (OECD)(2), and J.C. Glennon (3) prior to that, precluded the necessity to develop an entirely new model at this point.

This first phase of the research was carried out as an inhouse study, considering three highway sections of approximately 80 to 100 km in length on Highways 15, 16, and 17 in the Ottawa, Ontario area. The roadways were selected because of their different traffic volume, geometric and roadside fixed object characteristics. Over a similar 6 month period (May to December), data on single vehicle accidents, incidents and fixed object density was collected over the years 1973 to 1975, one highway section per year.

A roadway surveillance team of two observers monitored the highway section weekly, noting each instance of a run-off from such indicators as tire tracks on the shoulder, crushed roadside vegetation, etc., which was then cross-checked with police reported accidents by mileage location. At the same time, data on the location and density of particular fixed object classifications was also collected and plotted on a scale diagram for incremental sections of the roadway.

In total, the study collected data on 226 encroachments. Since the number of encroachments was considered limited for analysis purposes, additional data, which had been collected by the Province of Saskatchewan (4) over the winter of 1966-67, was included and adjusted to estimate the total number of encroachments for a year.

Findings from the study indicated:

- an average departure angle of 20 degrees to the right;
- there was no obvious relationship between the number of encroachments and the fixed object density;
- observed encroachments were 2 to 3 times the number reported by the police;
- encroachment frequency seemed to increase with ADT.

The data points for encroachment rate versus ADT are plotted in Figure 2. It should be noted that the curve shown is only an estimate of the fit of the data points. Consideration of the separate groups of data, such as those for Highway 17, could actually produce different curves - in this case with a downward slope from approximately 6,000 to 14,000 ADT. Surprisingly, this is similar to that reported by Cleveland and Kitamura (5).

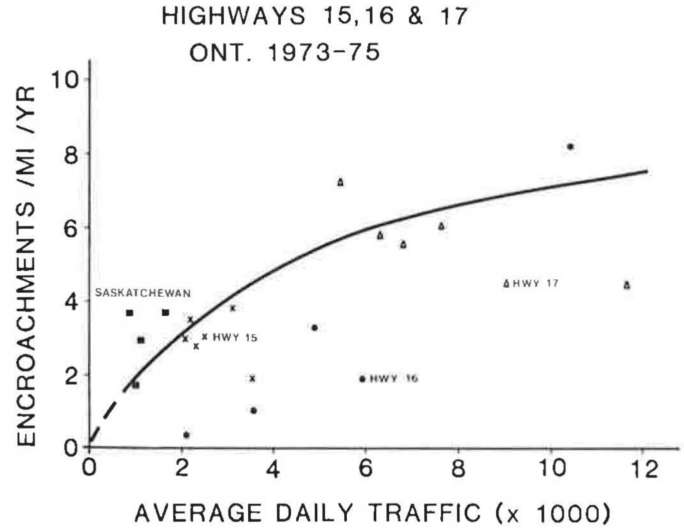

FIGURE 2 - Right Side Encroachment Rates

1973-77 Severity Data

At about the same time as the initial study on vehicle encroachments, data was also being collected in the provinces of New Brunswick, Ontario, Saskatchewan, British Columbia and Alberta, by Transport Canada's Multi-Disciplinary Accident Investigation (MDAI) teams on the severity of single vehicle accidents. Data collected included: accident type; departure angle; object struck; insurance costs and hospital costs. In all, 1168 case reports were collected.

The data was analyzed to determine the average accident costs associated with the various fixed object categories. Results of this analysis are presented in Table 1.

