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Experimental Plans for Accident Studies of Highway Design Elements:

Encroachment Accident Study

Research and Development
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FOREWORD

This report presents the results of a study to develop an experimental plan for developing improved estimates of vehicle roadside encroachments on rural highways. This experimental plan is one of several being developed in connection with the development of the accident analysis module for the Interactive Highway Safety Design Model (IHSDM).

The goal of IHSDM is to provide a tool for engineers to assess the safety impacts of alternative highway design decisions. IHSDM is envisioned as a series of computer programs or modules that will be integrated with commercially available computer-aided roadway design packages. The accident analysis module is one of the programs currently being developed.

The current concept of the accident analysis module is that it will allow a designer to conduct three different types of analyses depending on the data available. It will allow a designer to (1) estimate the expected number and severity of accidents based on the general characteristics of the roadway; (2) it will provide the capability of conducting a cost-effectiveness analysis of alternative roadside treatments; and (3) it will contain an expert system for assessing the safety of design decisions at the project level.

As this report will only be of interest to a limited number of researchers, a limited distribution of the report is being made. This report will be available from the National Technical Information Service.

A. George Ostensen, Director
Office of Safety and Traffic Operations
Research and Development

NOTICE

Technical Report Documentation Page

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16. Abstract

This report documents an investigation into the feasibility of using accident data to derive estimates of the rate at which errant vehicles unintentionally encroach into the roadside on level, tangent sections of two-lane rural roads. In addition, issues related to estimating the percentage of unreported accidents were also investigated. The report discusses results from the literature and an analysis of hit-utility-pole accident cases from the National Accident Sampling System (NASS). A pilot study involving 56 km (35 mi) of tangent, two-lane rural road sections in Idaho is also documented. For that pilot study, detailed roadside data were collected and accident and traffic data were obtained. Based on an analysis of that data, the resulting encroachment rate estimates were determined to be of the same order of magnitude as the encroachment rates that had been developed from previous research. It was concluded that the methodology is feasible, although it is limited by the current state of the knowledge with respect to data on the trajectories of vehicles involved in run-off-the-road and hit-fixed-object crashes. An experimental plan for future research that would produce improved estimates of roadside encroachment rates is also presented. Because the plan depends on the availability of detailed sign maintenance and roadside inventory data in electronic media, it is recommended that the plan not be implemented immediately. When and if it is implemented, the latest results from other research on trajectory data should be integrated into the plan.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
NOTE: Volumes greater than 1000 l shall be shown in m³.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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CHAPTER 1. INTRODUCTION

Many studies conducted over the past several decades have attempted to define the relationship between highway geometric design and safety. While researchers agree that highway design has a strong influence on traffic safety, no study has clearly and comprehensively quantified the exact nature of the relationship. Estimates of safety improvement are often based on professional experience or analysis of data bases of questionable quality and quantity. Frequently cited difficulties that hinder traffic accident research include:

- The lack of statistical control.
- The complexity in quantifying and measuring the interrelationships among the road, drivers, and vehicle dynamics.
- The lack of timely, quality data.

In response to these issues, the Federal Highway Administration (FHWA) embarked on a research program to develop models to better define the relationship between accidents and various highway geometric design elements or combinations of elements. As part of this program, FHWA awarded two contracts to conduct research for specific technical work requests. In general, the scope of these technical work requests included a literature review, development of a preliminary model to predict accidents, and design of an experimental plan. The experimental plans may be used as a basis for subsequent FHWA research.

The technical work request documented in this report focuses on two issues related to roadside design and run-off-the-road accidents. The first issue pertains to the rate at which vehicles traveling on tangent sections of two-lane rural roads encroach on the roadside. The second issue relates to the percentage of hit-fixed-object accidents that are unreported. It was hoped that the investigation of these two issues, in conjunction with other research studies that were underway at the time that this report was prepared, will contribute to a better understanding of the relationship between highway/roadside design and safety.

BACKGROUND

One of the underlying goals of this and other related FHWA research is to improve the safety on U.S. highways and reduce the motoring public's risks of injury. Over the past 30 years, researchers have attempted to produce results that would enhance the understanding of the often complex relationships between motor vehicle crashes and geometric design. One of the products of roadside safety research has been the development of tools that can be applied by highway designers to assess the relative cost-effectiveness of certain roadside designs. So-called roadside hazard models have been developed that allow designers to evaluate the design of roadside features such as culverts, guardrails, and other potential fixed objects. The underlying assumed average frequency at which vehicles unintentionally leave the roadway is an important element of roadside hazard models, which include the version that was presented in the American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide (RDG)*.[1] Cost-effectiveness-based analyses of roadside safety improvements are directly affected by the accuracy of the base encroachment value assumed in these hazard models. Thus, a good estimate of encroachment frequency is essential to make the most effective use of the limited resources available for roadside safety improvements.

Before proceeding, it is important to discuss the definition of a roadside encroachment. A vehicle traveling in one direction of a two-lane rural road may, from time to time, unintentionally stray from its desired lane of travel and either cross over the centerline to the left or the edgeline to the right. The consequences of these lane departures are often not severe because drivers frequently employ corrective action in a safe manner to get back into the desired lane. However, there are cases when the driver will not take an appropriate action or executes an action that over-compensates for his path deviation. In those cases, the vehicle may move beyond the edgeline and possibly beyond the edge of a paved shoulder (if one is present), thereby encroaching into the adjacent roadside. This is referred to as a "near-side" encroachment. In a similar manner, it is possible for a driver traveling in the opposite direction to unintentionally cross the centerline, the edgeline for the opposing lane of travel, and the edge of the outside paved shoulder for the opposite direction of travel. This is referred to as a "far-side" encroachment. For this study, an encroachment was defined as an errant vehicle that leaves the traveled way. For two-lane rural roads, a roadside encroachment occurs when a vehicle crosses the outside edgeline or the outer edge of the travel lane. Thus, the total number of encroachments into one side of a two-lane road is comprised of all the near-side lane departures and the fraction of far-side lane departures that reach a lateral displacement greater than the adjacent lane width. The frequency at which vehicles encroach on the roadside, measured in encroachments per kilometer (mile) per year, is a function of traffic volume. The exact relationship between roadside encroachment frequency and traffic volume, however, is the subject of debate.

Much of what is known about the relationship between encroachment frequency and traffic volume dates back to a study, *Medians of Divided Highways — Frequency and Nature of Vehicle Encroachments*, conducted by Hutchinson and Kennedy in the 1960s.[2] The study was based on indirect observations of encroachments into the medians of divided highways. It should be noted that they defined an encroachment as a vehicle that moved beyond the edge of the 1-m (3-ft) paved shoulder. The procedure involved periodic monitoring of highway test sections to detect evidence (e.g., tire tracks in the snow or mud) of vehicle encroachments into the median. These observations were used to determine encroachment frequency as a function of traffic volume, as

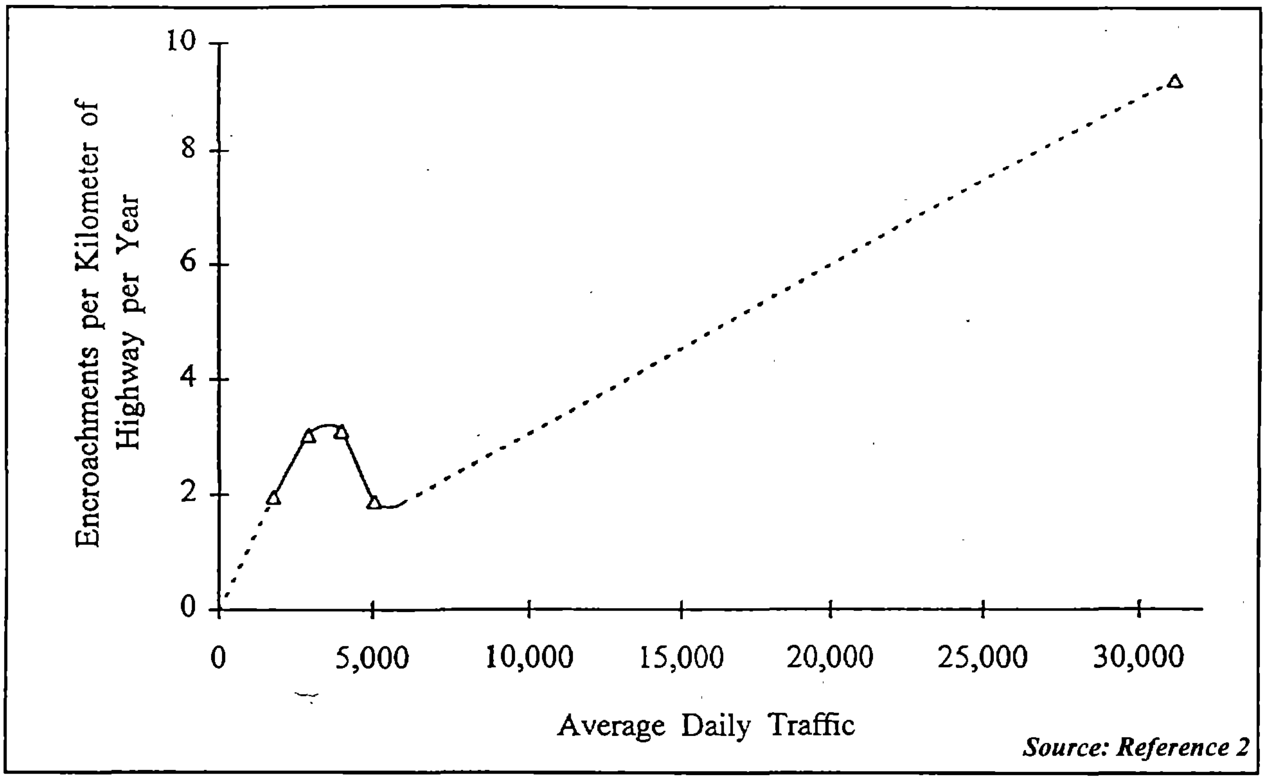


Figure 1. Encroachment frequency versus traffic volume.

well as the distributions of encroachment characteristics (e.g., extent of lateral travel, angle of encroachment, possible causes). Figure 1 shows the relationship between traffic volume and encroachment frequency from their report.

The results of Hutchinson and Kennedy's study have been criticized for a variety of reasons, which are described in greater detail later in this report. Despite attempts to reduce counting intentional encroachments by State vehicle and utility maintenance vehicles, Hutchinson and Kennedy indicated that they could not differentiate between controlled encroachments and uncontrolled, unintentional encroachments. When a driver intentionally encroaches into a median under a controlled encroachment, the severity of the outcome is generally less than when a driver unintentionally encroaches into a median. In addition to the question as to whether results obtained nearly 30 years ago are still valid, given today's vehicle/driver mix, there is also concern that these results may not be applicable to roadside encroachments on other types of roads such as two-lane rural roads. Finally, the issue of whether these results were based on an adequate sample size has also been raised. It was the need for a better estimate of encroachment frequency that motivated this study.

OBJECTIVES

Rather than duplicating the efforts of Hutchinson and Kennedy through costly indirect observation of encroachment evidence (i.e., tire tracks), this study used accident data to investigate the rate of encroachments on two-lane rural roads. The objectives of this research were to:

(1) Estimate base encroachment rates on tangents of two-lane rural roads using accident data.

(2) Estimate the percentage of unreported hit-utility-pole accidents and hit-sign-post accidents.

The primary objective was to estimate encroachment rates. Estimating the percentage of unreported accidents was a secondary objective that was intended to improve the accuracy of the encroachment rate estimates.

The study was limited to two-lane rural roads with average daily traffic (ADT) volumes of 2,000 to 10,000 vehicles. There was an intentional sampling bias towards sections with an ADT of 5,000 vehicles. It should be recognized that because the study is limited to level tangent sections only, there was no attempt to account for possible effects of horizontal and vertical alignments on encroachment frequency.

BASIC ENCROACHMENT MODEL

The basic approach for this study relies on the roadside hazard model developed by Glennon in *NCHRP Report 148*.[3] Over the years, this type of model has typically been applied to predict the number of accidents for an individual fixed object or roadside hazard. A very basic form of the model can be expressed as follows:

$$A = E * P_{(A/E)} \qquad (1)$$

where:

A = Number of expected accidents.

E = Number of roadside encroachments.

$P_{(A/E)}$ = Probability of an accident, given an encroachment.

The number of roadside encroachments, E, represents the fraction of the traffic volume passing a given object that happens to encroach while in the hazard envelope of that object. The hazard envelope represents the section of roadway in which a vehicle must have begun its encroachment for a collision with a given object to be possible. Assuming an average encroachment frequency (encroachments/km[mi]/yr), the number of encroachments in the hazard envelope (km)[mi] of that object during some time period (yr) can be estimated. $P_{(A/E)}$ then represents the fraction of vehicles encroaching in the hazard envelope that are expected to reach a great enough lateral displacement for a collision with the object. It is this number of vehicles that collide with the object that the model predicts. More detailed analyses, beyond the scope of this study, use further probability distributions, such as severity distributions of typical roadside objects, to consider the results of these collisions. In this way, the cost-effectiveness of safety improvements can be analyzed, based on the different roadside environments being considered.

To accomplish the goals set forth above, Glennon's overall approach to modeling roadside hazards was assumed to be valid. That is, it was necessary to assume the validity of $P_{(A/E)}$, as the scope of this study was limited to estimating encroachment frequency. Solving the model algebraically yields encroachment frequency as a function of accidents and the probability of an accident given an encroachment. For a given highway test section, the expected number of accidents in the model (normally the output of the calculations) was replaced by the number of accidents that actually occurred on those test sections. Thus, knowing the actual number of accidents on a given test section, not just those that are reported to the authorities, is paramount to the success of this approach. This illustrates why the study concurrently investigated the issue of unreported accidents. The encroachment frequency estimated in this manner can only be as accurate as the accident data used as input. The actual procedure is described later in more detail, along with a discussion of the results and conclusions.

LITERATURE REVIEW

Several documents addressing the issue of roadside safety were identified for critical review. Appendix A contains a more detailed literature review of all the documents used as references for this project. The following three documents were the primary references used to develop and conduct the analytical procedure:

- American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide.*[1]
- Hutchinson and Kennedy's *Medians of Divided Highways, Frequency and Nature of Vehicle Encroachments.*[2]
- Glennon's NCHRP Report 148, *Roadside Safety Improvement Programs on Freeways — A Cost-Effectiveness Approach.*[3]

The Hutchinson and Kennedy report is one of the few available documented sources of empirically determined encroachment data. The results of their study are essentially the only bench mark with which encroachment estimates can be compared. In general, they collected encroachment data by periodically monitoring the medians of divided highways for evidence of encroachments (e.g., tire tracks in the mud and snow). One of the frequently cited criticisms of their work concerns the fact that some of the data they collected was restricted to winter months. This was done to facilitate the data collection, as the tire tracks were easier to spot in the snow and mud. However, the data were obviously biased by this procedure, as the encroachment frequency is very likely higher during the winter than it is during the rest of the year. The authors fully recognized this when presenting the relationship between encroachment frequency and traffic volume (see figure 1). They stressed that they were only investigating the general shape of the curve on the encroachment frequency graph, rather than the actual encroachment frequency.

Another criticism of their results concerns intentional encroachments. Some encroachments were the result of vehicles that were intentionally driven on the median. For instance, utility trucks occasionally had legitimate reasons for traveling in the median. Hutchinson and Kennedy coordinated with utility companies to reduce the chances that the tire tracks from these trucks were included in the encroachment data. However, the remaining tire tracks could not always be positively attributed to unintentional encroachments.

Along with encroachment frequency, Hutchinson and Kennedy also investigated other aspects of median encroachments. Based on the detailed measurements they collected for each encroachment, they were able to investigate the distribution of encroachment angles and the distribution of lateral displacements. Both of these encroachment parameters play an important role in roadside hazard modeling. Of primary concern with these findings, however, is the effect that median conditions have on those parameters. For instance, a median with a steep slope would be expected to have a different distribution of lateral displacements than a median with a mild slope. Therefore, the applicability of Hutchinson and Kennedy's findings to roadsides with conditions that differ from what they studied is suspect at best.

Nonetheless, later researchers used Hutchinson and Kennedy's results for the purposes of roadside hazard modeling. Glennon's efforts in *NCHRP Report 148* are perhaps most notable. He developed a roadside hazard model to analyze roadside safety improvements on the basis of cost-effectiveness. For lack of another source of encroachment data, and despite the shortcomings of the Hutchinson and Kennedy study, he used their results in the development of his model. Furthermore, certain assumptions had to be made to apply those results to roadsides, as the encroachment data had been collected for medians. Although the individual components (e.g., the encroachment parameters and severity indices) had been determined empirically, the end result was a conceptual model of how the events leading up to a roadside accident are conditionally related. This lack of an empirical basis is one of the most prevalent criticisms of his model. It should also be noted that Glennon did not claim to be providing the actual values for the parameters to be used in his model. The disclaimer in the foreword of the report clearly stresses that the report is a demonstration of how such analyses could be made, rather than a presentation of what values should be used for such analyses.

AASHTO's *RDG* offers a roadside hazard model that is nearly identical to Glennon's model in concept. AASHTO, however, uses different values for the encroachment parameters than Glennon did. For instance, the *RDG* presents four different lateral extent probability distributions, corresponding to different design speeds. While this seems to be a useful refinement to the modeling process over the single distribution from the Hutchinson and Kennedy report, there is no source given to allow a critical review of their validity or appropriateness. The *RDG* also suggests the use of different encroachment angles as a function of design speed, whereas Glennon used one representative encroachment angle which was applicable to all speeds, based on analysis of the Hutchinson and Kennedy data. Finally, AASHTO presents a linear function for the relationship between encroachment frequency and traffic volume that, above moderate traffic volumes, is similar to the Hutchinson and Kennedy graph. At low volumes, however, the two sources of encroachment frequency differ significantly, because of the nonlinearity that Hutchinson and Kennedy found.

ACCIDENT-BASED APPROACH AND ENCROACHMENT-BASED APPROACH PHILOSOPHIES

Defining the relationship between safety and the roadside environment has been an ongoing effort for many years. The fundamental objective has been to develop the best possible tools (i.e., roadside safety relationships) to enhance the ability of the highway engineer to consider safety during the geometric design process. The underlying goals are to achieve safer roadsides and medians. Traditionally, there have been two approaches to defining the roadside safety relationship, both of which have strengths as well as weaknesses.

The first approach, accident-based modeling, generally uses statistical analysis techniques to define the relationship between accident measures (i.e., frequency, rate, severity) and roadside variables. These statistical models tend to be most useful in explaining the general relationship between roadside characteristics and accidents. The models typically reflect central tendencies of the population and may not be representative for specific conditions. For instance, a model of this type would be useful to investigate the difference in average accident occurrence between two-lane rural roads with 4:1 side slopes and two-lane rural roads with 6:1 side slopes.

The appeal of this approach is that a sound empirical basis can be used to develop a direct relationship between accident measures and roadside variables. In fact, there have been several studies that conducted this kind of research with some success. However, none of these studies has incorporated all possible roadside conditions into a single model. Additionally, the studies of this type have been criticized for several reasons. Some of the criticism concerns the limited sample sizes that were used in developing the existing models. Improper statistical analysis has also been cited with respect to these models. Some researchers have argued that typical regression analysis is inappropriate for accident modeling because of the discrete nature of accidents and the extremely low probability of occurrence. Even if acceptable statistical methods are used for this purpose, the predictive capacity of these models is limited to roadside variables and/or roadside features that were included in their development. Consequently, these models generally are not appropriate to determine the effects of other roadside conditions or combinations of roadside features.

One important point should be recognized about the accident data used as input for this type of analysis. With respect to roadside safety, perhaps the most frequent criticism of an accident-based approach concerns the issue of unreported accidents. Not all run-off-road, hit-fixed-object crashes are reported. Consequently, the resulting State traffic accident data files contain only a portion of all run-off-the-road, hit-fixed-object accidents.

Unreported crashes become an issue when making comparisons among roadside objects in terms of severity distributions. The damage caused by an impact with one type of object (e.g., a rigid barrier) may be so minor that drivers may attempt to drive away without notifying the police and having a police accident report prepared. It is possible that the only impacts that are reported are crashes that result in substantial damage or personal injury. By comparison, another type of object (e.g., a cable guardrail) may have a small incidence of unreported accidents. For example, an impact with a cable guardrail may have much higher probability of rendering the vehicle not driveable even if the impact was made at a relatively lower speed. Comparison of severity distributions may lead one to conclude that cable guardrails are safer than rigid barriers. However, that result may be caused by the fact that many of the lower speed impacts with a rigid barrier go unreported.

The second approach to defining the roadside-safety relationship is the encroachment-based approach. This approach uses a conceptual model to define the conditional relationships of events that result in a vehicle impacting with a roadside hazard. The different components of this type of model account for the probability of a roadside encroachment occurring in the hazard envelope of a roadside object, the probability of the encroaching vehicle reaching a lateral displacement necessary for collision with the object, and the probability of the collision resulting in some level of severity.

Critics point to the limited empirical basis of the existing encroachment data, upon which the accuracy of this type of model relies. One of the only available, documented sources for encroachment data is the study conducted by Hutchinson and Kennedy in the 1960s. The estimates of base encroachment rates are based on a relatively small sample size. In addition, there have been concerns expressed about measurements that were taken when snow was present in the median or when the medians were soft from rain. Are these estimates reflective of typical daily conditions throughout the year or are they higher than the average day because of weather conditions? Another criticism of Hutchinson and Kennedy's relationship between traffic volume and encroachment frequency is that the estimates that were derived 30 years ago for a different vehicle mix and driver population may no longer be applicable to today's drivers and vehicle fleet. Finally, the results of the Hutchinson and Kennedy study derived from encroachment data which was collected in medians of multilane, divided highways may not be appropriate for the roadside of other types of roadways, such as two-lane undivided highways.

Despite its shortcomings, the encroachment-based approach does have a great appeal in the flexibility it offers the analyst. As opposed to accident prediction equations that are developed for specific variables of interest, a roadside hazard model has the capacity to evaluate a wide variety of roadside hazards having a specific combination of dimensions and lateral offsets. This permits detailed analysis of the relative hazard presented by different designs for individual roadside objects, as well as general features (e.g., 3:1 slopes). For instance, the most cost-effective design for a culvert could be determined with the encroachment-based approach. Additional research of the individual components also would possibly produce improvements in the accuracy and applicability of the model.

CHAPTER 2. ESTIMATING THE PERCENTAGE OF UNREPORTED ACCIDENTS

As described previously, using the roadside hazard model to estimate encroachment frequency requires an accurate accounting of unreported accidents. For a given object or group of objects, the roadside hazard model is normally used to predict the total number of crashes expected to occur, regardless of whether or not the crashes are reported by police. However, police accident reports are not prepared for all motor vehicle crashes, especially single vehicle impacts with fixed objects. Some drivers leave the accident scene without reporting the incident if they are not seriously injured and their vehicles are operable. Also, because of reporting thresholds, police reports are not prepared for crashes involving minor damage. In the absence of continuous real- time roadside monitoring, it is not possible to know the true number of run-off-the-road crashes that occurred. Therefore, reported accident data are limited in terms of validating encroachment rate estimates.

Because the roadside hazard model predicts all run-off-the-road crashes whether they are reported or not, some estimate of the magnitude of unreported accidents was necessary. This estimate would then serve as an adjustment factor that could be applied to the number of reported accidents. Multiplying a reported accident rate by the adjustment factor would yield a more accurate value for input to the roadside hazard model. This, in turn, would result in an improved estimate of encroachment frequency.

It is intuitively obvious that the percentage of unreported accidents varies with the extent of vehicle damage and occupant injury, which in turn are affected by occupant protection systems, vehicle size, weight, body type, type of object struck, speed at impact, etc. The unreported percentage is expected to be inversely proportional to accident severity. For example, vehicles impacting with culvert head walls tend to result in severe crashes. Thus, it is expected that the percentage of unreported accidents of this type would be correspondingly lower compared to other objects.

As the percentage of unreported accidents varies with accident type, so do the possible methods used to estimate it. The method used for one type of hit-fixed-object accident may not be appropriate for another type of fixed object. The methods used to estimate the percentage of unreported accidents for the two objects included in this study, utility poles and small roadside signs, are described in the succeeding section. These objects were chosen specifically because of the expected likelihood of success in determining the percentage of unreported accidents.

ESTIMATING THE PERCENTAGE OF HIT-UTILITY-POLE ACCIDENTS

The percentage of unreported hit-sign-post accidents was estimated by comparing accident records with sign-post maintenance records. The fundamental assumption was that if an errant motor vehicle runs off the road and collides with a small sign post on the roadside, then there is a high probability that some type of maintenance activity will be required, even if the accident itself is not reported. This assumption is especially applicable to breakaway sign posts. However, this assumption is not as applicable to impacts with utility poles as it is to impacts with small breakaway signs. In general, only the most severe hit-utility-pole accidents, those in which the pole is broken, are likely to necessitate maintenance activity. It is unlikely that both the driver and the vehicle would be in a condition to leave the scene of such a severe accident to avoid reporting it to the authorities. Likewise, if both the driver and the vehicle are able to leave the scene of a hit-utility-pole accident to avoid reporting it, the pole would not likely have suffered sufficient damage to warrant maintenance activity. Even in cases where visible evidence indicates that a collision took place, the pole would not necessarily require maintenance. Therefore, another method had to be used to determine the percentage of unreported hit-utility-pole accidents.

The National Accident Sampling System (NASS) data base was explored to determine the feasibility of using it to estimate the percentage of unreported hit-utility-pole accidents. NASS was developed under the auspices of the National Highway Traffic Safety Administration (NHTSA). From about 1980 to 1985, data were collected from a variety of primary sampling units (PSUs) throughout the United States as part of the NASS Continuous Sampling System. NASS investigators selected a sample of police accident reports in each PSU for detailed analysis. Through appropriate statistical sampling techniques, the resulting NASS data base can be used to develop national estimates related to motor vehicle crashes. In 1986, the types of data collected were modified, and the NASS Continuous Sampling System was subsequently replaced with the General Estimates System. Hence, 1985 represented the latest year for which the desired data on utility pole crashes were available.

For a portion of the cases in the NASS data base, sufficient information was collected to allow reconstruction of accident speeds. The reconstruction was based primarily on vehicle crush measurements and trajectory data. The cumulative frequency distribution of impact speeds for these types of accidents was expected to yield an estimate of the magnitude of unreported accidents. The basis for this assumption was that the sampling scheme employed to develop the NASS data base intentionally over-sampled more severe accidents. This is supported by the fact that approximately 95 percent of the hit-utility-pole accident cases in the 1985 NASS data base involved vehicles that were towed from the scene of the accident. It is expected that relatively few vehicles would need to be towed from the scene of an accident if they were involved in minor (low speed) accidents. Thus, the relationship between impact speed and accident severity suggests that biases exist within the NASS data base with respect to impact speed. The evidence suggests that crashes with low impact speeds are under-represented in the NASS data base. As shown in figure 2, the distribution is expected to become asymptotic to the x-axis farther from the origin than it would if it were unbiased.

The percentage of unreported accidents would then be based on an extrapolation of the distribution. This extrapolation would reveal where the graph would intersect the y-axis (somewhere below the x-axis) if the sample were unbiased. This point could then be taken as the real origin of the graph. The distance along the y-axis between the new origin and the old origin would then approximate the percentage of unreported accidents.

The 1985 NASS computer data base was chosen for analysis because it was the last year in which data for selected key variables were available. As noted earlier, data collection practices

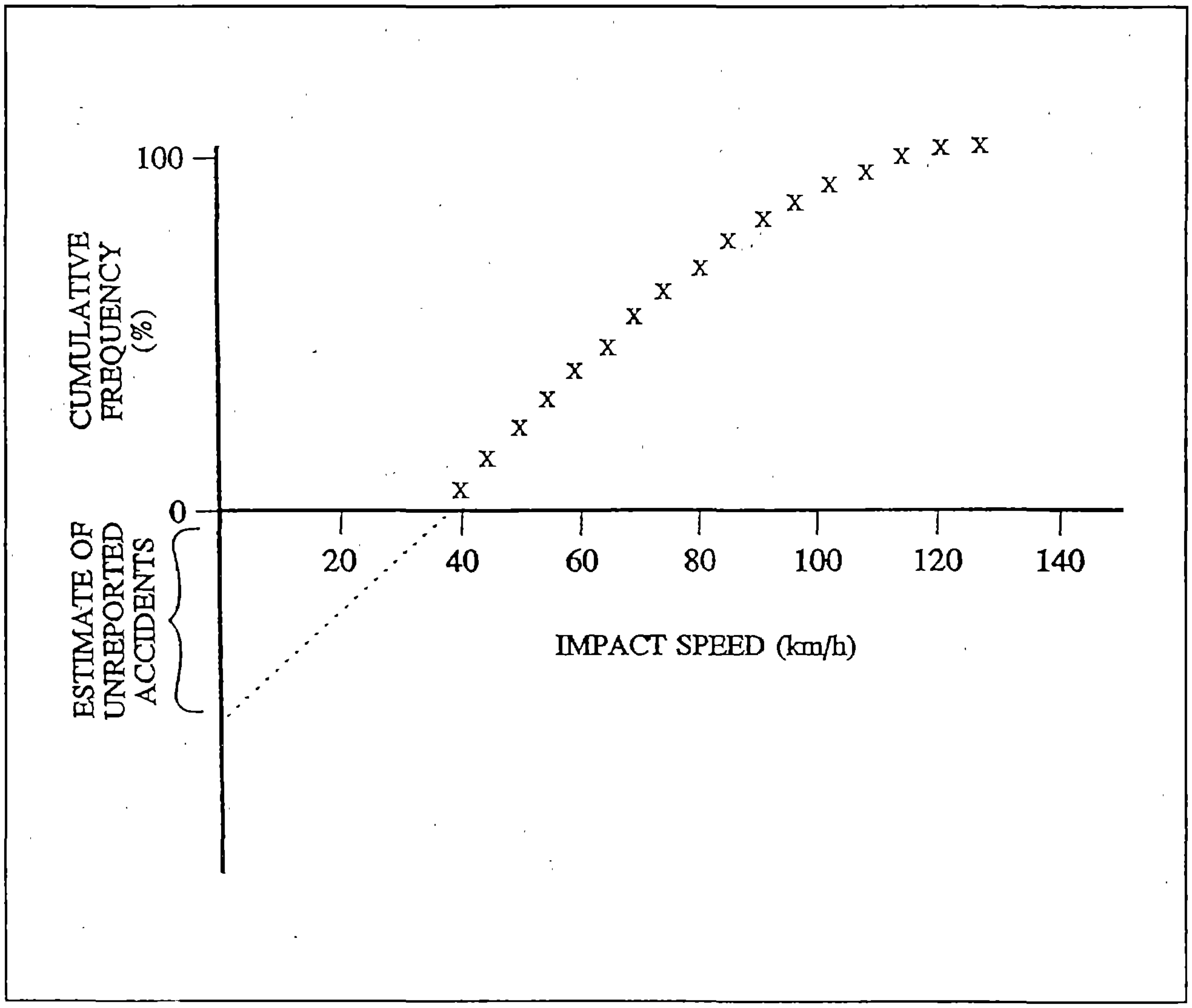


Figure 2. Expected distribution of impact speeds for hit-utility-pole accidents in the NASS data base.

changed in 1986, and the Continuous Sampling System was replaced by the General Estimates System. The records in the computer data base contain much of the information in the original hard copies of the NASS accident files. Three variables in the NASS data base were used to identify cases involving vehicles that struck a utility pole. These variables were:

HARMEV1	-	First harmful event.
OBJCONT1	-	Most harmful event.
OBJCONT2	-	Second most harmful event.

The 1985 NASS data base contains a total of 180 cases in which one or more of these variables was coded to indicate a collision with a utility pole. Figure 3 shows the distribution of these cases with respect to the variables defined above. Excluded from further analysis were the 23 cases in which the second most harmful event, but neither the first nor most harmful event, was the collision with the utility pole. Vehicles from this set of cases were involved in at least one collision before the collision with the utility pole and, furthermore, the collision with the utility pole was not the most harmful event. Thus, these cases were not felt to be representative of the accident type to be considered by this study.

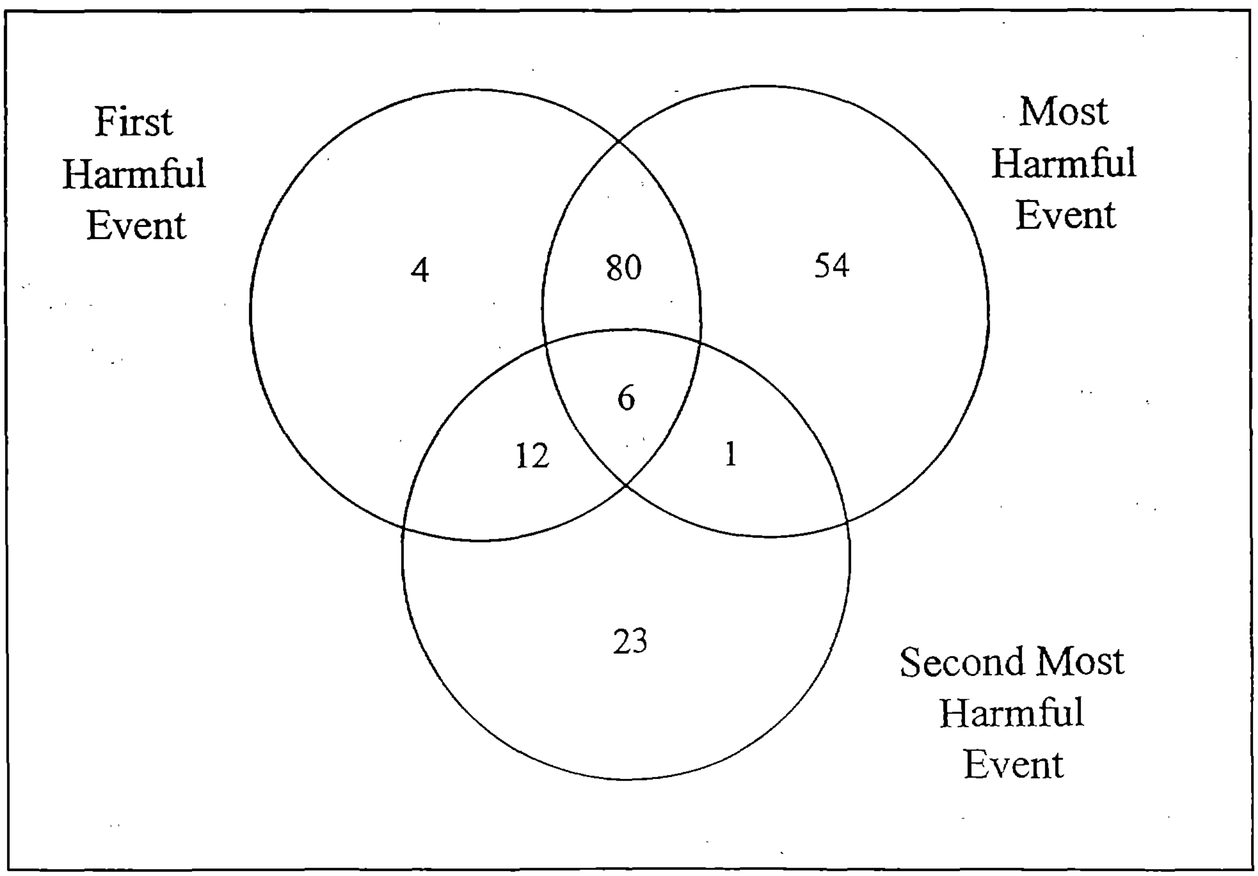


Figure 3. Distribution of hit-utility-pole accidents in the 1985 NASS data base.

Preliminary investigation revealed that, for a variety of reasons, many of the 157 cases to be included in the analysis had not been reconstructed. Furthermore, estimated impact speed was not directly available from the NASS computer data base for cases which had been reconstructed. It was determined, however, that an impact speed estimate could be derived from the information in the computer data base for a portion of those cases that were reconstructed. Even so, because of the relatively small percentage of cases for which an impact speed estimate could be derived, additional analysis was necessary to determine if the remaining cases should be included, or if their exclusion would be expected to bias the estimate of the percentage of unreported hit-utility-pole accidents. Thus, the sample was further stratified into the following three groups using DVBASIS, the NASS computer data base variable that indicates the method of reconstruction:

(1) CRASH software (Calspan Reconstruction of Accident Speeds on the Highway) - 37 cases.

(2) Yielding object algorithm - 34 cases.

(3) No reconstruction - 86 cases.

The analysis conducted for each of these groups is discussed below.

CRASH Reconstructed Cases

As mentioned previously, impact speed was not directly available from the NASS computer data base. For reconstructed cases, the data base does have values for the variable DELTA_V, which is an estimate of the total change in the velocity of the vehicle as a result of the most harmful event. For some cases, in which the vehicle strikes the utility pole and comes to a complete stop as a result of the collision, DELTA_V equals the impact speed. For other cases, however, in which the vehicle continues to move beyond the utility pole after the collision, the impact speed is greater than DELTA_V.

To illustrate the difference between DELTA_V and impact speed, consider two crashes. Vehicle A hits a utility pole at 32.2 km/h (20 mi/h) and comes to rest during the collision. DELTA_V for this crash would be 32.2 km/h (20 mi/h). If vehicle B hits a utility pole at 112.7 km/h (70 mi/h) and continues beyond the initial collision still traveling at 80.5 km/h (50 mi/h), then that crash would also have a DELTA_V value of 32.2 km/h (20 mi/h). These two crashes obviously involve different collision conditions. Although the velocity change (i.e., DELTA_V) would be the same for both vehicles, the energy dissipation would be much higher for vehicle B. The difference between these two crashes would not be apparent when only the

DELTA_V variable is considered. Thus, some method was necessary to estimate impact speed as DELTA_V was determined to be inappropriate as a surrogate.

Additional information in the data base can be used to estimate impact speed for some cases as described below. The following variables from the data base were used for this purpose:

DELTA_E - Estimated energy dissipation associated with the most harmful event.

CURBWGT - Estimated vehicle curb weight.

For relatively simple impacts (i.e., a single vehicle encroaches onto the roadside and collides with a utility pole without fracturing the pole or rolling over), the conservation of energy principle can be used to estimate the impact speed. That is, the kinetic energy of the vehicle before the impact minus the change in energy (DELTA_E) caused by the impact, equals the kinetic energy of the vehicle after the impact. The kinetic energy of the vehicle is a function of its mass and velocity. The basic energy equation is:

$$(\tfrac{1}{2}) * m_v * v_i^2 - \text{DELTA\_E} = (\tfrac{1}{2}) * m_v * v_f^2 \qquad (2)$$

where:

m_v = The mass of the vehicle.

v_i = The initial velocity (impact speed) of the vehicle.

v_f = The final velocity (speed after impact) of the vehicle.

For a given DELTA_E, there are an infinite number of pre- and post-impact vehicle speed combinations that could be solutions to the conservation of energy equation. Although there are two unknowns in equation 2 (i.e., v_i and v_f), the relationship between the two speeds is obtained from DELTA_V as follows:

$$v_i - v_f = \text{DELTA\_V} \qquad (3)$$

or

$$v_f = v_i - \text{DELTA\_V} \qquad (4)$$

As mentioned above, DELTA_V is also included in the NASS computer data base. Thus, there are two equations and two unknowns. Substituting equation (4) into equation (2) gives a unique solution for the pre- and post-impact speeds by the following equation:

$$(\tfrac{1}{2}) * m_v * v_i^2 - \text{DELTA\_E} = (\tfrac{1}{2}) * m_v * (v_i - \text{DELTA\_V})^2 \qquad (5)$$

This method was discussed in general with NHTSA personnel, who regarded the overall approach as acceptable for cases reconstructed using the CRASH software. However, they cautioned that the yielding object algorithm is considered to have produced unreliable results and recommended cases reconstructed using this software not be included in this type of analysis. The Transportation Research Center of Ohio, which maintains the CRASH software for NHTSA, was also contacted for technical assistance. The center was consulted to ensure that the method described above would give reasonable results. The center indicated that this method is indeed appropriate for single-vehicle accidents if no energy is assumed to be absorbed by the pole (i.e., a true fixed object which does not break or yield). Thus, based on the recommendations of personnel at NHTSA and the Transportation Research Center, cases reconstructed using the yielding object algorithm are considered separately in the following section.

This method was initially applied to a sample of NASS cases involving vehicles that came to rest in contact with the utility pole. These cases had been identified during a manual review of selected hard copies of accident files. For these cases, the DELTA_V value should be equal to the impact speed. As expected, the impact speeds calculated using the conservation of energy method were, in fact, equal to the value given for DELTA_V.

As noted above, there were 37 hit-utility-pole cases in the 1985 NASS data base that were reconstructed using the CRASH software. The following points should be noted regarding the final sample selection to which the method for estimating impact speed was applied:

(1) Two cases were excluded because of suspected coding errors in the NASS computer data base.

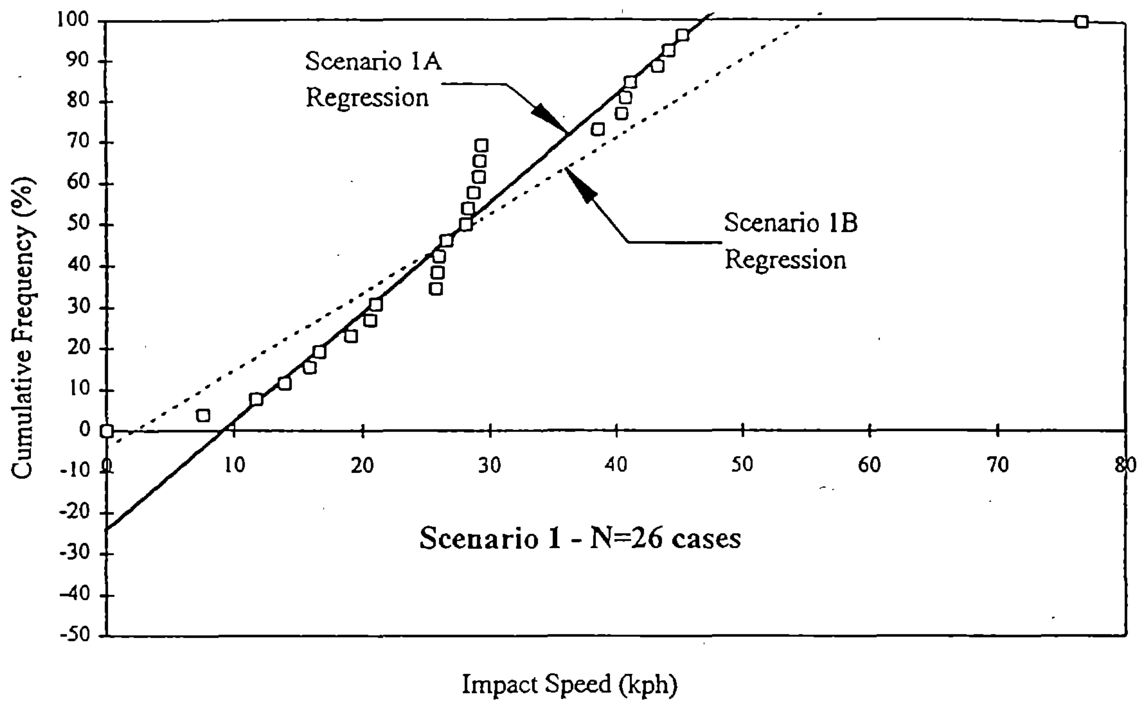
(2) There were 14 CRASH reconstructed cases in which the most, but not the first, harmful event was the collision with the utility pole. There was some question whether these cases should be included in this analysis. It can be argued that these types of crashes, in which the most harmful event is a collision with a utility pole, should be considered a hit-utility-pole crash. However, a vehicle in this type of case may not have struck the utility pole if not for the first harmful event, which may have altered the trajectory of the vehicle. Given the primary objective of this study, which is to determine the feasibility of estimating encroachment rate from accident data, it may be appropriate to exclude these cases because the encroachment model does not consider crashes caused by altered trajectories. Thus, these cases were reviewed to determine whether the vehicle trajectory might have been altered by a collision with another object before the collision with the utility pole. Based on this review, 9 of the 14 cases were excluded from further analysis. To illustrate the effect of the remaining five cases on the impact speed distribution, two scenarios were developed. Scenario 1 includes these cases while scenario 2 does not.

(3) There were four CRASH reconstructed cases in which the first, but not the most, harmful event was the collision with the utility pole. This is significant in that the values of DELTA_V and ENERGY in the NASS data base correspond to the most harmful event. Thus, for these cases, the DELTA_V and ENERGY values in the data base, as well as the subsequent impact speed estimate, are not associated with the collision with the utility pole. Assuming that these vehicles did not accelerate through the sequence of the accident events, then the impact speed at the prior, first harmful event collision with the utility pole would be greater than or equal to the impact speed estimated from the most harmful event information. These cases are identified in the impact speed distribution with arrows to indicate that the true impact speed at the utility pole could have been somewhat higher than what is shown. No attempt was made to estimate the additional uncertainty related to this issue.