Object Category	Average Accident Cost	Relative Cost Index
Guiderails & Fences	$ 3,100	1.0
Cross Slopes/Culverts	$ 15,900	5.1
Power/Telephone Poles	$ 3,700	1.2
Light Poles/Standards	$ 18,400	5.9
Rock Cuts	$ 7,500	2.4
Posts	$ 800	0.3
Bridge Abutments	$ 14,500	4.7
Trees & Hedges	$ 3,100	1.0
Ditches & Embankments	$ 4,800	1.5
Others	$ 15,600	5.0

Table 1 - Average Accident Costs for Various Fixed Object Categories

As an example of the use of this information in a cost-benefit model, a priority index may be calculated using the equation:

$$\text{Priority Index (P.I.)} = \text{Relative Cost Index} \times \text{Relative Accident Frequency}$$

For example, for Rock Cuts P.I. = 2.4 x 0.5 = 1.2
Posts P.I. = 0.3 x 31.8 = 9.5

From this example it can be seen that although Rock Cuts have a higher relative accident cost, in this priority ranking scheme, posts are approximately 8 times more important to treat.

As part of this analysis, to add to the development of the cost-benefit model for fixed object accidents, severity indices were also calculated for the fixed object categories. Severity indices were calculated using the formula:

$$S.I. = Av.\ \$PDO_i \times \frac{PDO}{Tot._{acc}} + Av.\ \$Inj_i \times \frac{Inj.}{Tot._{acc}} + Av.\ \$Fat_i \times \frac{Fat.}{Tot._{acc}}$$

where Av. $\$PDO_i$ = average property damage only accident for object category i.

$PDO_{acc}/Tot._{acc}$ = ratio of all property damage only accidents to all accidents.

Inj = injury accidents

Fat = fatal accidents

In general, the relative severities for each fixed object category are shown in Table 2.

Fixed Object Category	Relative Severity Index
Guiderail & Fences	1.00
Cross Slopes/Culverts	1.55
Power/Telephone Poles	1.04
Light Poles/Standards	1.17
Rock Cuts	2.26
Posts	1.03
Bridge Abutments	2.01
Trees & Hedges	1.72
Ditches & Embankments	1.00
Others	1.01

Table 2 - Relative Severity Indices for Various Fixed Object Categories

As with calculating priority indexes using relative costs, the same can be accomplished by using relative severity indices in place of the relative costs in the priority index formula given above.

1976-78 Multi-Lane Divided

In 1976, through the Canadian Centre for Remote Sensing, the opportunity became available to collect further data on single vehicle run-offs , this time through a feasibility study on the use of infra-red false color imagery.

A 9 km section of urban freeway through the city of Ottawa, with traffic volumes in the 50 - 100,000 AADT range, was selected for the experiment. Data was collected on film in weekly flights over the roadway section for a period of 5 months.

Apart from a 1 metre asphalt shoulder, the median and roadside in this section of roadway was primarily grass. Using the infra-red false color film, areas where vehicles encroached on the roadside or median were distinguishable on the film, since the damaged vegetation showed up in a different color hue. For the study period, 140 encroachments were noted. Again, police cooperation was required in matching reported accidents to those picked up from the film.

Although it was originally thought that this method would eliminate the need to have surveillance teams exposed to traffic, other drawbacks such as the time required to go over the films, the time required in establishing an expertise in discerning the proper color indicators, and the relative eye strain associated with it did not favor pursuing the technique any further.

However, there were some useful results. It was found from the study, that:

- the average departure angle was 14 degrees for both median and right side encroachments;
- there were twice as many median encroachments as those on the right side;
- the ratio of observed to reported encroachments was 3 to 1 for median encroachments and 4 to 1 for right side encroachments.

1978-81 Divided and Undivided Rural Highways

As part of a Federal Government initiative in 1978, it was possible to obtain funds to hire survey teams in 5 Canadian provinces to monitor 59 sections of highway (4,300 km) over a 4 month period to collect additional data on single vehicle runoffs. The basic questions addressed were: What causes encroachments? Can they be predicted? What are their characteristics? What controls the severity?.

Data was collected for 1,937 encroachments using the same method as for the 1973-75 study, and included information on such variables as: speed limit; alignment; grade; object struck; angle of departure; site plan; roadside layout and fixed object density. Although it was expected that with this amount of data a precise relationship between single vehicle accident rate and traffic volume could be established, a multiple regression analysis(6) using 51 variables could explain only 30 percent of the variance. This inability to account for 70% of the variance may very well be realistic when considering the many other factors contributing to accidents such as alcohol, weather conditions, driver variables etc.