Because of the exploratory nature of this research, there was also some question regarding the extrapolation of the impact speed distribution to estimate the percentage of unreported hit-utility-pole accidents for this subset of NASS cases. Thus, there are two regression lines presented for each of the scenarios described above. The regression analyses for scenarios 1A and 2A extrapolate the linear regions of these impact speed distributions. For scenario 1A, data points #2 to #25 (i.e., 24 of the 26 total data points) were used for the regression. For scenario 2A, data points #1 to #20 (i.e., 20 of the 21 total data points) were used for the regression. The regression for scenarios 1B and 2B, however, used all data points to develop a general extrapolation of the impact speed distribution. Figure 4 shows the resulting cumulative frequency distribution of impact speed for scenarios 1 and 2, as calculated using the principle of conservation of energy. Also shown are both regression lines for each scenario.

Using the previously described procedure, the y-axis intercept of the regression line for each of the scenarios was taken to be the new origin for estimating the percentage of unreported accidents. For example, the regression line for scenario 1A intersected the y-axis at -24.2. The distance between the old and new origins was taken to represent unreported hit-utility-pole accidents. To estimate the percentage of unreported hit-utility-pole accidents, this value (24.2) was divided by the total range of the new distribution (124.2). The results of this method estimate that approximately 19.5 percent of hit-utility-pole accidents for this subset of NASS cases are unreported. Using this procedure, the estimated percentage of unreported hit-utility-pole accidents for this subset of NASS cases were as follows:

Scenario	Estimated Percentage of Unreported Hit-Utility-Pole Accidents (CRASH subset)
Scenario 1A	19.5%
Scenario 1B	4.0%
Scenario 2A	30.2%
Scenario 2B	10.8.%



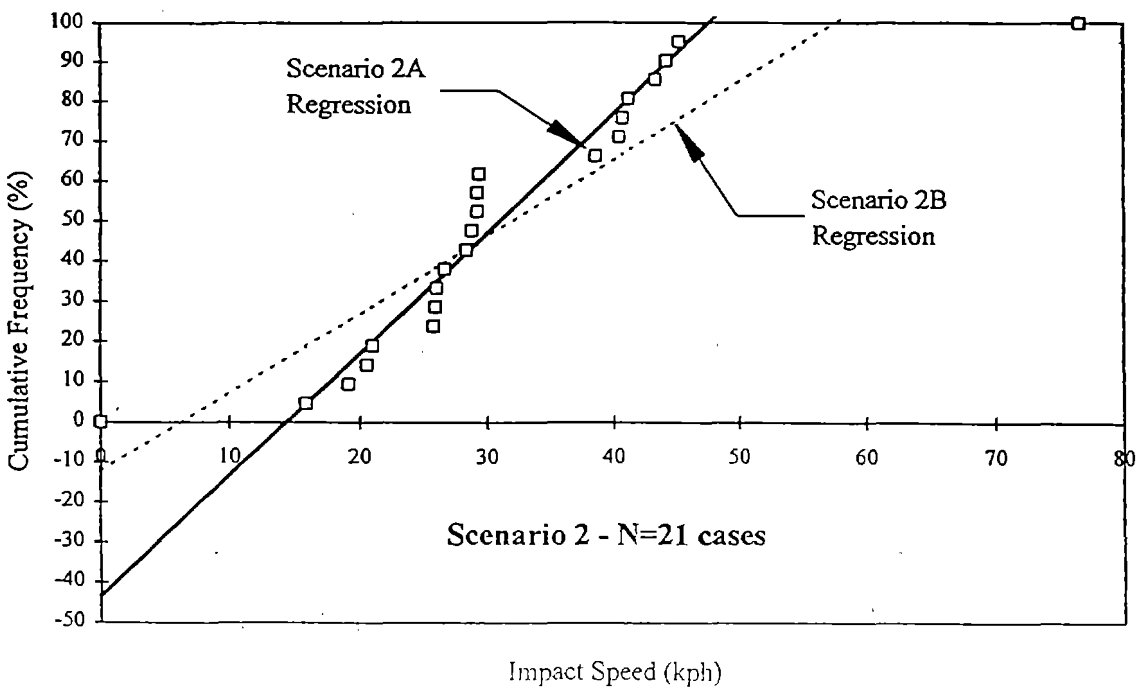


Figure 4. Cumulative frequency distribution of impact speeds for selected hit-utility-pole accidents in the 1985 NASS data base.

It should be remembered that these various unreported estimates for the percentage of unreported accidents, as a function of the scenario and regression analysis alternatives, apply only to the subset of hit-utility-pole cases analyzed with the CRASH software. Cases reconstructed using the yielding object algorithm and non-reconstructed cases are discussed later, including unreported accident estimates for those subsets, where appropriate, and an overall estimate weighted by subset sample size.

Also, it should be noted that the various estimates for the CRASH reconstructed subset were based on very small sample sizes of 21 and 26 cases. Given that the estimates for this subset required the development of a statistical distribution with a subsequent regression analysis, potential refinements could have been achieved by increasing the sample size. Additional cases could have been extracted from previous NASS years, such as 1984 and 1983, to supplement the sample. However, there were significant variations in coding and variable definition among those years because of changes in the data collection forms; consequently, merging previous data would not have been simple or straightforward. Because this was an exploratory investigation, the decision was made to use 1985 data only.

Possible Explanations for Limited Number of CRASH Reconstructed High Speed Impacts

Unexpectedly, there was only one case from the CRASH reconstructed subset of NASS cases involving an impact speed greater than 45 km/h (28 mi/h). A greater proportion of these hit-utility-pole accidents were initially expected to involve high speed impacts. The seemingly low number of higher impact speed cases could possibly be attributed to the fact that the CRASH cases are not representative of all hit-utility-pole accidents. For example, the 34 cases reconstructed using the yielding object algorithm were not included in the CRASH reconstructed distributions. As mentioned earlier, NHTSA indicated that results from this software were unreliable. It can be reasoned that, on average, accidents in which the utility pole was fractured tend to have higher impact speeds than crashes in which the pole does not break. This type of accident would have been analyzed with the yielding object algorithm and, therefore, would not have been included in the CRASH reconstructed subset. This could partially account for some of the missing high speed impact cases.

The limited number of CRASH reconstructed high speed impacts might also be related to the 86 cases that were not reconstructed at all during the original NASS investigation, and therefore had no value for DELTA_V or ENERGY. Among the cases in this category were those that were beyond the scope of acceptable reconstruction. Extremely severe accidents that resulted from high speed impacts would likely be in this category, also accounting for some of the missing high impact speeds. With no information to estimate the impact speeds of these accidents, they could not be included in the impact speed distributions.

Applicability of the CRASH Program to the Yielding Object and Non-Reconstructed Cases

Because of the very limited number of cases used to develop the impact speed distribution, the criteria for the applicability of the CRASH program were reviewed. The objective was to determine whether the sample size could be increased by applying the CRASH program to cases originally analyzed with the yielding object algorithm and those that were not reconstructed at all. The CRASH software documentation states that the program cannot be used for rollovers, sideswipes, severe override/underride crashes, non-horizontal collision forces, collisions with large trucks, trains in motion, yielding objects, pedestrians, bicyclists, or motorcyclists.

This clearly indicates that the CRASH program is inappropriate for the yielding object cases that were not included in the impact speed distribution. Thus, while these cases have the information necessary to execute the CRASH program (i.e., primarily the crush measurements and related information), the misapplication of the CRASH program to these cases would produce results that would not be meaningful. There were various reasons, explicitly coded in the NASS computer data base, that indicated why CRASH was not originally used to analyze the non-reconstructed cases. These reasons include insufficient information for reconstruction and collision/vehicle conditions beyond acceptable reconstruction. As during the original NASS investigation, it was not possible to use CRASH for estimating impact speed for these cases. Thus, they too could not be included in the impact speed distribution.

Assessment of Possible Bias from Missing Cases

Because the yielding object algorithm and non-reconstructed cases could not be included in the impact speed distribution, some investigation was necessary to determine whether the result of this was simply a smaller sample size or a biased estimate of the percentage of unreported hit-utility-pole accidents. First, as with the CRASH reconstructed cases, there were several yielding object and non-reconstructed cases in which the first harmful event was not hit-utility-pole. The same logic applied to the CRASH cases was used to determine whether these eight yielding object cases and 33 non-reconstructed cases should be included in the analysis. Once again, the concern was related to the possibility that the first harmful event had altered the trajectory of the vehicle in such a way that it would not have otherwise struck the utility pole. Based on this review, none of the yielding object cases or non-reconstructed cases in which the first harmful event was not the collision with the utility pole were included. Thus, the following discussion applies to accidents in which the first harmful event was the collision with the utility pole.

The basis for the investigation of the remaining cases was a comparison of all available information for each group (i.e., CRASH, yielding object, and non-reconstructed). If other groups of cases were found to be similar in nature to the CRASH cases, particularly with respect to severity measures, it could be assumed that they would have similar percentages of unreported crashes as the group of CRASH cases. In this case, the exclusion of the cases would not be expected to affect the unreported percentage estimate. However, if the differences among the groups in terms of severity were found to be substantial, the unreported percentage estimate would be expected to be biased because of the cases that could not be included. For example, a group might be found, on average, to consist of accidents that were significantly more severe than the CRASH cases. In this case, it would be expected that the percentage of unreported accidents would be lower than that estimated for the CRASH cases. Thus, some method would be necessary for including these cases in the overall estimate for the percentage of unreported hit-utility-pole accidents.

As noted above, the focus of this investigation primarily concerned accident severity measures, such as the maximum injury, number of people seriously injured, and whether or not the vehicle rolled over. It was reasoned that severity is closely associated with the probability of the accident being reported. In general, the more severe the accident is, the less likely the driver will have the option of not reporting it. Conversely, the less severe the accident is, the more likely a driver may be able to leave the scene without reporting the accident. It is recognized that relatively minor accidents may be reported for a number of reasons. For instance, a driver may be uninjured and a vehicle may have minor damage, but the minor damage may be such that the vehicle cannot be moved. Also, the accident may be reported by someone who witnessed it or the driver may report it for insurance purposes. For the purposes of this study, however, severity was considered an acceptable general indicator of the likelihood that an accident may go unreported. In addition, other factors were considered, such as weather, lighting, speed limit in the vicinity of the accident, vehicle type, and roadway alignment.

The investigation began with a review of the information in the NASS computer data base. The computer records for the CRASH cases, the yielding object cases, and the non-reconstructed cases were compared to identify similarities and differences between the groups. All variables in the extract file from the NASS computer data base were considered for this purpose. Based on this review, it was determined that neither the yielding object cases nor the group of non-reconstructed cases, as a whole, appeared to be similar enough to the CRASH cases to allow their exclusion from the analysis.

To further investigate the differences among the three groups of cases, the hard copies of the original accident records for selected cases were manually reviewed. These hard copies, which are maintained by an outside contractor under contract to NHTSA, contain the non-coded information that is not retrievable from the NASS computer data base. The available information, which varies from file to file, can include slides of the accident scene, hard copies of selected original forms, annotated sketches of the accident scene, narratives describing the sequence of accident events, and additional information. Findings from the review of the yielding object and non-reconstructed subsets are described in the following sections.

Yielding Object Cases

The yielding object algorithm was developed to apply to crashes in which the utility pole fractures as a result of the vehicle impact. For these types of cases, some energy is absorbed by the utility pole. Therefore, equation 2, used to estimate impact speed for the CRASH reconstructed subset, would not be appropriate for these types of accidents. Another term would be necessary to account for the energy absorbed by the pole yielding. The information necessary to estimate this term, which would vary from case to case, was not available. Furthermore, as noted previously, NHTSA personnel warned that results from the yielding object algorithm were considered unreliable. Given that the available reconstruction information for these cases was unreliable and crucial information was unavailable, these cases could not be included in the impact speed distribution.

Comparison of information from the hard copies of these cases indicated that, on average, the yielding object cases were relatively more severe than the CRASH reconstructed cases. The yielding object cases typically involved extensive vehicle damage as well as occupant injury. While there were severe CRASH reconstructed cases, the yielding object cases were considered, as a group, to be more severe.

For comparative purposes, the distribution of DELTA_V for each of these groups was examined. While the DELTA_V values that were generated from an application of the yielding object algorithm were considered unreliable for estimating the unreported percentage, this served as a general comparison of CRASH reconstructed and yielding object cases. As expected, the cumulative percentage distribution plot for the yielding object cases was skewed somewhat towards higher DELTA_V values compared to the CRASH distribution. This indicates that, on average, the yielding object crashes involved higher DELTA_V values compared to the CRASH cases. This is logical, as the yielding object cases, by definition, involve crashes in which the utility pole was fractured or shifted as a result of the impact. Similarly, the CRASH cases, by definition, do not include any cases in which a pole yielded on impact. Given the considerable amount of energy required for a utility pole to yield, it would be expected that the yielding object cases would have higher DELTA_V values (and consequently higher energy dissipation associated with higher DELTA_V values) compared to CRASH cases.

Based on consideration of all available information for these typically severe accidents, the 26 yielding object cases were assumed for the purpose of this study to have a 100-percent reporting level for the purpose of generating the overall estimate of unreported hit-utility-pole accidents. Although it is recognized that there is some finite probability that some of these cases go unreported, the assumption of no unreported accidents of this type was considered acceptable.

Non-Reconstructed Cases

The review of hard copies of the non-reconstructed cases yielded useful information pertaining to the approach being used to estimate the percentage of unreported hit-utility-pole crashes. Foremost was further stratification of the cases in the NASS data base. As described above, the sample was initially stratified into three categories: CRASH cases, yielding object cases, and non-reconstructed cases. This review revealed that the non-reconstructed cases would be more appropriately sub-divided according to the reason they were not reconstructed. Based on the variable in the NASS data base that indicates how the DELTA_V estimate was determined (i.e., DVBASIS), there were three subdivisions of the non-reconstructed cases:

(1) Cases for which at least one vehicle was beyond the scope of an acceptable reconstruction (DVBASIS=6).

(2) Cases for which at least one collision condition was beyond the scope of an acceptable reconstruction (DVBASIS=7).

(3) Cases for which there was insufficient data available for reconstruction (DVBASIS=8).

Manual review of the hard copies of the accident records revealed that the cases in the first subcategory (DVBASIS=6) could be excluded from the analysis. These cases involved a variety of vehicle types such as flat bed trailers, dump trucks, large motor homes/recreational vehicles, motorcycles, van type trucks, and other heavy trucks that were beyond the scope of the reconstruction software. The fact that there are large trucks and heavy vehicles that travel on two-lane rural and other roads raises an interesting issue related to encroachment rate. In general, encroachment rates have been expressed in terms of encroachments per kilometer (mile) per year per vehicle/day. The product of ADT and the base encroachment rate would yield an estimate of encroachments per kilometer (mile) per year. There has not been any distinction, based on documented literature, that has attempted to differentiate encroachments into truck encroachments and automobile encroachments. In the absence of evidence to the contrary, it must be assumed that an encroachment rate derived from data for passenger cars is equally applicable to all vehicle types.

The cases in the third subcategory (i.e., DVBASIS=8) were those in which insufficient data was available for reconstruction. Manual review of the hard copies revealed a variety of reasons for the lack of information. In some cases, the vehicle could not be located or the vehicle had already been repaired by the time the NASS investigators were able to interview the driver. In other cases, the owner refused to allow the vehicle to be inspected. Comparison of information in the computer data base and the hard copies of the accident records indicated that the insufficient data subset of non-reconstructed cases did not appear to be markedly different from the CRASH cases and yielding object cases with respect to any factors that would affect the percentage of unreported crashes (e.g., measures of severity). Thus, it was determined that this subset of cases was not, in general, more or less severe than the rest of the sample. It was reasonable to assume, therefore, that these cases would have a similar proportion of unreported accidents. Based on this reasoning, it was determined that these cases could also be excluded from the overall sample without introducing bias.

The investigation revealed, however, that cases in the second subcategory (i.e., DVBASIS=7) could not be excluded from the sample, as a whole, without introducing bias. This subcategory was comprised of cases that involved vehicles that rolled over, sideswiped a utility pole, or had overlapping damage from multiple impacts. Some severe crashes had overlapping damage caused by damage patterns that were altered by rescue equipment (e.g., the "jaws of life" were used to enable the removal of passengers and thereby affected the vehicle damage) or by the act of being towed. With respect to reporting levels, there appeared to be two types of cases in this subcategory: (1) accidents in which damage to the vehicle was so severe that it is highly unlikely that the accident could go unreported; and (2) accidents in which a vehicle sideswiped a utility pole and may have gone unreported.

The 10 rollover cases were assumed to have a 100-percent reporting level. The five catastrophic accident cases with overlapping damage, involving severe damage to the vehicle and occupant injury, were also assumed to have a 100-percent reporting level. However, it was determined that it would not be appropriate to assume so for the nine side-swipe crashes. Furthermore, excluding these types of cases from the analysis would introduce some bias to the estimate of the unreported percentage. Although this number of cases may represent a relatively small fraction of the NASS sample, it is not clear what fraction of actual hit-utility-pole crashes this is. In the absence of empirical data, a sensitivity analysis was conducted for these cases. Thus, for the purpose of generating an overall unreported estimate that considered all appropriate groups of NASS cases, this subset was assumed to have an unreported percentage ranging from 20 to 40 percent. While this still involves, in the end, a somewhat subjective estimate of the unreported percentage for a set of hit-utility-pole crashes, the uncertainty of the overall estimate for all hit-utility-pole crashes is minimized by using analytical techniques for the majority of the sample.

Overall Estimate for the Percentage of Unreported Hit-Utility-Pole Accidents

The unreported percentage estimates for each of the NASS subsets was combined to develop a weighted, overall unreported percentage estimate for hit-utility-poles. As noted previously, there were 180 total hit-utility-pole cases in the 1985 NASS data base. Of these, there were 23 cases in which the second most harmful event was a collision with the utility pole but neither the first nor most harmful events were the collision with a utility pole. These cases were not included in the analysis. Also, two cases were excluded for suspected miscoding. Table 1 summarizes how the remaining 155 hit-utility-pole cases from the 1985 NASS data base were included or excluded from the analysis, as described in the previous sections.

Table 1. Summary of 155 hit-utility-pole cases in the 1985 NASS data base.

		FHE = "hit utility pole"		FHE ≠ "hit utility pole"
		MHE ≠ "hit utility pole"	MHE = "hit utility pole"	MHE ≠ "hit utility pole"
CRASH reconstructed	Scenario 1 Scenario 2	4 4	17 17	5/14 included 0/14 included
Yielding object reconstructed		0	26 Assume 100% reported	8 All cases excluded
Non-reconstructed DVBASIS=6	Vehicles beyond scope (e.g., trucks)	0 All cases excluded	7 All cases excluded	4 All cases excluded
Non-reconstructed DVBASIS=7	Side-swipes	2 Assume 20-40% unreported	7 Assume 20-40% unreported	19 All cases excluded
	Rollovers	6 Assume 100% reported	4 Assume 100% reported	
	Overlapping damage	1 Assume 100% reported	4 Assume 100% reported	
Non-reconstructed DVBASIS=8	Insufficient information	2 All cases excluded	20 All cases excluded	10 All cases excluded

Combining the information for each of the groups of NASS cases, the number of reported accidents and total number of crashes were determined as follows:

$$\text{Reported accidents} = \sum [A + B + C_1 + C_2 + C_3] \quad (6)$$

and

$$\text{Total crashes} = \sum [(A^*F_A) + (B) + (C_1) + (C_2) + (C_3 * F_{C3})] \quad (7)$$

where:

A = Number of CRASH cases (26 and 21 for scenarios 1 and 2 respectively)
B = Number of yielding object cases (26)
C_1 = Number of DVBASIS=7 rollover cases (10)
C_2 = Number of DVBASIS=7 overlapping damage cases (5)
C_3 = Number of DVBASIS=7 side-swipe cases (9)
F_A = Unreported adjustment factor for CRASH cases (1.24, 1.04, 1.43, and 1.12 for scenarios 1A, 1B, 2A, and 2B respectively)
F_{C3} = Unreported adjustment factor for DVBASIS=7 side-swipe cases (1.25 to 1.67)

Combining equations (6) and (7), a weighted estimate for all hit-utility-pole accidents was calculated as follows:

$$\%\ \text{Unreported} = \frac{\text{Unreported Accidents}}{\text{Total Crashes}} = \frac{\text{Total Crashes - Reported Accidents}}{\text{Total Crashes}}$$

Table 2 summarizes the calculation of the overall estimate for the percentage of unreported hit-utility-pole accidents when all subsets described in table 1 are considered.

Based on all the findings from the NASS analysis, scenario 2A was considered to offer the most reasonable estimate of the percentage of unreported hit-utility-pole accidents. With respect to cases for which the first harmful event was not hit utility pole, it was determined that a cleaner estimate of encroachment rate would ultimately be generated by using only cases in which the first harmful event was the collision with a utility pole. This excludes cases in which the utility pole might not have been struck if it were not for a prior event that may have altered the trajectory of the vehicle. It should be recognized that there is some uncertainty associated with the inability to include accidents in which a utility pole would have been struck if not for a collision with another object that altered the path of the vehicle (i.e., the reverse condition of that in which the utility pole would not have been struck if not for a prior collision). However, thisuncertainty was considered to be within acceptable limits, compared to the uncertainty associated with the overall encroachment modeling process.

Potential Refinements to the NASS Analysis

The NASS data base includes weighting factors for each case. These factors are intended to account for the NASS sampling scheme by indicating the expected frequency of each accident. By weighting estimates according to these factors, more reliable results could potentially be achieved. Because of the exploratory nature of this pilot study, no attempt was made to include these weighting factors in the analysis. Thus, the unweighted NASS data base may not be exactly reflective of the true distribution of different types of hit-utility-pole accidents. For the

Table 2. Summary of overall unreported percentage calculation considering all NASS subsets.

	Scenario	Reported accidents	Estimate of percent unreported	Estimate of unreported accidents	Total accidents (reported plus unreported)
CRASH reconstructed	1A 1B 2A 2B	26 26 21 21	19.5% 4.0% 30.2% 10.8%	6.3 1.1 9.1 2.5	32.3 27.1 30.1 23.5
Yielding object reconstructed		26	0%	0	26
Side-swipes not reconstructed		9	20% - 40%	2.3 - 6.0	11.3 - 15.0
Rollovers not reconstructed		10	0%	0	10
Overlapping damage not reconstructed		5	0%	0	5
Total	1A 1B 2A 2B	76 76 71 71	10.2% - 13.9% 4.3% - 8.5% 13.8% - 17.5% 6.3% - 10.7%	8.6 - 12.3 3.4 - 7.1 11.4 - 15.1 4.8 - 8.5	84.6 - 88.3 79.4 - 83.1 82.4 - 86.1 75.8 - 79.5

purposes of this study, the additional uncertainty associated with this issue was considered acceptable. However, similar follow-up studies could potentially refine the unreported percentage estimate.

Also, given the limited number of cases that could be included in the analysis of this pilot study, potential refinement to estimating the percentage of unreported hit-utility-pole accidents may be possible by increasing the sample size. One approach would be to use additional years of NASS data. Such a study would build on the analysis of this project. It should be noted, however, that the NASS variables and codes were revised over time, complicating the process of aggregating data from different years. A more costly alternative would be a new study with the objective of estimating the unreported percentage of hit-utility-pole crashes. This new study would be similar to a scaled-down NASS effort for only hit-utility-pole crashes. Using this approach, a sample of reported hit-utility-pole crashes from a State's accident data base would be reconstructed to generate a cumulative percent distribution of impact speed. The study would include all hit-utility-pole cases identified in a State's accident data base for whatever time period and a given region as necessary to collect an appropriate sample size. This could avoid the sampling scheme issues described above for the NASS data base, that over-sampled severe accidents. This approach assumes that all hit-utility-pole crashes could be reliably reconstructed. If this is not possible, then the new study would encounter the same problems as this study did in using the NASS data base (i.e., unreliable reconstruction for some cases and no reconstruction possible for others). The feasibility of this approach would depend on available funding for such a study and the ability of current analytical techniques for reconstructing crashes that were previously not possible.

Conclusion and Summary of NASS Analysis

It should be remembered that the primary objective of this study was to determine the feasibility of estimating encroachment rate from reported accident data. Estimating the percentage of unreported hit-utility-pole accidents was a secondary objective intended to improve the accuracy of the encroachment rate estimate. Because the encroachment model predicts all crashes, whether they are reported or not, some accounting was necessary to adjust the number of reported accidents that were used as an input to the model. A comparison of maintenance records and reported accident records was determined to be unacceptable for this purpose because many hit-utility-pole crashes, particularly the minor ones that are most likely to be unreported, do not cause sufficient damage to the pole to require maintenance activity. Thus, the NASS data base was investigated, as an alternate method, to determine the feasibility of using it to estimate unreported hit-utility-pole accidents.

The NASS analysis centered on developing the distribution of impact speeds for hit-utility-pole accidents. The distribution was expected to lack low speed, unreported accidents. An extrapolation of the distribution would be used to estimate the percentage of unreported accidents missing from the distribution. The 1985 NASS computer data base was chosen for this exploratory analysis because it was the last year in which the necessary information was collected to allow the reconstruction of accident speeds. Impact speed was not directly available from the NASS computer data base. However, the conservation of energy principle could be used to calculate the impact speed for CRASH reconstructed accidents, using the variables DELTA_V, DELTA_E, and CURBWGT. Impact speed distributions were developed for two scenarios, with two extrapolations per scenario, resulting in a range for the unreported percentage estimate for this group of NASS cases.

This method could not be applied to cases reconstructed using the yielding object algorithm for two reasons: (1) the software was considered to have produced unreliable results; and (2) the additional term required in the conservation of energy equation to account for the energy absorbed by the pole was not readily available. Based on a review of the information in the NASS computer data base for these cases, as well as manual review of the corresponding hard copies of accident records, a 100-percent reporting level was assumed for this group of cases.

The conservation of energy method could also not be applied to the group of NASS cases that had not been reconstructed. These cases lacked the necessary information for DELTA_V and DELTA_E that are outputs of reconstruction. These cases were reviewed to determine if their exclusion would likely bias the overall estimate for the percentage of unreported hit-utility-pole accidents. Examination of the information in the NASS computer data base and the hard copies of the accident records revealed that there were three subsets of non-reconstructed cases. One subset was excluded because it consisted entirely of cases involving vehicles beyond the scope of this study (e.g., tractor trailers, dump trucks, recreational campers). A second subset involved cases with insufficient information for reconstruction. These cases were determined to be representative of all hit-utility-pole cases and, thus, it was deemed that their exclusion would not bias the overall estimate of the percentage of unreported hit-utility-pole accidents. The third subset consisted of accident cases that involved collision conditions beyond the scope of acceptable reconstruction. This subset was further stratified into rollovers, severe accidents with overlapping damage, and side-swipes. Because of their severity, cases involving rollovers or overlapping damage were assumed to have a 100-percent reporting level. For cases involving side-swipes, the unreported percentage was assumed to range from 20 to 40 percent.

An overall estimate of the percentage of unreported hit-utility-pole accidents was calculated by weighting the unreported estimate from each group of NASS cases according to the sample size for that group. Recognizing the limitations imposed by a very small sample size, the resulting range from 4.3 to 17.5 percent for the overall estimate was judged to be reasonably consistent with previously determined values. Based on the median value of the scenario that was judged to be most reasonable, a value of 15.6 percent unreported was used in the subsequent development of an average encroachment rate. Potential refinements to address the remaining uncertainty were noted but were beyond the scope of this exploratory analysis. Nonetheless, the results indicate that this method is acceptable, particularly for the primary purpose of this study which is to determine the feasibility of estimating encroachment rate from reported accident data.

ESTIMATING THE PERCENTAGE OF UNREPORTED HIT-SIGN-POST ACCIDENTS

The method for estimating the percentage of unreported hit-sign-post accidents was based on the comparison of reported accident records with sign maintenance records. The underlying assumption of this method is that all motor vehicle collisions with a sign post result in some type of maintenance activity. Therefore, for a given roadway section, it was assumed that the sign maintenance records could be used to estimate the number of vehicle-sign post crashes. Thus, the candidate State for this type of analysis needed to have an accurate sign inventory and maintenance records data base. Additionally, the reason for the sign maintenance activity was a critical piece of information that had to be resident within the data base. This permitted the separation of work done as a result of motor vehicle damage from maintenance performed for other reasons, such as vandalism, normal aging, and so forth. In addition, the State's police accident report form had to contain specific fields to allow for the identification of crashes involving sign posts and small signs. With these data, the number of police-reported accidents on a given roadway section could be compared to the actual number of accidents in the sign maintenance records to estimate the percentage of unreported hit-sign-post accidents. This would yield a factor by which police-reported accident rates could be adjusted to reflect unreported accidents for a better estimate of the true accident rates.

Idaho has both a sign maintenance records data base that identifies work performed as a result of motor vehicle damage and an accident report form with a specific category for hit-sign-post accidents. Therefore, Idaho was chosen as the State from which data would be collected for this project. First, hard copies of the sign maintenance records were obtained for all roads in the State highway system. Figure 5 shows an example page of the sign maintenance records that were obtained. Among the information that each record contains is the following:

- Type of sign, including legend.
- Location of the sign, including route number and milepost.
- Description of work performed on the sign.
- Reason the work was performed.
- Date the work was performed.

From this information it was possible to identify those signs in the study sample that required maintenance because of motor vehicle damage during the time period considered.

The sign maintenance records for each of the six Idaho highway districts were summarized by route number to survey the range of sign knockdowns per kilometer (mile). The goal was to identify roads with an average number of hit-sign-post accidents, according to the sign maintenance records, keeping in mind that a roadside inventory would need to be conducted for the included sections. Routes with too few hit-sign-post accidents were avoided so that an acceptable sample could be collected with the finite resources available. A low hit-sign-post accident rate could possibly indicate that there were few signs on the route, or perhaps the signs were generally behind guardrails. Similarly, routes with a very high number of hit-sign-post accidents were excluded as they might indicate unusual roadway characteristics that would bias the sample.

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                              IDAHO DEPARTMENT OF HIGHWAYS
'GM: HTR05056                 WORK & REASON CODES REPORT                 DATE: 06/30/93
    00-00000                  DISTRICT 3, AS OF 06/30/93                 PAGE:    81

KEY #      SEGMENT/ LOC/  SIGN NO    SIGN TYPE                DATES: INSTALL  REMOVAL
 ROUTE     MILEPOST AS #  CATALOG    LEGEND                          SIGN SIZE SPD RTE
---------  -------- ----  ---------  ---------------------------- --------- --- ---