As a particular example of the role of these other factors, further analysis of the data(6) along with precipitation records from Environment Canada's Atmospheric Environment Section for all pertinent study regions, was compared to the encroachment rates developed for the individual roadway sections. A precipitation factor was calculated and plotted. The relationship is shown in Figure 3.

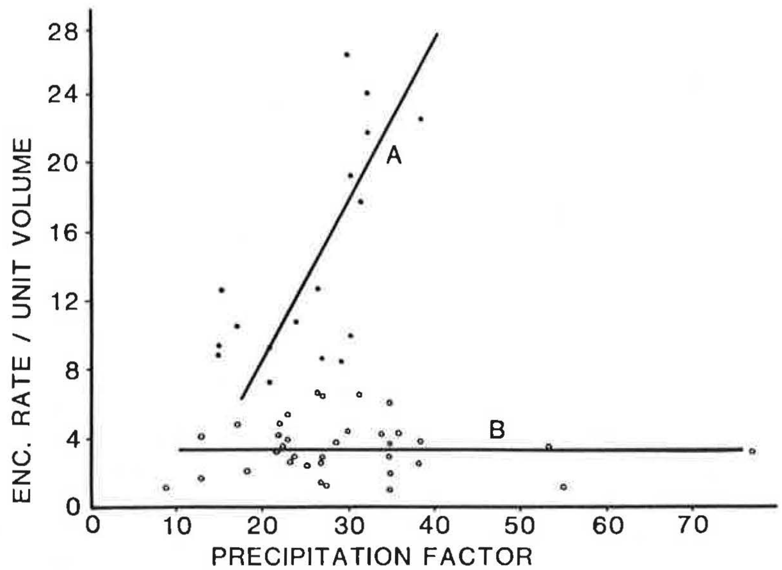

FIGURE 3 - Encroachment Rates by Precipitation Factor

The precipitation factor was defined as:

$$P.F. = \frac{\text{Normal Precipitation}}{\text{Actual Precipitation}} \times \frac{\text{No. of dry days}}{\text{preceding wet days}}$$

As can be seen in Figure 3, two distinct groups fell out of the analysis, with group "B" obviously not greatly affected by the precipitation factor, yet group "A" greatly influenced. A possible explanation for this may relate to the skid resistance of pavements associated with the different groups, but data on this variable was not available to investigate the relationship any further.

Similarly Table 3, taken from data gathered in the province of Ontario(7) comprising 213 single vehicle accidents, shows that only 1/3 of the accidents occurred in dry weather.

Weather Condition	Accident Involvement
Dry	33.8 %
Wet	16.0 %
Slush Covered	7.1 %
Snow Covered	11.7 %
Ice Covered	31.4 %

Table 3 - Accident Involvement by Weather Condition

Although part of this data collected was in winter months, the percent involvement for dry weather is still very low when considering that even in the winter months, the roads are mainly bare.

As another example of the possible influence of other variables on encroachments, Figure 4 taken from the same Ontario data noted above, shows the relationship of driving experience to the number of single vehicle accidents. As can be seen, the relationship is quite well defined and correlates well with other research carried out by Transport Canada in relating driver's relative risk of an accident to driving experience(8).