883004732  001540  G801  M1-4       US SHIELD 95      (W/BK)             /  /    99/99/99
 US  95    135.790  TA   543014567  95                                 24 X  24      95
 BLANK: 01  COLOR: 00  FACE/BACK: 05  POST TYPE: 08  NO: 01  LEN:         IC #:
 SIGN-> WORK: 03    REA: 09    REM:                                     DATE: 08/09/88
*---------------------------------------------------------------------------------------
883004739  001540  G901  R2-1       SPEED LIMIT 25                     04/00/75 99/99/99
 US  95    135.800       541021259  25                                 24 X  30 25
 BLANK: 01  COLOR: 00  FACE/BACK: 05  POST TYPE: 04  NO: 01  LEN:         IC #:
 SIGN-> WORK: 03    REA: 09    REM:                                     DATE: 04/00/75
*---------------------------------------------------------------------------------------
883004740  001540  G901  R2-1       SPEED LIMIT 25                     07/00/69 99/99/99
 US  95    135.900       541021259     25                              24 X  30 25
 BLANK: 01  COLOR: 00  FACE/BACK: 05  POST TYPE: 08  NO: 01  LEN:         IC #:
 SIGN-> WORK: 03    REA: 09    REM:                                     DATE: 05/00/78
*---------------------------------------------------------------------------------------
883004746  001540  G901  M1-4       US SHIELD 95      (W/BK)           02/00/75 99/99/99
 US  95    136.050  TA   543014567  95                                 24 X  24      95
 BLANK: 01  COLOR: 00  FACE/BACK: 05  POST TYPE: 06  NO: 01  LEN:         IC #:
 SIGN-> WORK: 99    REA: 09    REM:                                     DATE: 09/11/79
*---------------------------------------------------------------------------------------
883004743  001540  G902  W1-7A      2-HEAD ARROW <->                   05/13/81 99/99/99
 US  95    136.060       546017609                                     60 X  36
 BLANK: 04  COLOR: 07  FACE/BACK: 05  POST TYPE: 06  NO: 01  LEN:         IC #:
 SIGN-> WORK: 01    REA: 09    REM:                                     DATE: 05/13/81
*---------------------------------------------------------------------------------------
883004765  001540  G8A2  R1-1       STOP                               08/26/86 99/99/99
 US  95    136.640       541011300                                     30 X  30
 BLANK: 01  COLOR: 01  FACE/BACK: 05  POST TYPE: 04  NO: 01  LEN:         IC #:
 SIGN-> WORK: 03    REA: 09    REM:                                     DATE: 08/26/86
 POST-> WORK: 01    REA: 09    REM:                                     DATE: 08/26/86
*---------------------------------------------------------------------------------------
883004769  001540  G8A2  R1-1       STOP                               05/00/67 99/99/99
 US  95    137.140       541011300                                     30 X  30
 BLANK: 01  COLOR: 01  FACE/BACK: 05  POST TYPE: 04  NO: 01  LEN:         IC #:
 SIGN-> WORK: 03    REA: 09    REM:                                     DATE: 05/13/81
 POST-> WORK: 01    REA: 09    REM:                                     DATE: 05/13/81
*---------------------------------------------------------------------------------------
883004784  001540  G981  R1-1       STOP                               04/00/65 99/99/99
 US  95    139.160       541011300                                     30 X  30
 BLANK: 01  COLOR: 01  FACE/BACK: 05  POST TYPE: 04  NO: 01  LEN:         IC #:
 SIGN-> WORK: 03    REA: 09    REM:                                     DATE: 08/09/88
 POST-> WORK: 01    REA: 09    REM:                                     DATE: 08/09/88
 POST-> WORK: 01    REA: 09    REM:                                     DATE: 05/13/81
*---------------------------------------------------------------------------------------
883004791  001540  G8A2  R1-2A      YIELD                              08/27/81 99/99/99
 US  95    140.320       541012480                                     48 X  48
 BLANK: 01  COLOR: 01  FACE/BACK: 05  POST TYPE: 05  NO: 01  LEN:         IC #:
 SIGN-> WORK: 01    REA: 09    REM:                                     DATE: 10/28/81
 POST-> WORK: 01    REA: 09    REM:                                     DATE: 10/28/81
```

Figure 5. Example of Idaho's sign maintenance records.

Reported Accidents Data Base

The police-reported accident information was obtained in the form of a computer data base that was extracted from the State accident reporting system. The extracted data base included all accidents of any type that occurred on a selected subset of roads in the State highway system during the 3 years prior to this study. This selected subset of roads was defined to include all two-lane rural highways with an ADT between 2,000 and 10,000 vehicles per day, per the criteria established for this study.

A sample of roadway sections in Idaho were identified for the purposes of this study. These sections were to be used in a pilot test of the methodology in which encroachment rates are estimated using accident data.

The roadside inventory covered slightly more than 80.5 km (50 mi) of two-lane rural highway. Tangent sections, for which data was collected, represented about 56.4 km (35 mi) of the 80.5 km (50 mi). This yielded an effective sample size of approximately 112.7 km (70 mi) of tangent roadside, considering both sides of the highway. Traffic volumes on these sections ranged from 2,300 to 10,000 vehicles per day.

Data was collected for all sign posts and utility poles within approximately 12.2 m (40 ft) of the roadway that could possibly be struck by an errant vehicle. Posts and poles located behind guardrails, up a steep embankment, or beyond a nontraversable ditch were not included. The following information was collected for the more than 1,100 sign posts and utility poles in the study sections:

- Object type: Data was collected for wooden utility poles, wooden sign posts, metal sign posts, metal signs, and guardrails. Object markers (yellow background with black, diagonal striping) were classified as metal signs, rather than metal sign posts, because they are located so close to the ground. The sign panel, not the sign post, would be struck in this case. For all other signs, the vertical clearance was such that an errant vehicle would strike the post, not the panel.

- Object size: Utility poles - The approximate diameter of utility poles was recorded to the nearest 25.4 mm (1 in) during the data collection. However, the hazard model was developed for objects with a rectangular cross section. To simplify the analyses, all utility poles were approximated as an average 254- by 254-mm (10- by 10-in) rectangle.

  Sign posts - The length and width of rectangular wooden sign posts and metal U-channel posts were measured in the field to the nearest 12.7 mm (0.5 in). The actual dimensions of these objects were used in the analyses. Metal sign posts with a circular cross section and a 63.5-mm (2.5-in) diameter were approximated as 50.8- by 50.8-mm (2- by 2-in) rectangles.

- Kilometer (mile) point location: Object kilometer (mile) points were determined using a calibrated electronic distance measurer, accurate to approximately 1.525 m (5 ft).

- Lateral offset: Lateral offsets, which were determined using a measuring tape, represent the distance between the near-side of the object and the edge of the travel lane. For small signs, the near side of the object was taken to be either the edge of the sign or the sign post, depending on which one a vehicle would be likely to strike. In the model, 3.4 m (11 ft) was added to the lateral offset for calculating the probability of a collision because of a far-side encroachment. This represents a typical lane width and accounts for the extra lateral displacement a vehicle must reach to strike an object on the far side of the road.

- Sign description: A description of each sign, including the legend and *Manual on Uniform Traffic Control Devices* (MUTCD) code, was recorded as part of the data collection effort. This was helpful in matching a particular sign post to maintenance or accident records.

Comparison of Sign Maintenance Records with Reported Accidents

Sign maintenance records were compared with accident records for the road sections where roadside data was collected. Thus, the analysis to estimate the percentage of unreported hit-sign-post accidents considered only those road sections for which all of the necessary data was available.

The actual, usable sample consisted of approximately 56.4 km (35 mi) of roadway sections from five different highways. This represents the tangent sections within an overall roadway length of approximately 80.5 km (50 mi). The sign maintenance records, summarized in figure 6, indicated that there were 18 sign knockdowns within the overall limits of the study sample of roadway sections. Of these, 14 sign knockdowns occurred on tangents, the actual sample of road sections for which roadside data was collected. In general, the location of signs according to the maintenance records agreed very closely with the roadside inventory that was collected for this study.

Figure 7 summarizes the State's reported accident data. Shown in this figure are all hit-sign-post and hit-utility-pole accidents that occurred on the sampled roadways during the time period considered by the study. Of these, four hit-sign-post accidents occurred within the overall study sample and only two of these occurred on tangents where roadside data was collected.

Unfortunately, the comparison of the State's reported accident data and sign maintenance data did not bear out the expected results. As described previously, the fundamental assumption of

ROUTE	MILEPOST	SIGN	DATE	LOCATION	ADT
SH16	2.060	STOP	5/15/91	TANGENT	5200
SH16	2.220	IDAHO SHIELD 16	5/16/91	TANGENT	5200
SH16	5.540	NO PARKING	7/23/92	TANGENT	4900
SH16	5.820	NO PARKING	6/04/90	TANGENT	4900
SH16	6.230	STOP	7/23/92	TANGENT	4900
SH16	6.340	STOP	12/02/92	TANGENT	4900
SH16	11.820	CROSSROAD	12/01/92	CURVE	4900
SH16	11.970	STOP	5/16/91	CURVE	4900
SH19	13.000	M.P. MARKER-2 DIGIT	4/02/90	TOWN	3200
SH55	47.280	LEFT CURVE ARROW	5/15/91	TANGENT	5000
SH69	2.200	LARGE ARROW	2/25/91	CURVE	2300
SH69	5.170	STOP	8/25/92	TANGENT	3100
SH69	5.660	STOP	10/19/90	TANGENT	3400
SH69	6.000	M.P. MARKER1DIGITY	10/19/90	TANGENT	3400
SH69	6.580	OBJECT MARKER-BRIDGE	10/19/90	TANGENT	4200
SH69	6.826	DO NOT PASS	11/21/91	TANGENT	4200
US95H	71.050	STOP	9/26/90	TANGENT	5700
US95H	80.130	STOP	5/13/92	TANGENT	5700

Figure 6. Summary of Idaho's sign maintenance records for study sample.

this method was that every motor vehicle collision with a sign post should result in a maintenance activity. It was expected that all reported accidents would be matched to records in the sign maintenance records. Any unmatched sign maintenance records would then be considered unreported accidents. However, neither of the two reported accidents could be matched with a corresponding sign maintenance record.

Because of the small sample, this analysis was expanded to consider all 80.5 km (50 mi) of roadway within the study sample, regardless of horizontal alignment (i.e., include those sections

SIGN POSTS = 26

	SERIALL	ACCDATE	MILEPOSL	STREET1	STREET2	EVENT1	EVENT2
①	922470059	920806	15.809	ST19H	PINTOL	26	00
1	902480071	900810	0.998	ST55H	EDISO-	26	01
	902480071 0	900810	0.998	ST55H	EDISO-	26	01
2	923220104	921107	5.200	ST55H		26	16
3	901900055	900628	13.127	ST55H	FLORIA	26	00
	900880028 0	900217	13.629	ST55H	LAKEA	26	00
④	900880028	900217	13.629	ST55H	LAKEA	26	00
5	920270043	911231	131.295	ST55H	ROSBER	26	00
①	921620031	920524	2.160	ST69H	MERIDR	26	00
①	923500205	921211	72.242	US95H	NE21A	16	26
2	921250015	920418	137.250	US95H	GALENS	16	26
3	900580024	900207	238.800	US95H		26	16
4	903190019	901028	325.710	US95H	UNIFLR	01	26
5	911160014	910410	327.500	US95H	BECKE-	26	00
6	911710114	910609	360.600	US95H	ST6H	26	16
7	912490001	910830	383.000	US95H		26	20
8	922040040	920702	384.800	US95H		26	01
9	900880012	900303	394.930	US95H	PLUPOR	26	00
10	901970045	900624	402.600	US95H		26	16
11	913540069	911210	407.050	US95H		26	00
12	912910001	910611	411.900	US95H	SUNUBR	26	01
13	912730050	910830	448.450	US95H		26	01
14	903520011	901204	479.000	US95H		26	00

XXX UTILITY POLES = 20

	SERIALL	ACCDATE	MILEPOSL	STREET1	STREET2	EVENT1	EVENT2
①	913120001	911028	0.125	ST16H	ST44H	20	30
①	911630003	910601	13.089	ST19H	TUCKER	01	20
②	923090122	921019	15.327	ST19H	PINTOL	20	00
1	920520017	920208	3.967	ST55H	SYMMSR	20	27
2	922470055	920803	4.739	ST55H	LOWELR	20	30
3	903600114	901201	109.400	ST55H		20	30
4	910700092	910303	131.341	ST55H	TAMARD	20	00
5	910560053	910203	136.500	ST55H		20	30
6	910580003	900812	153.300	ST55H		20	00
7	910560003	910112	154.250	ST55H		20	00
1	902900031	901003	40.913	US95H	HOWER	34	20
2	923630057	921208	58.650	US95H	EBON-	20	01
3	921070060	920324	87.200	US95H		20	00
4	910940061	910316	115.000	US95H		20	00
	921210007 0	920409	194.601	US95H		20	00
5	921210007	920409	194.601	US95H		20	00
6	903190016	901025	296.200	US95H	WEBBR	51	20
7	912910004	910921	297.273	US95H		39	20
8	900600020	900206	297.900	US95H		20	00
9	923280087	921114	298.400	US95H		20	01
10	912660019	910824	326.500	US95H	EVANSR	01	20
11	910170055	901201	361.600	US95H	ST6H	20	00
12	912490001	910830	383.000	US95H		26	20
13	920780002	920301	456.500	US95H		20	30
14	903410012	901202	478.100	US95H		25	20
15	901000023	900310	481.820	US95H		20	00
16	921890035	920518	505.168	US95H		20	25

Figure 7. Summary of Idaho's accident records for study sample.

for which roadside data was not collected, such as curves). Once again, none of the seven hit-sign-post accidents could be matched with a specific sign maintenance record. It was hypothesized that possibly one or both of the identified milepoints were inaccurate or there were significant differences in time between the accident and the sign maintenance activity. These reasons could possibly account for some of these differences. All types of reported accidents on this subsample were compared to the sign maintenance records for the corresponding road sections. The speculation was that possibly some reported accidents involving a hit-sign post were just not being coded as such. However, even with generous consideration for both the time lag from accident occurrence to maintenance activity and the inaccuracy in the reported location of accidents, not a single accident record could be matched with a sign maintenance record.

The unexpected results of this analysis necessitated a somewhat modified methodology. The total number of accidents was taken to be the sum of the reported accidents and the number of sign knockdowns according to the maintenance records. The percentage of unreported hit-sign-post accidents was then expressed as the ratio of the unreported sign knockdowns determined from sign maintenance records (i.e., all of them) to the total number of hit-sign-post accidents as follows:

$$\text{\% Unreported Hit-Sign-Post Accidents} = \frac{(16 - 2)}{(16)} = 87.5 \text{ percent}$$

Thus, this analysis indicated that a very high percentage of vehicle collisions with signs go unreported. It should also be noted that this estimate is based on a very small sample size. In addition, two reported accidents from this study were not reflected in the sign maintenance records. Thus, it is reasonable to assume that there could have been other unreported hit-sign-post accidents not reflected in the maintenance records as well.

COMPARISON OF RESULTS WITH PREVIOUS ESTIMATES FOR UNREPORTED ACCIDENTS

The 1980 Mak and Mason study on pole accidents included estimates for the percentage of unreported hit-sign-pole and hit-utility-pole accidents.[10] Their estimates were based on a sample size of 1,637 reported hit-pole accidents, of which 1,099 were hit-utility-pole accidents. There was a total of 261 hit-sign accidents between the two categories of breakaway and nonbreakaway sign structures. The remaining cases involved other types of poles.

The numbers of unreported accidents for utility poles and sign posts were estimated by comparing maintenance records with reported accident records. The analysis for that study determined the percentage of unreported hit-sign accidents to be approximately 68 percent, which is somewhat lower than the estimate of 88 percent determined by this study. This study, however, included only small, breakaway sign posts. The sample in the 1980 study included large, nonbreakaway signs as well, which would be expected to have a lower percentage of unreported accidents. Thus, while the two estimates differ, both indicate that a large majority of hit-sign accidents are not reported.

There is a larger difference, however, between the estimates for the percentage of unreported hit-utility-pole accidents. The 1980 study found 11 percent of these accidents were unreported, while the estimate from this study was a much higher 26 percent. Some of this difference can be attributed to the fact that the estimate from the 1980 study is likely lower than the actual percentage of unreported accidents. As mentioned previously, very minor hit-utility-pole accidents may not result in maintenance activity and would not, therefore, show up as an unreported accident with this procedure. In fact, that is why this study chose to estimate the percentage using another method. Also, it is likely that the results of this study from the analysis of the NASS data base overestimate the percentage of unreported hit-utility-pole accidents. As described previously, the unreported percentage may apply to only a subset of the NASS cases, rather than the entire sample. Accounting for the excluded cases, which were typically more severe than the CRASH cases, would yield an estimate closer to that found by Mak and Mason.

CHAPTER 3. ESTIMATING ENCROACHMENT FREQUENCY FROM ACCIDENT DATA

This study developed an approach for estimating encroachment rate from accident data, based on the use of Glennon's roadside hazard model presented in *NCHRP Report 148*.[3] In general, this model would typically be used to predict the number of accidents for an individual fixed object over some time period, based on the following:

- An average encroachment frequency.
- An average angle of encroachment.
- The dimensions of the fixed object.
- The lateral offset of the fixed object.
- The distribution of lateral displacements of encroaching vehicles.
- An average vehicle width.

For the purposes of this study, the general form of the model for two-lane rural roads was expressed as:

$$A_i = T * D * L_i * P_i \tag{8}$$

where:

A_i = Number of run-off-the-road-right, hit-fixed-object crashes in which a vehicle traveling in one direction impacts the i^{th} object on the near roadside during the time period considered by the study.

T = Time period considered by the study in years.

D = Lane departure frequency per lane, to the right near side, with units of lane departures per kilometer (mile) per year.

L_i = Length of the hazard envelope associated with the i^{th} object in kilometer (mile).

P_i = Probability of an accident, given that a lane departure occurs within the hazard envelope of the i^{th} object.

Similarly, a general equation can be developed that pertains to run-off-the-road-left, hit-fixed-object crashes involving the i^{th} object on the far roadside of two-lane rural roads. The predicted total number of accidents for this i^{th} object would be the sum of the estimates of the near side impacts involving vehicles traveling in the adjacent direction that run off the road to the right and far-side impacts involving vehicles traveling in the opposite direction that run off the road to the left.

From Glennon's roadside hazard model, the total length of the hazard envelope for an individual object is comprised of three contiguous sections. The different sections correspond to the different points on the object that the errant vehicle may strike, depending on which section of the hazard envelope the vehicle was in when it began to encroach on the roadside. Given a sufficient lateral displacement while in the hazard envelope of a roadside object, an encroaching vehicle will strike either:

- The face of the object perpendicular to the roadway.
- The near side, upstream corner of the object.
- The face of the object parallel to the roadway.

Figure 8 shows the relationships between an encroaching vehicle, a roadside object, and the three sections of the associated hazard envelope. The total length of the hazard envelope, L_i, is calculated as follows:

$$L_i = L_o + \frac{W_v}{\sin\Theta} + \frac{W_o}{\tan\Theta} \qquad (9)$$

where:

L_i = Length of the hazard envelope for the i^{th} object, in meters (feet).

L_o = Length of the i^{th} object, parallel to the roadway, in meters (feet).

W_v = Width of the vehicle, in meters (feet).

W_o = Width of the object, in meters (feet).

Θ = Angle of encroachment.

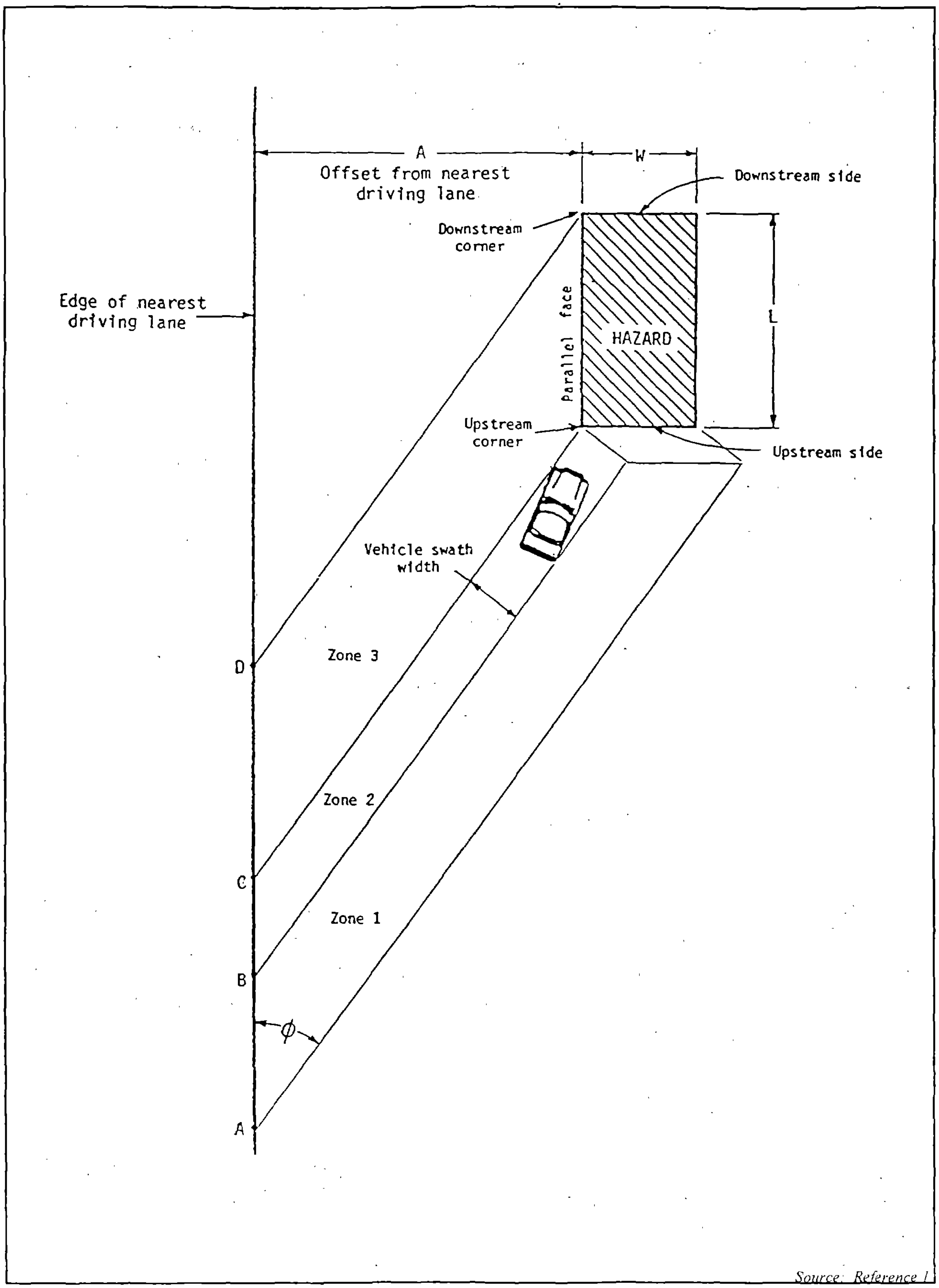


Figure 8. Geometry of an encroachment assumed by the roadside hazard model.

The probability of an accident, P_i, given a lane departure in the hazard envelope of the i^{th} object, is determined from the distribution of lateral displacements of errant vehicles. This represents the fraction of lane departures that are expected to reach a lateral displacement greater than or equal to the lateral offset of the i^{th} object. There are two main sources for this information, also known as the lateral extent probability distribution:

- AASHTO's *Roadside Design Guide (RDG)*.[1]
- Hutchinson and Kennedy's study of median encroachments.[2]

Glennon presented a lateral extent probability distribution in *NCHRP Report 148* for divided freeway analyses that was based on the data Hutchinson and Kennedy collected. He also presented distributions in a subsequent study that sought to extend the procedures developed in *NCHRP Report 148* to all classes of highway.[4] Those distributions resulted from his analyses of accident data.

For comparative purposes, the analyses of this study were conducted using both AASHTO's distribution and the distribution Glennon presented in *NCHRP Report 148,* along with their respective assumptions (e.g., average angle of encroachment, vehicle swath width, etc.) Using equations (8) and (9) to solve for D, the lane departure frequency, yields the following equation when summed over all of the objects in the sample:

$$D = \frac{\Sigma A_i}{T * \Sigma (L_i * P_i)} \tag{10}$$

The numerator is equal to the total number of observed accidents (i.e., reported and unreported) with the objects in the sample during the time period being considered. Three years was judged to be an appropriate time period. Beyond that, there is greater uncertainty with respect to the roadway, roadside, and traffic volume conditions compared to the current conditions for which data was collected. The summation in the denominator can be determined from the roadside inventory data that was collected, based on the above discussion concerning hazard envelopes and lateral extent probabilities.

The result of these calculations, D, is the number of lane departures to one side for one lane. For two-lane roads, a lane departure occurs when a vehicle leaves its lane of travel by crossing either the near-side edge line or the center line. Assuming that an errant vehicle is equally likely to depart to the left or right, the total number of lane departures per lane is equal to twice the result of the above calculation. This does not, however, equal the roadside encroachment frequency.

A roadside encroachment occurs when an errant vehicle crosses an edge line and travels onto the shoulder (if one exists) or beyond. For a two-lane road, this is the result of a vehicle crossing the near-side edge line, or traversing the adjacent lane and crossing the far-side edge line. Thus, the total number of roadside encroachments per side is less than twice the value of D. This is due to the fact that not all vehicles that cross the center line continue beyond the far-side edge line onto the roadside. Some vehicles recover before they reach a lateral displacement equal to the adjacent lane width. For two-lane roads with equal traffic volumes in both directions of travel, the roadside encroachment frequency can be estimated by the following equation:

$$EF_{rs} = D * (1 + P_{s>w}) \quad (11)$$

where:

EF_{rs} = The roadside encroachment frequency, per side.

D = The lane departure frequency to one side, per lane.

$P_{s>w}$ = The fraction of errant vehicles expected to reach a lateral displacement, s, greater than the adjacent lane width, w, according to the lateral extent probability distributions.

Thus, the roadside encroachment frequency, per side, is the sum of all the near-side lane departures and the fraction of far-side lane encroachments whose lateral displacement is greater than the lane width. This reasoning can be extended to estimate the roadside encroachment frequency for any lateral displacement beyond the edge line.

IDAHO DATA COLLECTION

Additional data required by the roadside hazard model had to be collected in the field, as it was not available in any existing data base. Determining the number of hit-utility-pole and hit-sign-post accidents, adjusted for those that are not reported, accounts for only part of the input to the model. The description of the roadside corresponding to those accidents, with respect to the objects included in the study, is equally important.

To apply the roadside hazard model, the location and dimensions of every sign post and utility pole in the study sections in Idaho had to be collected in the field. The dimensions of each object were needed to calculate L_i, the length of each hazard envelope. The location of each object was also essential. In particular, the lateral offset of each object was used to determine the probability of an accident, P_i, given a lane departure in the hazard envelope of the object. The longitudinal location of each object served to identify it for analysis of the sign maintenance and reported accident records. It was also used to investigate the extent of shielding in the sample. This occurs when hazard envelopes overlap, such that one object is fully or partially prevented from being struck because of the location of other roadside objects. The type of roadside data collected was described in chapter 2 of this report under the heading "Estimating the Percentage of Unreported Accidents."

APPLICATION OF THE ENCROACHMENT-BASED ROADSIDE HAZARD MODEL

Because encroachment frequency is a function of ADTs, an analytical approach considering discrete traffic intervals was necessary. Ideally, a large sample of data could be stratified into intervals in increments of 500 vehicles per day (e.g. 3,000 to 3,500, 3,500 to 4,000, etc.). Separate analyses would then be carried out to determine the encroachment frequency for each traffic volume interval, based on data collected for objects on roadway sections with ADTs within that interval. The limited amount of data that could be collected for the sample in this study was grouped into two categories:

(1) Sign posts and utility poles exposed to a traffic volume between 2,000 and 4,000 vehicles per day.

(2) Sign posts and utility poles exposed to a traffic volume between 4,000 and 6,000 vehicles per day.

To estimate encroachment frequency using the data collected for sign posts, the number of hit-sign-post accidents (as determined by the method described earlier) becomes the value for ΣA_i in the numerator of equation (10). The total number of hit-sign-post accidents was taken to be the sum of those identified in the sign maintenance records and the reported accident data base. There was a total of 16 hit-sign-post accidents for the study sample during the time period considered.

The value of T in the denominator of equation (10) is 3 years, which corresponds to the time period for which sign maintenance records and accident records were reviewed. The remainder of the denominator is the sum of the individual values of $L_i * P_i$, for each of the sign posts in the initial sample. A computer spreadsheet was developed to manipulate the data from the roadside inventory for this purpose. The spreadsheet calculated and summed the values for all of the hazard envelope lengths and lateral extent probabilities.

As mentioned above, the analysis was conducted for two different lateral extent probability distributions to illustrate the range of results that can be expected, depending on the particular assumptions made for the analysis. The first probability distribution was taken from appendix A of AASHTO's *RDG*. AASHTO actually offers four different distributions, corresponding to different design speeds ranging from 64.4 km/h (40 mi/h) to 112.7 km/h (70 mi/h). This study used the distribution presented for roads with a 80.5 km/h (50 mi/h) design speed. The second distribution, which was based on his analyses of the encroachment data collected by Hutchinson and Kennedy, was taken from Glennon's efforts in *NCHRP Report 148.*

The sources from which these distributions were taken also use different assumptions for the parameters that affect the calculated length of the hazard envelope. These assumptions were used with their respective lateral extent probability distributions for this analysis. The length of each hazard envelope, L_i , is a function of the dimensions of the sign post, the assumed average width of a vehicle, and the assumed angle of encroachment. The actual dimensions of the sign posts were used, accurate to the nearest 12.7 mm (0.5 in), as collected in the field. The remaining parameters affecting L_i were as follows:

(1) From AASHTO's *RDG*, for roads with a 80.5-km/h (50-mi/h) design speed:

Near-side encroachment angle	=	15.2°
Far-side encroachment angle	=	15.2°
Effective vehicle width	=	3.66 m (12.0 ft)

(2) From *NCHRP Report 148* and the subsequent research efforts:

Near-side encroachment angle	=	6.1°
Far-side encroachment angle	=	11.5°
Effective vehicle width	=	1.83 m (6.0 ft)

Glennon's roadside hazard model in *NCHRP Report 148* had been developed for analyses of freeway roadsides. In that report, his analysis of the Hutchinson and Kennedy data revealed that a single angle of 11 degrees would suffice for both near- and far-side encroachments. However, his further research sought to make the model applicable to all classes of highways. It is from the section on two-lane rural roads in the subsequent research effort that the above encroachment angles were taken. They were based on his analysis of diagrams from accident reports. Similar analysis was used to develop a lateral extent probability distribution specifically for two-lane rural roads. It was not used in this study, however, because of the small sample from which it had been derived and the fact that it did not vary substantially from the Hutchinson and Kennedy distribution. Thus, the Hutchinson and Kennedy distribution was used.

Few of the hazard envelopes overlapped; therefore, to simplify the analysis, the hazard envelope lengths were not adjusted to account for the effects of shielding. Another simplification for this analysis concerned the probability of an accident given a lane departure in the hazard envelope of a given object. A more rigorous application of the model would have considered the varying lateral displacements of the vehicle that would correspond to collisions with different points along the object. The hazard envelope would have been split into a number of subsections, with the length of each subsection multiplied by the probability that a vehicle would reach or exceed that lateral displacement. As an approximation, this study used the overall length of the envelope multiplied by the probability that a vehicle would reach a displacement greater than or equal to the lateral offset of the near side of the object.

As mentioned above, the roadside inventory data was categorized into two groups based on traffic volume. Within each traffic volume category, sign posts and utility poles were analyzed independently. The first traffic volume category contained the data for objects that were exposed to an ADT of 2,000 to 4,000 vehicles per day. The traffic volume range for the second category was 4,000 to 6,000 vehicles per day. The following example calculations are for the sign post data in the lower traffic volume category, using the AASHTO parameters. The weighted average traffic volume of this category was approximately 3,050 vehicles per day, or 1,525 vehicles per lane per day. Three of the 16 hit-sign-post accidents identified in the maintenance records and reported accidents data base occurred on roads sections in this traffic volume category. Based on the assumptions listed above and the lateral extent probability distribution from AASHTO's *RDG*, equation (10) for this data category was calculated as follows:

$$D_{1525} = \frac{\Sigma A_i}{T * \Sigma (L_i * P_i)} = \frac{(3 \text{ acc})}{(3 \text{ yr}) * (0.547745 \text{ km acc/lane enc})}$$

D_{1525} = 1.83 lane dep/km/yr (2.94 lane dep/mi/yr) (lane departures to one side, per lane)

This frequency converts to a lane departure rate (to one side) per hundred million (HM) vehicle kilometers, as defined in the Hutchinson and Kennedy report, of:

$$D_{1525} = \frac{(1.83 \text{ lane dep/km/yr}) * (100 \times 10^6 \text{ km/HM km})}{(1{,}525 \text{ veh/day}) * (365 \text{ day/yr})}$$

D_{1525} = 329 lane dep/HM veh-km (528 lane dep/HM veh-mi) (lane departures to one side, per lane)

Another way to express the above lane departure rate (to one side), as in AASHTO's *RDG*, is as follows:

$$D_{1525} = \frac{(1.83 \text{ lane dep/km/yr})}{(1{,}525 \text{ veh/day})}$$

D_{1525} = 0.00120 lane dep/km/yr/ADT (0.00193 lane dep/mi/yr/ADT) (lane departures to one side, per lane)

COMPARISON OF STUDY RESULTS WITH EXISTING ENCROACHMENT VALUES

Some common ground must be established to compare the results of this study with the previously found values for encroachment frequency. The lane departure values determined by this study represent the rate at which errant vehicles are expected to leave their lane to one side. This is the same as the definition of the base encroachment rate presented in AASHTO's *RDG*, which could allow for a direct comparison of these values.

Comparison with the encroachment values Glennon used is not as straight forward. Glennon developed a cost-effectiveness-based approach to analyzing the roadsides of divided freeways. For encroachment frequency, one of the parameters in his probabilistic roadside hazard model, he referred to the Hutchinson and Kennedy study. The Hutchinson and Kennedy study, however, had been conducted to determine the encroachment frequency for divided highway medians. Lacking any empirical estimates, Glennon had to apply their results for median encroachment analysis to his analysis of divided highway roadsides.

Glennon reasoned that the encroachment frequency for the combined roadsides was the same as the median encroachment frequency. That is, half the median encroachments were expected to come from each side of the divided highway. Furthermore, for a given side of the highway, he assumed an equal number of encroachments onto the roadside as into the median. Thus, considering both sides of the highway, the total roadside encroachment frequency was approximated as being numerically equal to the median encroachment frequency. Glennon then used a factor of 0.5 in the model to estimate the encroachment frequency for one roadside. Because his model used a roadside encroachment frequency derived from Hutchinson and Kennedy, rather than a lane departure frequency, the results of this study and AASHTO's values are not directly comparable to Glennon's.

The expected total roadside encroachment frequency (i.e., for both sides of the road) was chosen as the common ground for comparison of encroachment values. After all, it is the number of vehicles that reach the potentially hazardous roadside that is important for roadside safety analysis, not merely the number of vehicles that inadvertently leave their lanes. As described in equation (11), the roadside encroachment frequency for one side of the road can be estimated from the lane departure frequency. The results of that calculation are doubled to estimate the total roadside encroachment frequency for both sides of the road. The following example estimates the total roadside encroachment frequency corresponding to the lane departure frequency from the example calculations above (i.e., from the sign post data in the lower traffic volume category using the AASHTO parameters):

$$EF_{rs-1525} = D * (1 + P_{s>11}) \qquad (12)$$

where:

D = 1.83 lane dep/km/yr (2.94 lane dep/mi/yr)

$P_{s>11}$ = 0.3607 (from page A-9 of AASHTO's *RDG*, 80.5 km/h (50 mi/h) design speed)

therefore:

$$EF_{rs-1525} = (1.83) * (1 + 0.3607)$$

$EF_{rs-1525}$ = 2.49 roadside enc/km/yr (one side)

$EF_{rs-1525}$ = 4.98 roadside enc/km/yr (both sides)

Although converting the lane departure values to an equivalent number of roadside encroachments establishes a common ground, a direct comparison between a two-lane undivided highway and a four-lane divided highway is still less than ideal. Hutchinson and Kennedy noted in their report that divided highways are designed to "relieve the driver of many of the operational decisions necessary on two-lane highways, leading to inattentiveness that increases the probability of an encroachment." No attempt was made to account for this difference in encroachment frequency between divided and undivided highways.

Another difference concerns the traffic volume per lane, given an equal overall traffic volume. As an approximation, the roadside encroachment frequency for the two-lane roads in this study was compared with that of Hutchinson and Kennedy for four-lane roads with twice the traffic volume of that in the study sections. That is, the total roadside encroachment frequency calculated in the example above was for a two-lane road with a total traffic volume of 3,050 vehicles per day, or 1,525 vehicles per lane. This was compared to the encroachment frequency from Glennon/Hutchinson and Kennedy for a four-lane road with a total traffic volume of approximately 6,100 vehicles per day, or 1,525 vehicles per lane.

The differing lane departure values were, therefore, compared with the existing roadside encroachment values as follows:

(1) Using the lane departure values determined by this study which includes AASHTO's parameters (i.e., lateral extent probability, encroachment angles, vehicle swath width), the total roadside encroachment frequency was calculated, considering both roadsides and both directions of traffic.

(2) Step 1 was repeated for the lane departure values determined by this study using Glennon's parameters.

(3) Step 1 was repeated for the base encroachment values in AASHTO's *RDG*.

(4) The results of steps 1, 2, and 3 were compared to the expected number of roadside encroachments for a road with twice the traffic volume of that in the study sections, based on Glennon's assumptions in *NCHRP Report 148* (the number of median encroachments from Hutchinson and Kennedy's graph, as described previously).

Table 3 summarizes the results of these calculations for the sign post data, for both traffic volume categories and both sets of parameters. Table 4 presents the corresponding results from the utility

Table 3. Comparison of results for sign post data from this study with existing encroachment values.

Source	Total ADT	Lane departures per km per year	Lane departures per hundred million veh km	Roadside encroachments per km per year	Roadside encroachments per hundred million veh km
Values from this study (AASHTO's parameters)	3,050	1.83	329	4.98	447
	5,300	1.79	185	4.87	252
Values from this study (Glennon's parameters)	3,050	0.57	102	2.16	194
	5,300	0.58	60	2.21	114
Base encroachment values from AASHTO's RDG	3,050	0.47	85	1.29	116
	5,300	0.82	85	2.23	116
Glennon's values (from Hutchinson and Kennedy's study)	6,100	n/a	n/a	1.78	80
	10,600	n/a	n/a	2.99	77

(1 km = 0.621 mi)

Table 4. Comparison of results for utility pole data from this study with existing encroachment values.

Source	Total ADT	Lane departures per km per year	Lane departures per hundred million veh km	Roadside encroachments per km per year	Roadside encroachments per hundred million veh km
Values from this study (AASHTO's parameters)	5,400	0.59	60	1.61	82
Values from this study (Glennon's parameters)	5,400	0.18	18	0.68	34
Base encroachment values from AASHTO's RDG	5,400	0.84	85	2.28	116
Glennon's values (from Hutchinson and Kennedy's median study)	10,800	n/a	n/a	3.04	77

(1 km = 0.621 mi)

pole data. As described earlier, the total number of hit-sign-post accidents per traffic volume category was taken to be the sum of the reported accidents and the number of sign knockdowns according to the maintenance records. The number of hit-utility-pole accidents was taken to be the number of reported accidents multiplied by the adjustment factor described earlier.

Figure 9 shows the Hutchinson and Kennedy encroachment frequency graph Glennon used for roadside analysis. Also shown are the comparable, total roadside encroachment frequencies found by this study using the method described above. The corresponding roadside encroachment rate values are shown in figure 10.

Although the results of this study are not conclusive, given the small sample size, it is interesting to note where the different encroachment values are, relative to each other. For traffic volumes above 5,000 vehicles per day, AASHTO's base encroachment rate predicts a roadside encroachment rate close to the median encroachment rate that Hutchinson and Kennedy had found empirically. However, the linear function that AASHTO uses to describe the relationship between traffic volume and encroachment frequency is significantly different from what Hutchinson and Kennedy found for traffic volumes below 5,000 vehicles per day.

The roadside encroachment frequencies calculated with the AASHTO parameters are significantly greater than the values obtained from using the Glennon/Hutchinson and Kennedy parameters. This is due in part to the nature of the AASHTO lateral extent probability distribution. Compared

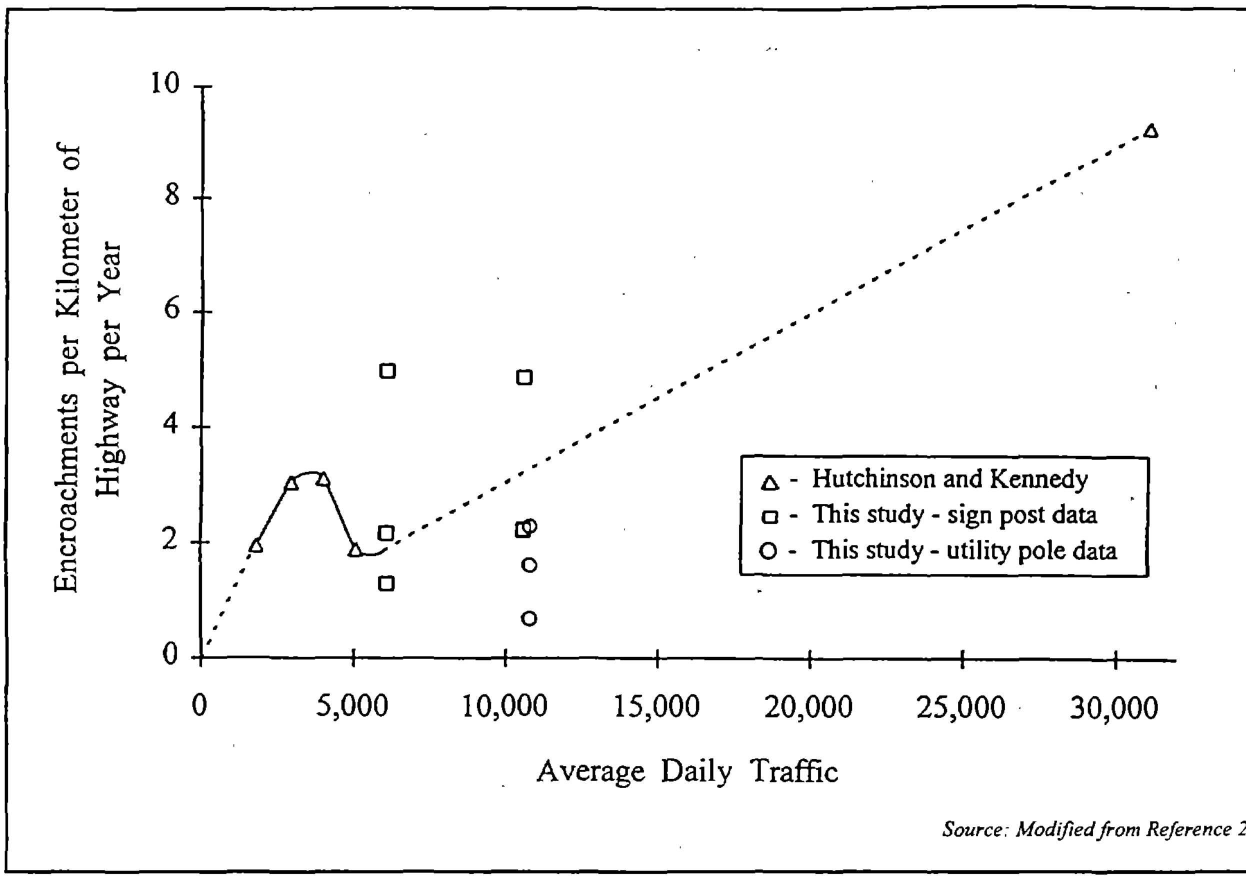


Figure 9. Comparison of existing encroachment frequency values with results from this study.

to that of Hutchinson and Kennedy, this distribution implies that the errant vehicle of a given encroachment is less likely to reach the lateral displacement necessary to impact a fixed object. Another way of viewing this implication is that a smaller percentage of all encroaching vehicles is predicted to reach a lateral displacement large enough to impact a fixed object. As a result, a comparatively higher number of total encroachments is necessary for a given number of observed accidents, assuming the AASHTO probability distribution.

Compounding the effect of the difference in the probability distributions is the sharper encroachment angles assumed by AASHTO. This leads to a shorter hazard envelope than that of Glennon's model. The effect of this difference is that AASHTO predicts a smaller percentage of encroaching vehicles will strike a given fixed object, regardless of the lateral displacement they reach, because they are less likely to be in the hazard envelope when they begin the encroachment. This, too, results in a higher calculated number of encroachments for a given number of observed accidents. Countering the effect of the differences in the probability distributions and the effect of different encroachment angles is the wider vehicle swath width that AASHTO assumes. Because this increases the probability of an accident given an encroachment, it lowers the number of encroachments necessary for a given number of accidents. However, this is more than offset by the differences in the lateral extent probability distributions and encroachment angles.

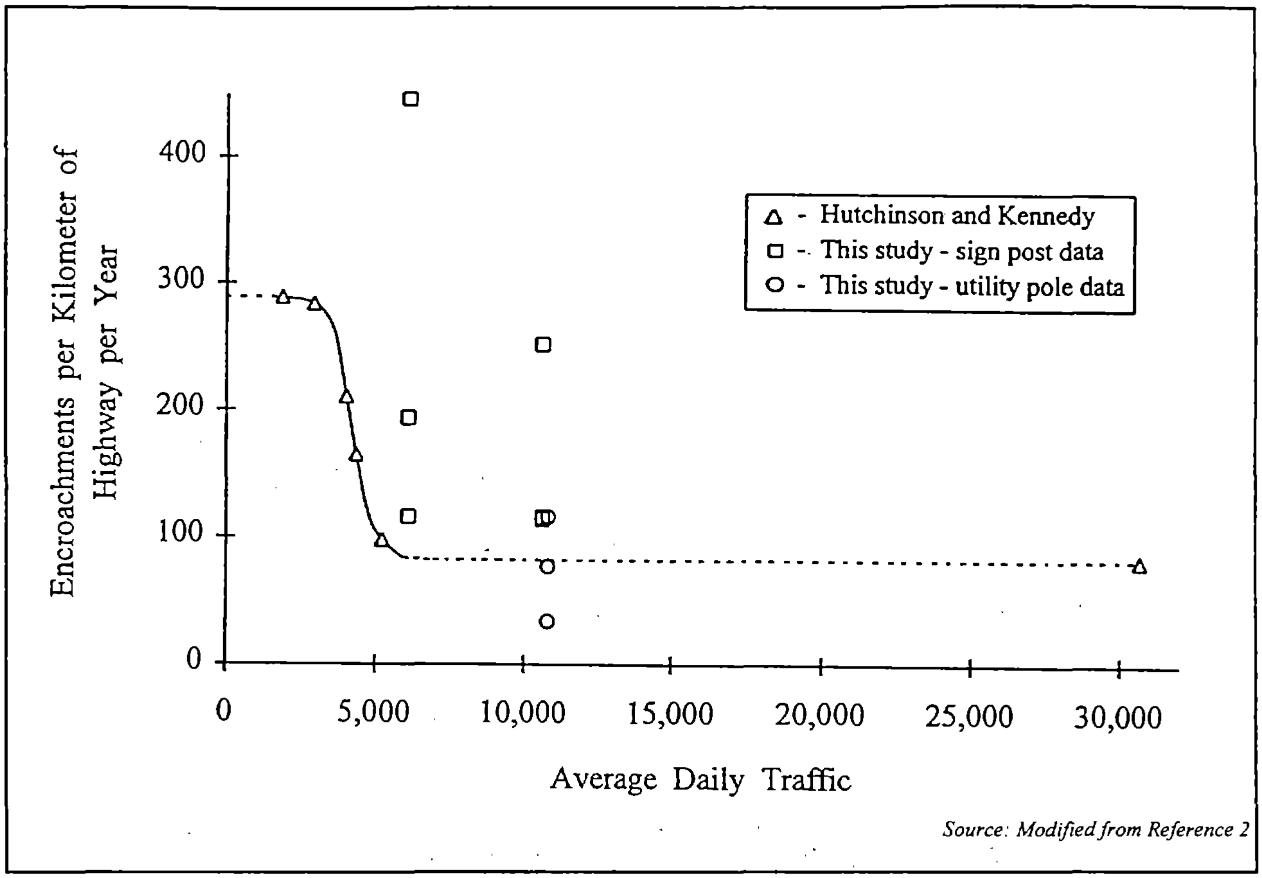


Figure 10. Comparison of existing encroachment rate values with results from this study.

CHAPTER 4. ISSUES AND CONCLUSIONS

While the previous chapters described a viable approach to estimating encroachment rates using run-off-the-road accident data, there are several critical issues that need to be understood and properly addressed. This chapter attempts to synthesize concerns about those issues.

LATERAL EXTENT PROBABILITY DISTRIBUTIONS

It has been demonstrated that the roadside hazard model can be used with reported accident data to estimate encroachment frequency. The necessary accident, sign maintenance, and roadside data can be collected, and the model can be manipulated in such a fashion as to yield an estimate of encroachment frequency. Thus, the method is conceptually appropriate. However, the accuracy of the results depend on the accuracy of the input parameters. Assumptions are required to use this methodology, namely the acceptance of the existing lateral extent probability distributions. Two distributions were used in this exploratory investigation, and they differed greatly. Figure 11 shows these distributions relative to each other, as well as the remaining distributions from AASHTO's *RDG* for the other design speeds.[1] Also shown is a distribution developed by Glennon for two-lane rural roads, which was based on his analyses of accident data.[4] As can be seen, there is a noticeably large difference between the two distributions over much of the range of lateral displacements. Compared to the lateral displacement relationships currently assumed in AASHTO's *RDG*, Hutchinson and Kennedy's data predict more than three times as many errant vehicles will reach a lateral displacement of at least 6.1 m (20 ft).[1,2]

The basis for the *RDG*'s probability distribution is not discussed, which makes it difficult either to criticize or support these lateral extent probability distributions. The distribution presented by Glennon is based on the encroachment data that Hutchinson and Kennedy collected. Therefore, there exists some empirical evidence to support the Glennon distribution.[2,3] However, there are two concerns that should be recognized in using this distribution: (1) the methods used to collect the encroachment data were questionable; and (2) the distribution was developed based on data collected from only two roadway segments that had similar median cross sections.

Hutchinson and Kennedy showed that roadside slopes clearly affected the distribution of lateral displacements. Thus, it is reasonable to assume that a roadway with a roadside cross-section different from the median cross-section studied by Hutchinson and Kennedy will have a different distribution of lateral displacements. For instance, vehicles encroaching on a roadside with a steep negative side slope on fill will reach greater lateral displacements than on a roadside with a milder side slope. Probability distributions that consider the roadside should therefore be developed. It is intuitively obvious that there would be similar differences in lateral extent when comparing two different side slopes. Thus, side slope should be explicitly considered when using an encroachment-based approach. For this reason, the small amount of data collected for a

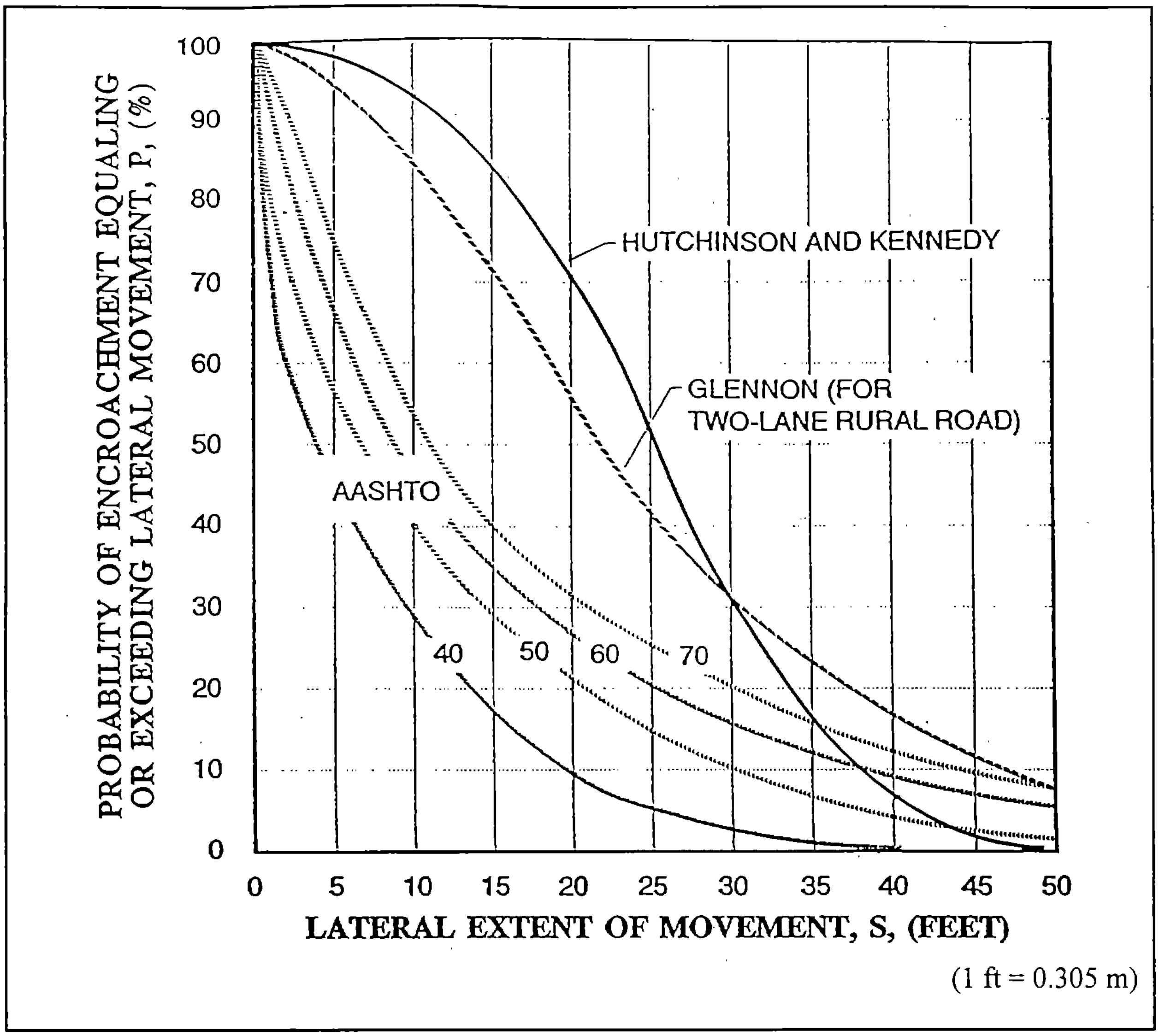


Figure 11. Comparison of lateral extent probability distributions.

narrow range of side slopes should not be applied to situations that differ significantly from the conditions for which that data was collected.

While the relationship between side slopes and paved shoulder width and roadside encroachments has not yet been established, there were research activities, which were underway at the time this report was prepared, that seek to address the above noted deficiencies concerning lateral extent probability. One effort, in particular, is NCHRP 17-11. Entitled "Determination of Safe/Cost Effective Roadside Slopes and Associated Clear Distances," this project includes task activities that seek to address the issue of how side slope affects the lateral extent of movement. One possible approach suggested by the amplified work plan would be to reanalyze existing encroachment data. The work plan noted that it may be possible to use the other to estimate the effects of several variables, including horizontal curvature, vertical grade, traffic volume, and simulation studies using the Highway-Vehicle-Object-Simulation-Model (HVOSM). The Texas Transportation Institute (TTI) had conducted preliminary simulations to study lateral extent probability as a function of side slope for large and small passenger cars. This effort was to be expanded to include additional variables.

Another research effort, NCHRP 22-9, also proposed new activities to address deficiencies in the area of lateral extent probability. Entitled "Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features," this project was intended to develop improved microcomputer-based cost-effectiveness analysis procedures. To this end, the interim report noted the deficiencies in the available data for lateral extent probability and, similar to NCHRP 17-11, suggested reanalysis of the existing encroachment data that was collected during prior research.

CURRENT SIGN INVENTORY AND MAINTENANCE RECORDS SYSTEMS

Also of great concern is the use of sign maintenance data for determining the number of accidents on a particular segment. Some judgment was necessary in converting the number of maintenance activities to a number of observed accidents. For instance, two stop signs that were replaced during the time period considered were not included in the accident count. It was not possible to determine if the "damage due to motor vehicle" was the result of a vehicle on the main road or on the cross road. These accidents were excluded, based on the lateral offsets of the signs and the location of other fixed objects in the vicinity. In another instance, multiple work was performed on a single sign on different dates. Approximately 6 weeks after a sign post was replaced, the sign panel was replaced as well. Both of these were attributable to "damage due to motor vehicle." It was considered unlikely that there were two accidents with the same sign in such a short period of time. Consequently, the multiple work was counted as one hit-sign-post accident. Furthermore, as mentioned earlier, the reported accident data could not be matched to the sign maintenance data for determining the percentage of unreported hit-sign-post accidents.

Advances have been made and continue to be made in the field of sign management systems. Technologies that facilitate the collection of sign inventory data are reaching a mature stage of development. It is anticipated that more highway agencies will implement these data collection technologies and automated sign management systems within the next 5 years. With respect to utility poles, the method for estimating the percentage of unreported hit-utility-pole accidents met with limited success, which was largely attributable to the small sample size of NASS cases with sufficient information.

TRAJECTORY DATA FOR ERRANT VEHICLES THAT ENCROACH ON ROADSIDES

Another reservation concerns parameters used in the roadside hazard model, such as the encroachment angle and effective vehicle width. AASHTO uses an effective vehicle width, or swath path, of 3.7 m (12 ft). Glennon suggests a much smaller vehicle width of 1.83 m (6 ft). In this case, the AASHTO value seems more appropriate because it is based on a standard vehicle to be straight, Glennon also apparently assumes the vehicle to be tracking during the encroachment, given the narrow vehicle width that he offers.

For the encroachment angle, AASHTO's *RDG* uses a single value for both near- and far-side departures, depending on design speed. AASHTO encroachment angles range from 17.2 to 11.6 degrees for design speeds of 64.4 to 112.7 km/h (40 to 70 mi/h), respectively. Glennon, while not accounting for different design speeds, does offer different angles for near- and far-side departures of 6.1 and 11.5 degrees, respectively. He did note, however, that for objects that can be hit from both directions, separate angles for near- and far-side encroachments offer little additional refinement over a single representative encroachment angle. For this study, the separate encroachment angles were used.

The many different parameters in the roadside hazard model could be subjected to much refinement in the name of calibrating the model to a given set of data. In this case, Glennon's parameters and those from AASHTO differed significantly. Yet the differences offset each other to yield estimates of encroachment frequency that were both comparable in terms of order of magnitude to the existing encroachment frequency values. Perhaps some combination of the two parameter sets would have resulted in encroachment values closer to the existing estimates. In fact, it is conceivable that a set of unrealistic parameters could be fit to match a set of data. For instance, an unrealistically narrow vehicle width could be used with an unrealistically high probability of an accident given an encroachment. If the effects offset each other, the model could still give accurate results.

ACCURACY AND RELIABILITY OF REPORTED ACCIDENTS

Even if the model was assumed to be perfect, with the exception of the need for a more accurate estimate of encroachment frequency, the estimated encroachment frequency would only be as accurate as the accident data used as a basis to derive it. The difficulties encountered in estimating the percentage of unreported accidents only adds to the uncertainty of this method to estimate encroachment frequency.

ROADSIDE DATA

In addition to accidents, there are also issues related to roadside inventory data. The collection of roadside data using manual, labor-intensive methods is costly. For the pilot study conducted in Idaho, measurements of milepoint and lateral offset were made for numerous utility poles and small signs. Approximately 6 person-weeks of effort were expended to obtain data for these roadside objects on only 80.1 km (50 mi) of two-lane rural roads in Idaho. Care must be exercised to ensure that guardrails and other objects that effectively screen utility poles are properly considered. For example, there were numerous cases in Idaho where objects placed behind guardrails or utility poles were located high on the backslope, which limited the probability that they would be struck by an errant vehicle. To develop estimates for encroachment rates using accident data, roadside inventory data are critical. Given current procedures, it may be cost-prohibitive to collect accurate roadside inventory data to achieve a sufficient sample size for encroachment rate estimation purposes.

CONCLUSIONS

Despite these issues, it is concluded that the proposed methodology to develop encroachment rate estimates for two-lane rural roads using reported accident data as a fundamental basis is feasible. The initial results, which were based on very limited sample sizes, were encouraging in terms of order of magnitude. Moreover, it is emphasized that these analyses were conducted primarily to assess the feasibility of the proposed approach. It should not be construed that the results have sufficient foundation to advocate their use.

Among the most pressing issues that beset this proposed approach are the following:

- Reliance on questionable trajectory data for vehicles that run-off-the-road.
- The accuracy and reliability of sign maintenance records in electronic media.
- The accuracy and reliability of police-reported accidents, especially with respect to location.
- The availability and accuracy of roadside inventory data in electronic media, especially with respect to location of guardrails, side slopes, and lateral offsets to fixed objects.

At the time that this report was prepared, research on vehicle trajectory data was underway. It was hoped that the results of those research studies would result in a better understanding of the lateral extent probabilities, angles of departures, and other vehicle dynamics related to the path, speed, and outcome of vehicle encroachments. Consequently, although an experimental plan was developed and is included in appendix B of this report in conformance with contract requirements, it is strongly suggested that this experimental plan be deferred to a later date. Desirably, work on the experimental plan should be deferred until after the results of the trajectory research become known. Since the proposed approach relies on assumption of post vehicle trajectories, it would be beneficial to employ the best and latest available trajectory data while performing this proposed research. Delaying the start of this research will also allow States a longer time to make improvements in accident record systems, sign management systems, and roadside inventory computer-based data files. For these reasons, it appears appropriate to defer implementation of this plan for at least 3 to 5 years from the report date.

APPENDIX A. LITERATURE REVIEW

Medians of Divided Highways — Frequency and Nature of Vehicle Encroachments
J. W. Hutchinson and T. W. Kennedy, 1966[2]

For this study, Hutchinson and Kennedy investigated the frequency, nature, and causes of vehicle encroachments on medians of divided highways. The goal was to obtain the information needed to establish traffic safety criteria for median width and cross-section design. The effects of median width and cross section, traffic volume, roadway alignment, weather, roadside signs, grade separation structures, and other features of the highway and driving environment were considered. The collected data were analyzed to determine the relationships between traffic volume and the frequency and nature of median encroachments.

The study approach consisted of weekly examinations of selected highway segments for evidence of vehicle encroachments (i.e., tire tracks in the mud and snow). Surveillance was often more frequent to avoid losing evidence because of snow storms, melting snow, and maintenance activities. Frequent contacts with maintenance personnel and a knowledge of their operations were thought to decrease the possibility of including their tire tracks as encroachments. With this method, however, there was still no way to be certain whether the remaining tire tracks were the result of controlled or uncontrolled encroachments.

Encroachments were divided into two basic classes: (1) inadvertent encroachments caused by lack of adequate driver alertness; and (2) encroachments because of emergency action taken to avoid a collision. Low-volume rural highways were expected to have a higher probability of the first type, whereas high-volume urban expressways were expected to have a higher probability of the second type. Thus, an attempt was made to study both extremes in traffic volumes, and highway segments were chosen accordingly.

The data collected in the field were fairly comprehensive. A sketch of the vehicle path at each site included the angle of encroachment, maximum extent of lateral and longitudinal travel, as well as other pertinent data. A visual record of each site was compiled with photographs. To avoid duplicate reporting, the record number of the encroachment was painted on the pavement during the investigation.

The encroachment frequencies were determined using all recorded incidents for both urban and rural segments. Available resources limited the encroachment frequency portion of the study to four-lane highways. The included segments of the two roads that were selected had equal pavement widths, complete control of access, and similar, essentially tangent alignments. One median was 12.2 m (40 ft) wide and depressed about .9 m (3 ft), while the other was only 5.5 m (18 ft) wide and depressed about 15.2 cm (6 in). This difference was thought to affect the outcome of each encroachment (e.g., the extent of lateral displacement and length of longitudinal travel), but not the encroachment frequency itself. The study suggested that the most important factor affecting encroachment frequency was the difference in levels of roadway delineation. The rural highway had reflective delineators, whereas the urban highway had only wooden cable-barrier posts.

The rural highway data was collected continuously by project personnel for a period of 3 ½ years. The urban data collected by the Illinois Division of Highways, however, only covered December 1 to March 31 of the three prior winters. Thus, the reported encroachment frequencies of the high volume urban expressway are probably higher than they should be because the data collection was limited to the season when encroachments are most common.

The rural and urban data were both plotted against traffic volume, giving the classic encroachment frequency graph. The authors recognized that there were differences between the two sets of data, primarily with respect to roadway delineation and data collection procedures (i.e., collecting urban data only during the winter). They stressed that the plot of the urban data was not an extrapolation of the rural data and was only meant to show the general shape and direction of the relationship of the volume-frequency relationship. The same reasoning applies to the encroachment rate data, derived from the encroachment frequency, which presented the rates for both roads on the same graph. Later researchers used these graphs, for lack of other actual encroachment data, despite the shortcomings that the authors readily acknowledged in their report.

A thorough discussion of the volume-frequency relationship was presented by the authors as follows:

- In general, encroachments at low traffic volumes were attributed to the reduced alertness of isolated drivers operating their vehicles independently. At these low traffic volumes, the encroachment frequency was said to be a linear function of the number of vehicles on the road. Thus, increased traffic volume was associated with an increase in the number of encroachments.

- Contrary to this was the reduction in encroachment frequency with increased traffic volume at approximately 4,000 vehicles per day. This reduction was attributed to increased driver alertness and increased roadway delineation because of vehicle caravaning with increased traffic volumes.

- Eventually, the friction and conflicts between vehicles at higher traffic volumes offset the benefits of increased alertness and roadway delineation. Once again, encroachment frequency increased with traffic volume in a linear fashion.

The authors then explained how to calculate the traffic volume above which the encroachment rate may be expected to remain constant. This was based on the minimum headway below which increased traffic no longer affects encroachment rate. A comparison of the relatively constant encroachment rates for different highways would indicate the relative safety of different design features.

The nature of encroachments (i.e., encroachment angle, lateral extent of travel, and variation of encroachment types) was also related to traffic volume. For instance, encroachment angles were observed to increase with traffic volume. At low traffic volumes, inattentive drivers tended to drift off the roadway at more shallow angles. The sharper encroachment angles at higher traffic volumes were theorized to be the result of evasive action to avoid accidents. Also, roads with high traffic volumes still had some encroachments similar to those found on low volume roads because traffic volume was relatively low during certain parts of the day.

Encroachment nature was determined only for those incidents in which sufficient accuracy and detail were available from both the field data and the accident report. Segments of two rural highways, both with dual 7.3 m wide (24 ft wide) pavements and medians depressed about .9 m (3 ft), were selected for analysis. One road, over essentially level terrain, had a 12.2-m (40-ft) single-ditch median, while the other road, over very rolling terrain, had a 24.4-m (80-ft) double-ditch median.

Data were limited to (assumed) unintentional encroachments with lateral movements in excess of .9 m (3 ft), because of the extreme difficulty in detecting encroachments on the stabilized shoulder. A graph showing the distribution of encroachment angles was presented, with an equation that closely approximated the distribution. Deviation at low angles was attributed to the omission of shallow encroachments, and deviation at high angles was attributed to the possibility that encroachments at this angle were of a different nature. It was argued that encroachment angles greater than 25 degrees were most likely the result of a vehicle that was traveling at a slow speed, was involved in a relatively severe collision, or initially ran off the pavement to the right. While available data did not allow consideration of the first two possibilities, deviation at high angles was greatly reduced by excluding encroachments of vehicles that initially ran off the pavement to the right.

The distribution of longitudinal travel lengths was presented with data for both roads shown on one graph because there was no significant difference between roads. The great length of travel of encroaching vehicles combined with the number of objects located in the median was said to limit seriously the potential for safe stopping or recovery.

The distribution of maximum lateral displacements was presented for both roads individually and combined. The combination was said to be justified, as the first 12.2 m (40 ft) of the wider median had essentially the same cross section as the more narrow median. The distribution of lateral displacements was shown to be related to the median cross section. For example, the slope of the distribution curve was fairly flat where it corresponded to the steep negative superelevation of the median ditch side-slope. This indicated that few vehicles recovered in this region, as would be expected. Conversely, the steeper slope of the graph corresponding to the back-slope indicated that more vehicles were able to recover because of the positive superelevation in this region.

Attempts to determine significant relationships between the three basic parameters (angle of encroachment and lateral and longitudinal encroachment travel distances) were not successful, because of the many variables that could not be measured. They were, however, related to the point of initial recovery-to-the-right. The correlation coefficient of the regression line which approximated this relationship indicated a large amount of deviation. Thus, a definite relationship was found to exist, but it was not a reliable prediction of lateral or longitudinal travel distances.

Possible encroachment causes were discussed for one of the rural roads that was included in the study of encroachment frequency and nature. The authors state that the factors leading to an encroachment are normally so subtle that they seriously affect only one trip in 10,000. They based this argument on the fact that there were over 6 million vehicle trips through the study section in 3 ½ years, during which they detected only 302 encroachments. They did conclude, however, that individual driver, vehicle, and highway factors that consistently have overriding effects on driver behavior include lighting, fatigue, roadway alignment, weather, roadside signs, grade separation structures, and terrain features.

The study did not attempt to determine the cause of individual encroachments, because of the small number of encroachments at any given location. The average number of encroachments observed per unit length of highway was found to be very small when only 152.5 to 305 m (500 to 1,000 ft) of highway was examined in connection with a particular road feature, such as a curve or roadside sign. No appropriate statistical test was available to measure the significance of such a small number of encroachments. Only those factors that applied to the entire length of the study section were considered in the analysis of encroachment causes. The authors listed the following factors that they determined to have a significant effect on encroachment frequency:

- Encroachments were found to be unevenly distributed by direction. The number of encroachments for the westbound traffic was close to 40 percent more than the eastbound traffic. This was partly attributed to afternoon sunlight and fatigued drivers at the end of the day.
- The relatively high percentage of encroachments near the ends of the study section for both directions was also attributed to fatigue.
- The windbreak effect associated with some objects, such as overpass abutments, was found to increase the probability of an encroachment. As the prevailing wind and storms came from the west for the study area, this effect was magnified on westbound traffic, contributing to the higher encroachment frequency for vehicles headed in that direction.

Almost twice as many encroachments were found to originate immediately before a grade separation structure for the traffic headed into the prevailing winds. Additionally, quicker snow and rain accumulation on the windshields of westbound vehicles lowered the visibility of those drivers.

- Some erratic vehicle movement was found to be associated with large roadside signs, possibly caused by high air turbulence from the windbreak effect mentioned above. The authors also theorized that vehicles tended to veer away from large roadside signs for other reasons, such as optical illusion. For instance, downstream signs hidden by a grade separation structure seem to move out from behind the abutment as they come into view. This phenomenon was thought to affect driver behavior, possibly on a subconscious level.

- Contrary to intuition, curves by themselves were not found to have a significant effect on encroachment frequency. The combined length of influence area for all curves was 15.1 percent of the total mileage of the test section, within which 15.1 percent of the encroachments occurred. In the absence of other effects, such as windbreak from large roadside signs, the curves might possibly have had the lowest encroachment frequency for the entire study area. While the authors did not address it, curves are known to have higher accident rates and are associated with more severe accidents, compared to tangents. Perhaps this is more directly attributable to the outcome of encroachments, rather than the encroachment frequency. That is, with all other factors being equal, a given number of encroachments on curves will result in a higher number of accidents with a greater average severity than the same number of encroachments on a tangent section.

- Landscaping was found to increase roadway delineation, which can reduce encroachment frequency. However, these benefits can be largely offset by the increased windbreak effect, depending on the size and density of the trees.

The Hutchinson and Kennedy report also presented a discussion of alternative methods to detect vehicle encroachments. Because the chosen method of collecting encroachment data (i.e., weekly monitoring of medians for tire tracks) was expensive and labor intensive, other possible methods were investigated. Aerial photography using infrared film to detect encroachment tire tracks met with very limited success. There was no success in similar experiments with black and white film. A semiautomatic electronic system imbedded in the shoulder to detect vehicles encroaching on the median was somewhat successful. Cold weather performance of the equipment, however, was unsatisfactory. Because the additional personnel, facilities, and money needed to overcome this difficulty were not available, work in this area was terminated.

The results of this report indicate that the current study to estimate encroachment frequency from accident data could be complicated because of the traffic volume interval for which it is geared.

With this traffic volume interval, approximately 5,000 vehicles per day, there is much variation in the encroachment frequency. At these volumes, according to this report, the benefits of an increase in roadway delineation are gradually offset by the increased vehicle friction associated with higher traffic volumes. Thus, it may be difficult to determine an encroachment frequency at these volumes, because of the wide variation for this interval.

"Objective Criteria for Guardrail Installation," ***Highway Research Record 174***,
J. C. Glennon and T. N. Tamburi, 1967[5]

At the time this article was published, the warrants for guardrail installation were very subjective in nature. It required judgment of the relative effect of certain factors for each installation, which often varied greatly from one design engineer to another. The lack of an appropriate analytical procedure hindered attempts to minimize the consequences of running off the road. The purpose of this study was to develop a more objective basis for installing guardrail on embankments and next to fixed objects.

To establish an objective basis for guardrail placement, this study developed a mathematical relationship to evaluate accident severity and accident frequency. The relative safety of guardrail could then be compared with that of embankments and fixed objects.

Accidents were defined by three categories, which included property damage only (PDO), injury (I), and fatal (F) accidents. A weighted severity index was based on the ratio of direct costs of single vehicle accidents to the total number of accidents for the given condition. Including indirect costs was investigated and found to affect guardrail placement for embankments but not for fixed objects.

The probability index was defined as the ratio of the number of accidents for a given set of conditions to the number of vehicles exposed to the condition during the study period. This relationship assumed that the accident rate was independent of the time rate of exposure of traffic, although the study recognized that this was not actually the case. The reasoning to justify this was that for comparison purposes, if the volume distribution was similar for locations for each of the conditions compared, then the probability indices would not be affected by the volume versus accident-rate relationship.

The collision index was defined as the product of the severity index and the probability index. This gave the ratio of equivalent PDO accidents to exposure (i.e., traffic volume). The determination of the probability index, for all combinations of roadway and environmental variables, was said to be beyond the scope of the study. The relative safety of guardrail versus embankments was compared on the severity basis alone. Two years of accident data were used to determine the severity ratio for single vehicle accidents involving guardrail in front of embankments. One year of accident data were used in the statistical analysis to determine which embankment factors influenced accident severity.

Regression analysis of the relationship between accident severity and embankment variables showed a strong correlation for embankment height and slope. To determine the best fit for the data, linear, semi-log, and log-log equations were tried with several different severity ratios for the three accident classes. Then the calculated embankment severity index was substituted into the best fit, and the resulting two-dimensional equation of embankment height versus slope was presented in a graphical format.

This provided a convenient way to determine if a given embankment was likely to be safer with or without guardrails, depending on where the embankment conditions in question plotted relative to the graph.

Investigation of the relative safety of fixed objects and guardrail required several assumptions to simplify the comparisons and obtain sufficient sample sizes. For instance, accidents involving guardrails were not categorized according to the particular type of guardrail. The same treatment was applied to bridge rails, light poles, and steel posts because no consideration was given to different types of design. Furthermore, accidents involving abutments, piers, and columns were all grouped in the same category. Roadway geometry and lateral placement of fixed objects were not considered as variables. Also, fixed objects off the outside shoulder were assumed to be exposed to one-half the total two-way volume, whereas fixed objects in the median were assumed to be exposed to the total two-way volume (unless site conditions made exposure possible from one direction only). Finally, as mentioned above, the accident rate was assumed to be independent of the time rate exposure of traffic. This assumption was investigated and found to have negligible effects on the comparison of fixed objects and guardrails.

A field inventory of fixed objects on 1,771 km (1,100 mi) of freeway, combined with volumes from traffic census data, yielded the probability indices for each type of object, with and without guardrails present. Accident data for the same time period was used to calculate the corresponding severity indices. Comparison of the collision indices, calculated as the product of the probability and severity indices, was used to draw conclusions about where a guardrail is needed and where it is not. Expected reduction in the number of each accident type for the time period of the study was presented. This prediction assumed guardrail placement or omission at all of the sites was in accordance with the findings of the study.

***Development of Design Criteria for Safer Luminaire Supports*, NCHRP Report 77,**
W. F. McFarland, H. E. Ross, Jr., T. C. Edwards, and J. E. Martinez, 1969[6]

The major intent of this study was to provide a method for improving the economic analysis of roadway illumination. The study considered initial costs, accident costs, and maintenance costs. Different lighting systems could then be compared on the basis of cost-effectiveness. Appendix C describes the hazard model that was used for this study.

This study recognized that the validity of the cost-effectiveness-based comparisons was limited by the accuracy of the input data. The authors mentioned the lack of information in the area of encroachment rate; however, improving the accuracy of the estimation of encroachment rates was beyond the scope of the study, which focused on the number of expected accidents for a given estimated encroachment frequency.

The estimates for encroachment frequency were taken from the Hutchinson and Kennedy report. One-half the value obtained from their graph of median encroachment frequency versus traffic volume was used as an approximation for encroachments on an individual roadside. Traffic volume and, therefore, encroachment frequency were assumed to be linear functions with respect to time in the cost-effectiveness model. Accident costs were summed for each year of the expected useful life, based on projected traffic volumes.

Two normal distributions were used to approximate the actual distribution of lateral displacements found by Hutchinson and Kennedy. Both distributions had a mean of 7.015 m (23.0 ft), based on the findings of Hutchinson and Kennedy. The first distribution used a standard deviation of 2.745 m (9.0 ft) and was a close approximation of the actual distribution for lateral displacements up to 5.3375 m (17.5 ft). The second distribution, with a standard deviation of 3.355 m (11.0 ft), was a better approximation for lateral displacements between 5.3375 m (17.5 ft) and 7.32 m (24 ft). The report noted that the distributions would not be appropriate for roadside conditions that are significantly different from the median cross sections studied by Hutchinson and Kennedy.

The authors noted that insufficient data were available to determine the effective vehicle width. Therefore, the average length and width of the vehicle was used in this model as an approximation of the vehicle's swath. The authors suggested that a rigorous statistical analysis would consider the distribution of vehicle sizes for a given highway, although an average value for all vehicles could be used.

The geometry of an encroaching vehicle was presented, based on the encroachment parameters discussed above. Equations to predict the expected number of accidents were then derived, taking into account encroachment frequency, vehicle swath, pole spacing, average angle of encroachment, and the distribution of lateral displacements. The form of the model ultimately used in the report was an approximation of those equations that sharply reduced the complexity of the calculations. The report warned that this approximation could mathematically predict more accidents than encroachments, in which case the number of accidents should be set equal to the number of encroachments. This could occur for analysis of very closely spaced poles, or if the analysis considered very small encroachment angles, large vehicle swath widths, or some combination of these conditions.

The remaining economic analysis tied together the total costs involved. Two examples were presented to illustrate the use of the derived equations, and three case studies were conducted to evaluate the accuracy of the light-pole-accident-rate prediction. The reported accident rates compared to the rates predicted by the model are as follows:

	Case Study		
Accident Rate (acc/km/yr)	(1)	(2)	(3)
Reported Rate	0.87	0.19	0.43
Predicted Rate	0.50	0.56	0.69

Note: 1 acc/km/yr = 1.61 acc/mi/yr

The model presented in the appendix of this report only applies to luminaire supports, for which it was developed, and other point objects of similar size with uniform spacing. It would not be directly applicable to fixed objects in general, such as guardrails, embankments, and other obstacles with variable dimensions. The more important information obtained from this report came from the main body. In testing, the breakaway luminaire supports were nearly always knocked down, even at low impact speeds. Therefore, nearly all collisions with a pole of this type would require repairs that would be reflected in maintenance reports, facilitating analysis to estimate the percentage of unreported accidents for this type of object. This suggests that this type of object would be suitable if the current study to estimate encroachment frequency from accident data was extended to a more urban setting.

***Roadside Safety Improvement Programs on Freeways - A Cost Effectiveness Approach*, NCHRP Report 148**, J. C. Glennon, 1974[3]

This report described a rational approach to developing highway safety improvement programs. A probabilistic hazard index model was developed to rank safety improvements based on cost-effective analysis. The model considered the (1) encroachment frequency and lateral extent probability; (2) lateral placement and size of roadside articles; and (3) accident severity associated with different obstacle types. The existing method for selecting spot improvements to roadside hazards involved the identification of locations with known, high accident experience. The procedure developed in this report was intended to compliment the existing method, rather than supplant it. Furthermore, the report intended to demonstrate how to make such analyses, and not necessarily present the actual values that should be used.

The cost-effectiveness method presented in this report used a hazard index that was the product of accident frequency and accident severity. Accident frequency, in simplified terms, was the product of the encroachment frequency and the probability that an encroachment would result in a collision. Severity index, as defined by this study, was the fraction of total accidents that resulted in either injury or fatality. Thus, the hazard index for a given object represented the expected number of fatal plus nonfatal injury accidents per year.

For a given angle of encroachment, the model considered a hazard envelope that was comprised of three contiguous sections. These sections were defined for vehicles that hit the side of the object parallel to the roadway, the nearest corner of the object, and the side of the object perpendicular to the roadway. A vehicle would have to be in one of these three sections of the total hazard envelope for some object when it began to encroach, or it would not have a collision, regardless of the lateral displacement it reached.

For encroachment frequency, the author suggested using the results of the Hutchinson and Kennedy study because there was, and still is, no other source available for that type of data. He made the assumption that the total number of encroachments for both sides of a road would be approximately equal to the total number of encroachments in the median. Then, to approximate the number of encroachments on one roadside, he took half the value for median encroachment frequency.

He also referred to the Hutchinson and Kennedy report for the distribution of lateral displacements. This was an important parameter, as not all encroaching vehicles would be expected to reach a lateral displacement greater than or equal to the lateral offset of a given roadside object (i.e., some drivers would regain control of the vehicle). Their distribution of lateral displacements was based on all of the encroachment data they had collected, and it included encroachments with a wide variety of encroachment angles. Thus, to use this distribution would seemingly require a hazard model that considered the full range of possible encroachment angles as well. Therefore, the author investigated lateral displacement as a function of encroachment angle for three angle ranges. Each angle range was then represented by the average angle for that range. It was found that the lateral extent distribution for the range including angles of 6 to 19 degrees very closely matched the overall distribution for all encroachment angles. Thus, the average angle for that range, 11 degrees, could be used to approximate the results that would be obtained by considering several different angles, each with a corresponding lateral extent probability distribution. Additionally, an aggregate percentile distribution was generated by multiplying the relationship for each angle range by the probability of being in that range. This also closely matched the overall distribution, which further justified the use of the average encroachment angle.

Some other approximations were made to simplify the use of the model. One double integral in the most explicit form of the hazard equation was replaced by an approximately equivalent single integral. A second double integral was replaced by a stepwise summation of a single integral.

Obviously, the accuracy of this model was dependent on the accuracy of the encroachment data presented by Hutchinson and Kennedy. They had not presented separate relationships for horizontal and vertical alignment. Their average encroachment rates were based on the total composition of geometry for the freeways included in their study. Their investigation had not shown significant differences based on the number of lanes or horizontal curvature, however. Although lateral extent was not defined as a function of median slope, there was clear evidence that slope did in fact influence the extent of lateral displacement.

Also, different vehicle speeds were only accounted for indirectly in this study, as part of the severity indices. They were computed from accident data which encompassed a wide variety of vehicle speeds. Thus, the model does not attempt to compute the hazard for one vehicle of a particular speed, but rather the long-run hazard for run-off-the-road vehicles of varying speeds. This was acceptable for the cost-effectiveness method, which totals cost over several years and includes many types of accidents.

The study suggested that the generalized model was probably insensitive to all but extreme variations in the parameters that are not included. The greatest generalization consistent with allowable accuracy was regarded as an acceptable tradeoff for ease of implementation.

The report then went on to develop a cost-effectiveness-based economic analysis that could be used to rank possible safety improvements for various roadside obstacles. This analysis went beyond the scope of the current project to estimate encroachment frequency based on accident data. This current project was not concerned with the severity of the accident or how to reduce it, but only whether or not a collision occurred. For this purpose, the basic hazard model developed by Glennon seems to be well suited for use in the current project.