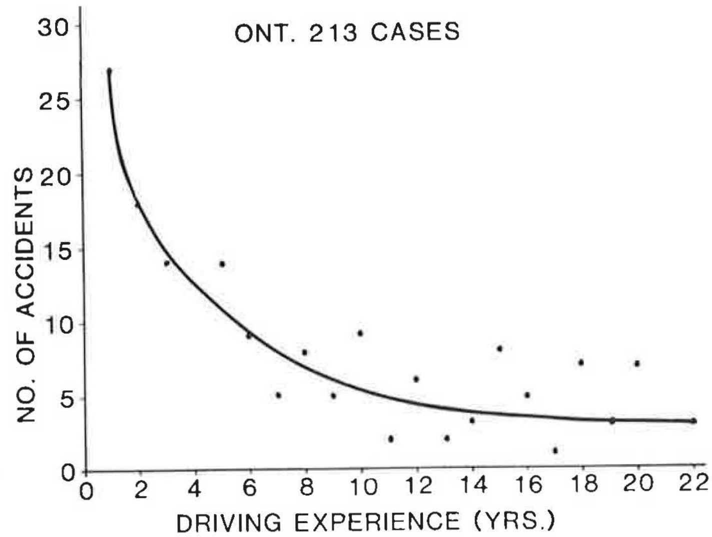

FIGURE 4 - Single Vehicle Accidents by Driving Experience

Although the explained variance mentioned previously for the main study was only 30%, a predictor equation was developed, primarily due to previous emphasis on developing encroachment rate predictors in other research. The equation developed takes the form:

$$\begin{aligned}\text{Enc. Rate} = & -0.00445 \times (\%\ \text{vacation traffic}) \\ & +0.00806 \times (\text{ADT})^2 \\ & -0.0000885 \times (\text{ADT}) \\ & +0.0110 \times (\%\ \text{heavy vehicles}) \\ & + (\text{a Regional Factor})\end{aligned}$$

where the Regional Factor = -0.007 for Eastern Canada
= +1.248 for Southern Ontario
= +0.234 for Western Canada

It should be noted that although ADT is included in the equation, it was found that it was not a very significant variable in the multiple regression analysis in explaining the variance. Actually, the original predictor equation contained no terms relating to ADT, yet variables relating to team numbers (i.e. the provinces in which they were located) did appear. The equation above resulted from a forced inclusion of traffic volume terms for each of the team areas, with the Regional Factors resulting from the best fits for each of these regions. It should also be noted that this equation applies only to undivided highways since there was not enough data to generate the same type of equation for divided highways.

When ADT is plotted against the corresponding normalized accident rate, Figure 5 results. It is interesting to note that the higher accident grouping is the same one as that found previously to be related to the precipitation factor.

When the raw data is plotted for encroachment rate versus 500 vehicles per day (vpd) groupings, Figure 6 is produced. As can be seen, there is no strong indication of any particular relationship. However, when the data is forced into wider 2000 vpd ranges and averaged over the ranges (see Figure 7), a relationship very similar to that originally constructed by Hutchinson and Kennedy(1) can be derived. This however does not take into account the fact that the standard deviations of the data are so high that no special significance can be drawn from the relative position of most of the data points shown in Figure 6, and similarly in Figure 7. The resultant curve in Figure 7 also depends a great deal on the importance attached to the first data point, and requiring the curve to go through the origin. In light of all this, it leads one to wonder if such a relationship is only a result of the particular data aggregation technique used or a real phenomenon. The resultant curve certainly is difficult to explain logically.

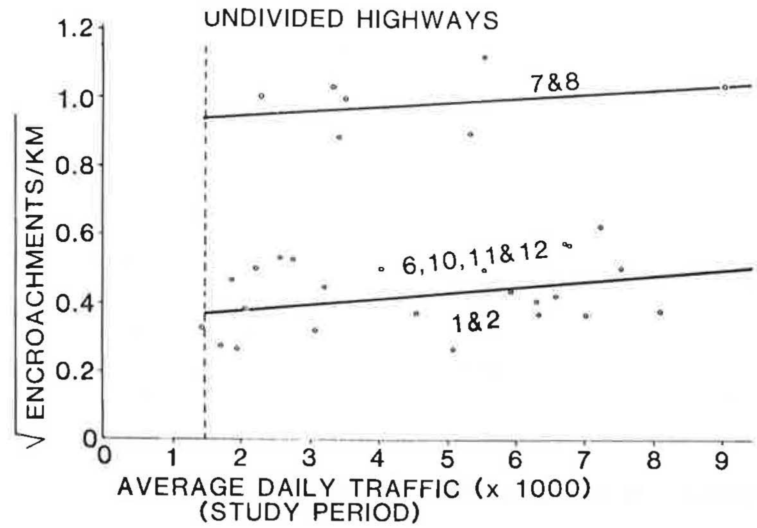

FIGURE 5 - Normalized Encroachment Rates

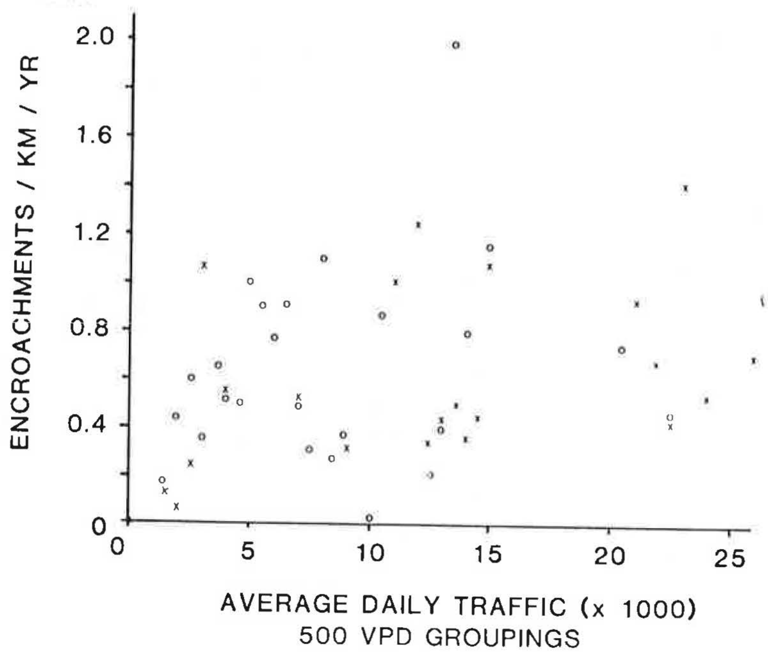

FIGURE 6 - Encroachment Rates by 500 vpd Groupings

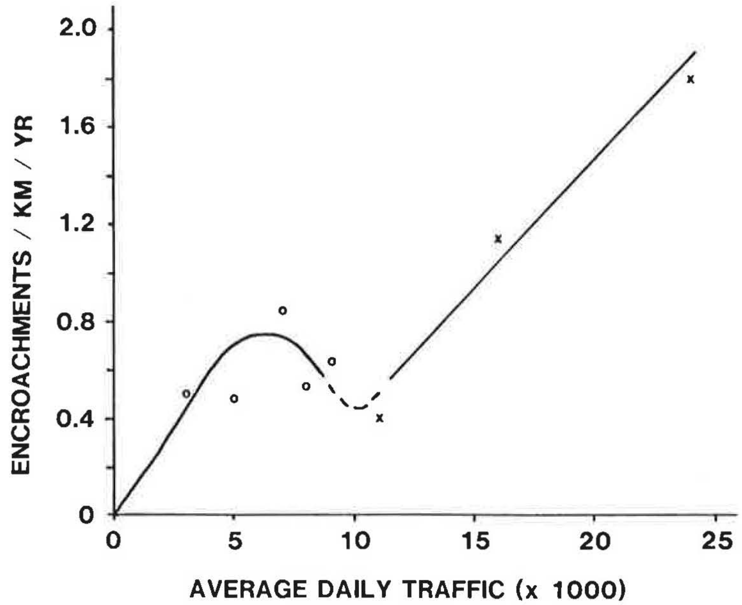

FIGURE 7 - Encroachment Rates by 2000 vpd Groupings

As with previous studies, the relationship of observed encroachments to reported encroachments was also investigated. For analysis purposes, 2-lane undivided highways were classified as those roadways having speed limits up to 90 km/h, and multilane divided highways as those with speed limits greater than 90 km/h. On the average, the ratio for observed to police reported run-offs was 3.75 to 1 for 2-lane undivided and 5 to 1 for multi-lane divided. With more data available from this study, it was possible to carry this analysis a little further. Table 4 illustrates the relationship of accident ratios for undivided and divided by roadway alignment (categories developed for the analysis).

Roadway	Accident Ratio	
Alignment	Undivided	Divided
long tangent-flat	10.4	6.5
long tangent-grade	13.3	4.7
long tangent-curvilinear-flat	5.9	5.6
long tangent-curvilinear-grade	3.6	2.9
long curve-tangent-flat	1.5	--
long curve-curvilinear-flat	6.8	17.9
long curve-curvilinear-grade	2.8	5.0
short curve-long tangent-flat	4.8	4.0
short curve-long tangent-grade	4.2	--
short curve-curvilinear-flat	3.8	3.7
short curve-curvilinear-grade	3.0	4.5
long curvilinear-flat	6.8	4.5
long curvilinear-grade	2.3	--
tangent+curve-curvilinear-flat	4.7	7.0
tangent+curve-curvilinear-grade	3.5	13.0
reverse curves-curvilinear-flat	2.9	5.5
reverse curve-curvilinear-grade	2.6	4.0

Table 4 - Accident Ratios by Roadway Alignment

In the above Table, the roadway alignment descriptor is made up of the description of the roadway section immediately preceding the section being studied, as well as the description of the section itself. For example,long tangent-curvilinear-flat means that the section is preceded by a long tangent, but the alignment of the section itself is curvilinear and flat. For a short descriptor such as long tangent-flat, it means that both the preceding section and the main section are long tangents and flat.

As can be seen from the figures presented in Table 4, there are no obvious trends in the data with respect to the roadway alignment. The only definite statement that can be made is that the average accident ratio for divided highways is higher than that for undivided highways, and is consistent with the findings of previous research.

Other findings in this phase of the analysis were:

- in terms of horizontal alignment factors, long tangent sections had the smallest number of reported accidents, even though there was a greater proportion of total vehicle run-offs on them;
- encroachment rates were higher on grades (particularly down grades) than on flat sections;
- vehicle steerback is a common occurrence. Analysis of a subset of data (394 encroachments cases) showed that 42% of them could be classified as controlled encroachments, 47% as partly controlled, and only 11% as uncontrolled, when compared to the results of computer simulations of vehicle run-offs;
- the cumulative distribution of travel distance is similar to previously published data (see Figure 8);

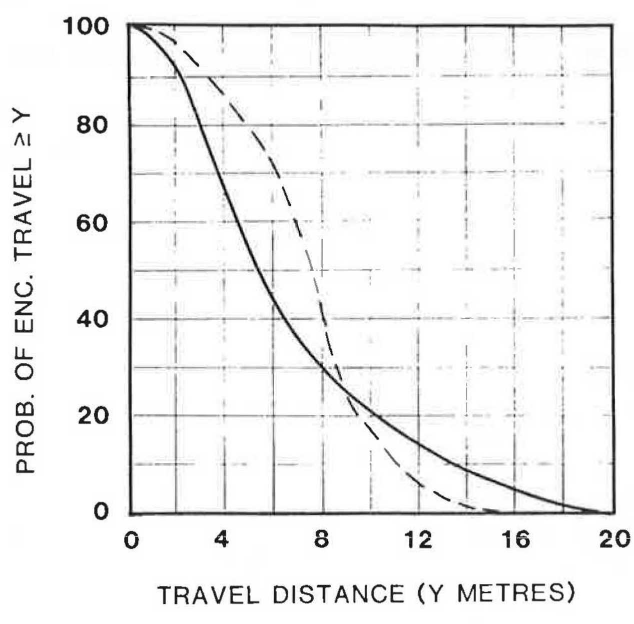

FIGURE 8 - Cumulative Distribution of Travel Distance

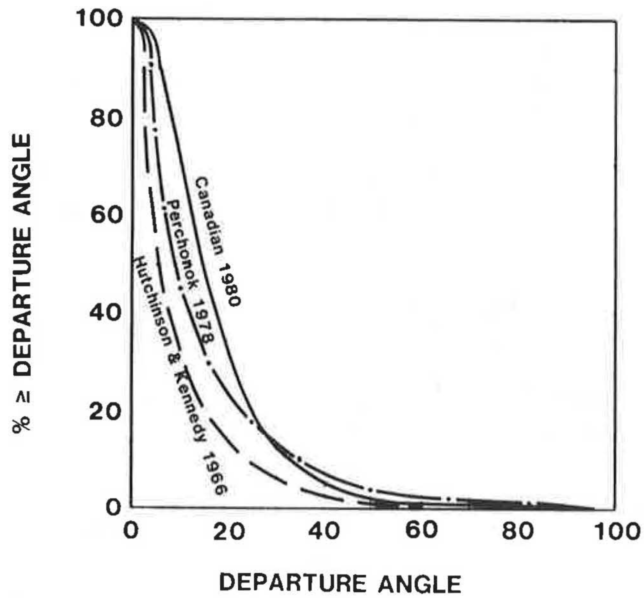

FIGURE 9 - Cumulative Distribution of Departure Angles

- the cumulative distribution of vehicle departure angles is similar to previously published data (see Figure 9);
- there was no relationship observed capable of relating the number of encroachments to roadside fixed object density, which confirms the findings of the 1973-75 study findings;
- the frequency distribution of object struck is shown below in Table 5:

Object Struck	Frequency (%)
No Object	84.2
Ditch/Embankment	6.0
Fences	1.8
Guiderails	1.4
Posts	1.4
Rock Cuts	1.2
Trees/Hedges	0.9
Utility/Light Poles	0.8
Culverts/Cross Slopes	0.6
Bridges/Abutments	0.2
Others	1.5

Table 5 - Frequency of Object Struck

Current Status

In establishing our position originally, three alternatives were identified:

- a systematic approach to the off-road accident process, defining probabilities in a cause and effect event chain;
- establishing different single vehicle accident rates associated with road sections of varying characteristics subject to countermeasure application;
- refining or restructuring existing conceptual models such as that developed by Glennon(3), based on hazards associated with certain fixed objects.

While there are certain advantages in adopting either of the latter two concepts, it was decided that the flexibility inherent in the first approach was more advantageous.

Our approach deals with the problem in two distinct phases. First, what is the probability of a vehicle leaving the roadway? Second, what are the consequences, or probabilities of different levels of accident severity, given that a vehicle has left the roadway?

In relation to encroachment rate, we tend to believe that the factors that influence accident rates also influence encroachment rates, and that the ratio of unreported to reported encroachments is a good indicator of the 'safety' of the roadway, which is related to the construction standards of the various roadway classifications.

In his report on modifications to his roadside hazard model, Glennon(9) established encroachment rates for various roadway classifications by multiplying the accident rate by a factor of 5.23 (twice the median encroachment rate originally reported by Hutchinson and Kennedy(1). Calcote(10) also used this factor in his model for cost-effective guardrail selection, but noted that the factor may be a bit too high. As mentioned above, we believe that this factor varies with roadway classification. From the Canadian data, it was found that this factor was from 2.75 to 3.75 for 2-lane undivided highways, and 3.5 to 5.0 for multi-lane divided highways. This is similar to that suggested in NCHRP Report 239(11), that the ratio of unreported to reported encroachments (k-factor) varies by highway classification, and the authors suggest that an upper limit of 8.0 be used for urban freeways. Using ratios of accident rates, the k-factors were calculated for all other highway and street classifications, and are shown below in Table 6.

Classification	K-Factor
Urban	
Freeway	8.0
Major Arterial	7.0
Minor Arterial	3.5
Collector	1.4
Rural	
Freeway	4.1
Major Arterial	2.8
Minor Arterial	2.3
Collector	1.4

Table 6 - Accident Ratios (k-factors) by Highway Classification

It was suggested by the authors that the k-factor would be lower for rural areas since the speeds would be higher, and therefore the severity of the accidents higher than the urban areas, thus more accidents would be reported in the rural area than the urban area.

The Roadside Hazard Simulation Model

In relation to the consequences of the accidents, data collected during our studies of single vehicle run-offs have yielded valuable data in calibrating the Roadside Hazard Simulation Model(12).

Work was begun on developing a model in 1977, using the data previously collected, to calculate cost-effective approaches in the treatment of roadside hazards. The model, which has been modified several times to date, basically is a point-mass model using the theory of power dissipation to calculate probabilities of fatal, injury or property damage only (PDO) accidents. At frequent time intervals, the trajectory is examined to determine the position and velocity of the vehicle, and the average acceleration it has experienced during that time interval. The amount of kinetic energy dissipated in the interval is examined and converted to an average power level, which can then be transformed into probabilities that the energy dissipated would result in a fatal, injury or PDO accident. The probability at each interval is a conditional one governed by the previous stage, and the total consequence of a single trajectory is therefore the sum of the conditional probabilities of all points along the trajectory. This sum is then normalized to indicate the consequence for one angle and speed. The model then weights all trajectories with the probabilities of speed and angle combinations, and a set of consequence probabilities is generated.

Using the data from our studies, we have been able to calibrate and update the model(6) in the following areas:

- lateral distance travelled distribution (again similar to previous research findings, but extent of maximum distance travelled is greater);
- departure angle distribution (similar, but somewhat different than previous research findings);
- departure speed (found to be approximately 0.8 times the speed limit);
- combined probability of speed and angle distribution (since these two variables were found to be related);
- seat belt influence on consequences;
- roll probability (calculated from raw data of roadside configuration and end results of the encroachments);
- driver steerback (originally thought not to occur, but found to be common. Now included in calculations of the probability of a roll to occur at the transition from edge of roadway to side slope, and also on the side slope);
- vehicle braking (originally thought to be applied in various proportions, but due to side slope reactions, now considered to be dichotomous - i.e. either fully applied or not).

Summary and Conclusions

Over a period of 9 years involving 4 separate studies, considerable data have been gathered in trying to identify the characteristics and frequency of single vehicle run-off accidents. Although the subject of other research efforts as well, there still does not seem to be an identifiable encroachment rate. Evidence does indicate however that there seems to be a relationship between the ratio of unreported to reported encroachments and accident rates, which in turn are related to the geometric standards of the roadways.

In the interest of reducing the number of single vehicle run-off accidents, it is our position that since there are so many variables influencing the encroachment rate, making it difficult to establish such a rate, that the best approach at present for a highway agency is to use the RHSM in calculating the consequences of various object/roadside conditions for vehicle encroachments, and use these consequences in combination with encroachment rates either established from local data or from currently available predictor equations. With this information, the agency may then establish a priority ranking of locations or object categories which will prove to be the most cost-effective for treatment.

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CONCRETE MEDIAN BARRIERS CRASH TESTS AND ACCIDENT INVESTIGATIONS

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Abstract

Concrete median barriers have been tested in France since 1972. The first concrete barriers tested were precast. The results were disappointing, and we quickly moved toward the use of slipformed concrete barriers.

Over the past several years, the use of these devices has been increasing. The road standards specify concrete median barrier use on urban and suburban highways and at locations with restricted circulation conditions. At present, the Transportation Ministry provides for the expansion to all highways with limited speeds and on new four lane divided roads with narrow median widths.

The purpose of this paper is to describe the research carried out in France on these concrete barriers, to give crash tests results and to analyze their behavior in the field.

Introduction

The road construction effort in highway safety has been especially noticeable since 1965 in France. It became integrated into the development policy of the motorway network and led the Transportation Department to launch extensive studies concerning traffic barrier devices.