***Effectiveness of Roadside Safety Improvements: Vol. I, A Methodology for Determining the Safety Effectiveness of Improvements on All Classes of Highways*, Publication No. FHWA-RD-75-23**, J. C. Glennon and C. J. Wilton, 1974[4]

The research documented in this report sought to expand the applicability of the freeway hazard model developed in *NCHRP Report 148* to cover all classes of highways. The expansion covered urban arterial streets, rural two-lane highways and rural multilane highways. Additional data were collected for these types of roads to be used in predicting encroachment rates, distribution of encroachment angles, distribution of lateral displacements, and obstacle severity indices. The results suggested that little effectiveness could be gained by implementing roadside safety improvements on highways other than freeways because of the high volume of traffic required to find a significant hazard reduction.

As in *NCHRP Report 148*, the obstacle severity index was defined as the fraction of accidents that produce fatal and nonfatal injuries. The severity indices for different objects were categorized according to roadway classification for freeways, rural highways, and urban streets. The accident data used to calculate these severity indices came from eight cities and 10 State agencies.

The nature of roadside encroachments was not studied directly. Detailed accident reports were analyzed, for lack of better information, to determine the basic encroachment parameters. Two years of accident data from one city were collected for the urban analysis, and 3 years of accident data from one State were used for the rural analysis. The selection of both urban and rural road sections was based on appropriate criteria, as were the accident records that corresponded to those sections.

In an attempt to achieve maximum discrimination, several variables were investigated, such as speed limit and frequency of fixed objects. Of all the classification variables examined, only two provided significantly different results. These were the type of highways in rural areas and the roadbed width for two-lane rural highways.

To estimate the encroachment frequency for different types of roadways, the ratio of total encroachment frequency to total accident frequency for all highways was assumed to be equal to the freeway ratio. No justification was given for this assumption, which may or may not be valid. As an approximation, the authors doubled the freeway median encroachment frequency found by Hutchinson and Kennedy to account for the expected roadside encroachments. The ratio of this total encroachment frequency to the total accident frequency for freeways (determined by this study) was assumed to be equal to the same ratio for other types of roadways.

First, for a given type of highway, the accident frequencies calculated by this study were plotted against traffic volume. Linear regression was then used to approximate the observed accident data, with the data points weighted by section length. The encroachment frequency line was assumed to pass through the origin, with its slope estimated as the slope of the accident regression line multiplied by the ratio discussed above. The results were presented as "order of magnitude estimates to be used in the absence of true encroachment data." They seem to be very rough approximations and do not resemble the well known shape of the encroachment frequency versus traffic volume graph presented by Hutchinson and Kennedy for freeway medians.

For urban streets, the distribution of encroachment angles was determined by collision diagrams from 67 accident records, which does not seem to be an acceptably large sample size. Attempts to discriminate different distributions according to speed limit, street type, and left- versus right-side encroachments were unsuccessful.

The distribution of lateral displacements for urban streets was not derived from the accident reports, however, as almost all of those involved a collision with a fixed object. This would have introduced a bias and distorted the true relationship of the distribution, as a collision with a fixed object affects the maximum lateral displacement the unrestricted errant vehicle may have reached. An estimated distribution was generated using the observed angle distribution combined with an estimated stopping distance. The stopping distance was calculated assuming a straight path, using a friction factor of 0.5, and an initial speed of 72.5 km/h (45 mi/h). No assessment of the accuracy of these assumptions was presented. The approximated distribution does not take into account the effects of side slopes on the lateral extent of travel. The distributions generated by this approach would not seem to be acceptable for the purposes of the current study to estimate encroachment frequency based on accident data.

For rural roads, a similar approach used 99 accident records to determine the distribution of encroachment angles. For the reason mentioned above, only those accidents that did not include a collision with a fixed object were used to generate the distribution of lateral displacements. Most of the data were for two-lane rural highways. Separate angle distributions were presented for encroachments to the left and right sides, as well as a combined distribution. The combined distribution was suggested for use except where an obstacle could only be hit from one side. Because there was not enough data for multilane divided highways, both encroachment angle and lateral displacement distributions were assumed to be the same as for freeways.

An ideal application of the hazard model would sum the probabilities for combinations of encroachment angles and lateral displacement. However, this would be fairly awkward to handle and would require much more data to develop. The authors recommended the use of a single representative angle, with a distribution typical of the overall distribution. For each distribution, the representative angle was assumed to be the average angle.

The authors concluded that, in general, relatively little effectiveness could be gained by implementing roadside safety improvements on highways other than freeways. This was due, in large part, to the low number of encroachments on low-volume roads. However, it stressed the average rates presented did not account for higher encroachment frequencies at specific locations, such as curves or weaving sections. The data needed to detect these variances from the average had not been investigated by anyone because of the difficulty in compiling it.

Research Methods for Improving Roadside Safety Analysis, paper submitted for presentation and publication at the 1979 Annual Meeting of the Transportation Research Board, J. C. Glennon and M. C. Sharp, January 1978[7]

This paper reviewed the current technology of roadside safety improvement analysis. Particular attention was given to the roadside hazard model developed by Glennon in *NCHRP Report 148*. This paper demonstrated the need for additional research to validate or add precision to the Glennon model. The approach suggested analysis of empirical accident data, assuming a Poisson probability distribution. Bayes theorem was suggested as the basis for constructing a discrete model that would more precisely predict the hazard of any roadside condition.

The first part of this paper was devoted to a review of the development of the hazard model, as presented in *NCHRP Report 148* for freeways and in the follow-up study that sought to increase its applicability to all highways. The following reasons were given for the fact that few States were using the model:

- Many practicing highway engineers had not used advanced mathematics since leaving college and preferred using good engineering judgment.

- In its most precise form, the model was more complex, because of the consideration of contiguous hazards, such as a steep embankment.

- Application of the model in a roadside safety program would require the formidable task of a hazard inventory.

- The model was simplistic with respect to the nature of the available input relationships. For instance, although the suggested severity indices accounted for broad types of highway, they did not account for variances caused by curvature, grade, or speed limit.

- Many practicing engineers were skeptical because the model did not demonstrate hazard through direct empirical results.

- The input relationships developed by Hutchinson and Kennedy had not been validated.

Two reports were mentioned that attempted to improve on the Glennon model. A study by the Maryland DOT generally accounted for the contributions of highway geometrics and operating speeds to roadside hazard, but not in any way that could be incorporated into an objective hazard formulation.

A study by the Michigan DOT used multivariate analysis to show that for highway curves, in general, both the frequency and severity of roadside accidents were higher than on tangent sections. This report did not state whether the Michigan study had attributed higher accident frequency to higher encroachment frequency. For instance, the increase may have been due to a higher probability of an accident, given an encroachment on a curve. Another report had linked increased accident severity on curves to a higher probability that the impact would occur on the side of the vehicle, rather than the front. Side impacts were reported to be more dangerous because any deformation would intrude on the passenger compartment.

This paper identified a major problem with using multivariate analysis for very low probability events, such as the highway safety area. Standard multiple regression, which is a continuous representation, encounters problems because of the discrete nature of the dependent and independent variables found in accident analysis. Review of several research efforts employing this type of technique indicated the futility of these kinds of studies. This paper suggested categorizing the continuous variables and building a discrete prediction model based on those categories.

Bayesian statistics were recommended as the basis of a discrete model to validate and add precision to the Glennon model. This approach would calculate the probability of an occurrence, given a condition, if all the reverse conditional probabilities and all the unconditional probabilities were known. It would require the massive effort of a large-scale roadside obstacle inventory and the collection of corresponding accident records. The paper suggested the accident data should cover a time period of no more than 3 years to avoid errors caused by changes in the roadways. The accident reporting level, a major source of error in studies of this nature, was not considered as a possible problem. This was because only the more severe accidents would be of interest, and those types of accidents are expected to have a much lower unreported percentage.

The model would assume independence of the considered variables, which is the equivalent of a similar assumption used in standard regression analysis. Careful selection of variables to avoid any logical dependencies would help justify this assumption. The more explicit form of the model would then predict the expected number of fatal and nonfatal injury accidents, under the assumption that they follow a Poisson distribution.

The paper suggested using the Glennon model variables in the new model and comparing the results of the two. A reasonable level of correspondence would imply that the best available representation of roadside hazard would be the new model in its more explicit form.

Bayesian statistics, or some other type of discrete modeling, may eventually be considered the best method to define the relationship between roadside conditions and safety. By skipping over the issue of encroachment frequency, as well as the other questionable probability distributions, and directly estimating accident rates based on roadside conditions, a more accurate model may be possible. It would not appear, however, that this type of model would lend itself to estimating encroachment frequency based on accident data, which is the goal of the current project.

***Accident Analysis — Breakaway and Nonbreakaway Poles Including Sign and Light Standards Along Highways*, Publication No. DOT-HS-805-605**, K. K. Mak and R. L. Mason, 1980[10]

The objectives of this study were to:

(1) Determine the extent of the pole accident problem.

(2) Determine the accident and injury severity rates associated with pole accidents.

(3) Assess vehicle crash worthiness, highway design, and operational characteristics for pole accidents.

(4) Evaluate the performance, cost-effectiveness, and injury severity reduction of breakaway versus nonbreakaway poles.

The extensive data collection effort included computerized accident data files, hard copies of police accident reports, maintenance agency records, scene inspections, vehicle inspections, interviews with occupants, medical records, and photologs and manual inventories of pole locations. There were two study areas in which the data were collected, one of which was primarily urban while the other was primarily rural. The report notes that, because of the limited number of study areas, the results may not be representative of the Nation as a whole, but they do provide for a contrast between urban and rural areas.

Although pole accidents represent only 3.3 percent of all accidents, the study found that they account for 20.6 percent and 9.9 percent of fatal and injury accidents, respectively. Utility poles were found to be the most frequently-struck type of pole, followed by sign supports, then luminaires. Both urban and rural areas had nearly identical rates of 3.4 pole accidents per billion vehicle-pole interactions. The greater number of pole accidents in the urban study area was due to the higher exposure rates for urban roadways. The report noted that arterials, which were found to have the highest pole accident rates, should receive the most attention for consideration of countermeasures.

The study estimated the percentage of unreported hit-pole accidents, based on a comparison of reported accident records and maintenance agency records. This investigation revealed that a large percentage of pole accidents are not reported. More than 10 percent of hit-utility-pole accidents and almost 70 percent of hit-sign-post accidents were found to be unreported. Most of the unreported accidents were in the urban study area and involved small signs on local roads.

Analysis of accident site characteristics showed that pole density and lateral offset affected the probability of a pole being struck. Horizontal and vertical alignment of the roadway were also shown to influence the frequency of pole accidents, but because of a lack of data for nonaccident sites the relationships were not well defined. These accident site characteristics were found to have only a subtle influence on accident and injury severity.

Pole accidents in the rural study area typically had a higher injury severity than did pole accidents in the urban study area. This was a result of higher impact speeds. The median impact speeds for urban and rural pole accidents were 38.5 km/h (23.9 mi/h) and 46.4 km/h (28.8 mi/h), respectively. Thus, the study concluded that the majority of pole accidents are at relatively low impact speeds.

The study also investigated vehicle damage characteristics and occupant injury characteristics, and evaluated pole performance. These topics were beyond the scope of the current study, as was the cost-effectiveness analysis of using breakaway pole designs.

***Cost-Effectiveness of Countermeasures for Utility Pole Accidents*, Publication No. FHWA/RD-83/063**, C. V. Zegeer and M. R. Parker, Jr., 1985[(8)]

The purpose of this study was to develop a cost-effectiveness analysis procedure for the optimal selection of countermeasures for utility pole accidents. It involved the collection and analysis of accident, traffic, and roadway data for over 4 025 km (2,500 mi) of urban and rural roads from four States. The results of the data analysis showed that lateral pole offset, traffic volume, and pole density were the factors most highly related to utility pole accidents. A predictive model for utility pole accidents was developed.

The authors reported findings from a 1980 study by Jones and Baum.[(9)] That study had reviewed over 8,000 single-vehicle accidents in 20 urban areas throughout the United States. They found the most important variables in predicting a pole accident, given that a single-vehicle accident has occurred, are pole density or spacing, lateral offset, road grade, road path, and speed limit. The following results relate to urban roads and may not necessarily apply to rural settings.

- Utility pole accidents were over-represented on straight and level roads and under-represented on grades. This does not seem to agree with other studies that suggest curves and grades are more likely to have higher accident rates than tangent and straight sections.

- Many of the roadway variables, such as traffic volume, speed limit, road type, and road width, were highly intercorrelated. This makes it difficult to separate their individual effects.

- Utility pole accidents were also over-represented on roads with no shoulders. This seems to make sense because a vehicle is probably more likely to recover safely if there is a shoulder present. It does not necessarily mean there is a different encroachment rate for this condition. For instance, the same number of encroachments could just result in a higher number of accidents.

- Twenty-five percent of utility pole accidents occurred at intersections; however, in most cases the intersection was judged to be incidental to the accident.

The authors commented on the 1980 Mak and Mason study of pole accidents.[10] That study found that 85 percent of pole accidents were in urban areas. Both urban and rural areas exhibited identical rates of 3.4 accidents per billion vehicle-pole interactions. Accident frequency was found to be related to pole density, pole offset, and both horizontal and vertical alignment. The relationships were not well defined, according to the authors, because there were no comparisons to nonaccident sites.

Noted were several other studies that also found pole accidents related to the previously mentioned factors. However, there were many interrelationships between roadway and traffic variables. None of the models mentioned was capable of analysis that would determine the effects on pole accidents because of changes in individual roadway factors.

Sample size calculations were performed to determine the minimum number of kilometers (miles) of roadway for which data had to be collected. Utility pole accidents were assumed to follow a Poisson distribution, and the sample size requirements were computed as described in *Accident Research Manual* by Council et al.[11]

Data were collected for many roadway and utility pole variables, along with corresponding accident information, for the sections included in the study. These were the common factors associated with pole accidents. Data collection sites were selected according to several criteria, such as no major construction in the recent past, ability of the sections to meet the data collection requirements, and existence of poles within a specified lateral offset. Sections had to be fairly homogeneous so that an attempt could be made to isolate the individual effects of traffic and roadway variables.

Much of the roadway and utility pole data were extracted from State photologs. A calibrated grid was placed over the photolog viewing screen to collect lateral and longitudinal distances, such as shoulder width, pole offsets, and location. Additionally, roadway data that were collected from agency files, maps, and other documents could easily be verified with the photologs.

The accident data base included many years worth of data from several States. The number of years collected from each State varied from 5 to 10 years. The accident data, as well as the roadway data, were thoroughly screened and checked for errors, before and after being transferred to a computerized file system. This included statistical checks for entries that seemed to fall outside the bounds of what should be expected for a given data element. These checks assured that the data base contained the best possible information for analysis.

The data analysis sought to answer the following two major questions:

(1) What is the dimension of the utility pole accident problem?

(2) What factors or combinations of factors significantly affect the frequency or severity of utility pole accidents?

Data analysis showed the overall accident rate agreed very closely with the value found by the 1980 Mak and Mason study. The accident rates were 10.32 and 9.94 accidents per hundred million vehicle kilometers (16.61 and 16 utility pole accidents per hundred million vehicle-miles), respectively. This study found a rate of 4.1 accidents per billion vehicle-pole interactions, which was slightly higher than the Mak and Mason rate of 3.4. Although this study found the urban accident frequency and rate higher than the corresponding rural values, the number of accidents per billion vehicle-pole interactions matched very closely. The study noted that it was possible for low-volume roads to have relatively high accident rates, but low accident frequencies.

Correlation analysis was conducted to determine if relationships existed between the independent and dependent variables. It also identified relationships between the independent variables, which helped avoid problems with colinearity. As expected, the continuous independent variables found to be most highly correlated with utility pole accident frequency were traffic volume, pole offset, and pole density. Analysis indicated a moderate degree of dependency between these variables.

Analysis showed that most of the discrete independent variables were intercorrelated. For instance, area type and speed limit were the most highly correlated. This was because almost all rural speed limits were 80.5 or 88.5 km/h (50 or 55 mi/h) and all the urban speed limits were under 72.5 km/h (45 mi/h).

Branching analysis showed what combinations of independent variables explained the most amount of variance for each dependent variable. For the three dependent variables (acc/km/yr, acc/HM veh km, and acc/bil veh km), the same three independent variables (traffic volume, pole offset, and pole density) explained the largest percentage of variance. Pole offset was the single variable that explained the greatest amount of variance. The frequency variable had much more of its variance explained than the other two rate-dependent variables. Thus, the accident frequency variable was considered preferable to the accident rate variables for predictive purposes.

When controlling the three covariates listed above, the following discrete variables were found to have a significant impact on accident experience:

- State.
- Shoulder width.
- Lighting.
- Roadway classification.
- Horizontal curvature.
- Speed limit.

The following variables showed no significant differences for accident frequency:

- Area type.
- Number of lanes.
- Pole type.
- Side slope.

The following factors were found to explain the same variance because of their interaction and should not be used together in regression analysis:

- State and area type.
- State and roadway classification.
- Roadway classification and area type.
- Area type and speed limit.
- Pole type and speed limit.

The covariance analysis was also used to determine accident reduction factors. A series of graphs was presented that showed the effects of each covariate on accident frequency, provided the other two covariates were accounted for.

Accident severity was also investigated by such methods as branching analysis and contingency table analysis. The following conclusions were drawn, based on those analyses:

- For pole offsets up to 3 m (10 ft), accident severity for wooden poles was significantly higher than for metal poles. This was probably because of the fact that most of the metal poles included in the study were designed with breakaway bases to reduce accident severity.

- Speed limit was found to have no significant effect on the severity of utility pole accidents. This conflicted with the Jones and Baum study, which found that severity increased on roads with higher speed limits. This may have been because of the fact that this study only considered three severity categories, including property damage only, injury, and fatality accidents.

- For speeds limits under 64.4 km/h (40 mi/h) and over 72.5 km/h (45 mi/h), severity increased with increasing roadway curvature. There was a limited sample size and lack of a wide range of curvature for sections with speed limits of 64.4 km/h (40 mi/h) and 72.5 km/h (45 mi/h), which may have been the reason that severity was not found to be affected by curvature for that speed group.

A predictive model for utility pole accidents, as a function of roadway and utility pole characteristics, was developed for use in the cost-effectiveness model. The statistical analysis determined which independent variables should be used in the regression equations. Traffic volume, pole offset, and pole density were the variables used. Including other independent variables, such as area type and road class, would have explained little additional variance. Their discrete nature was also less suited to regression analysis.

A multiplicative model was chosen for use from the many linear and nonlinear models that were tested for their fit of the sampled data. It had the best combination of high explained variance, low constant, low standard of error, and closeness of fit at the extreme ranges of the data values.

Nine random sites in the data base had been set aside for validation of the model and were not used in its development. The model provided a close fit for seven of the sites, and statistical analysis showed the model was a reasonably good predictor of utility pole accidents. The most variability in utility pole accidents was found for high volumes of traffic, high pole density, and low pole offset. The model was most likely to deviate from observed accident rates under those conditions.

The remainder of the report dealt with utility pole countermeasures. Accident reduction figures were explained, and cost estimates for various countermeasures were given. A detailed discussion on cost-effectiveness was presented by the authors; however, this was beyond the scope of the current project to estimate encroachment frequency from accident data.

Designing Safer Roads – Practices for Resurfacing, Restoration, and Rehabilitation. TRB Special Report 214, 1987[12]

Appendix F of this report described the efforts to calibrate and test a roadside encroachment model for two-lane highways. Previous efforts had tried to estimate accident frequency from the limited amount of available encroachment data. However, this data was said to be inappropriate for accurate analysis of roadside hazards on two-lane highways. As a result, this study sought to calibrate the model using a different approach. The objective was to estimate encroachment frequency and lateral extent probability from known accident data. Thus, the overall goal was the same as for the current project.

This study used the same hazard envelope and general hazard equations as the Glennon model. The Glennon model and similar efforts that focused on cost-effectiveness relied largely on the Hutchinson and Kennedy freeway data to estimate encroachment frequency and lateral extent probability. The purpose of this study, however, was to use accident data to obtain better estimates of these functions for two-lane highways, rather than using the existing encroachment data to estimate accident rates.

The study used the same extensive data base that had been developed for the Zegeer and Parker study of hit-utility-pole accidents. About 9,500 accidents over 4 025 km (2,500 mi) of roadway in four States were included in this data base.

The expected number of encroachments was assumed to depend only on traffic volume. It was modeled as the product of a constant and the traffic volume raised to a power. The exponent and the constant were both calculated from statistical analysis of the accident data. This model did not specifically account for curves, grade, windbreak effects, or any of the other factors that have been speculated or found to affect accidents and encroachment frequency.

For lateral extent probability, three different functions were analyzed for best fit, based on the observed accident data. The three distributions used in the study were linear, exponential, and sinusoidal functions. Each function had a calibration constant that was calculated by the statistical analysis.

The utility poles were assumed to have a square cross section, with 20.3-cm (8-in) sides, and the vehicle swath width was taken as 1.83 m (6 ft). The encroachment angles of 11.5 degrees and 6.1 degrees, for left- and right-side departures respectively, were taken from the 1974 study by Glennon and Wilton. That study had reported that using average angles from separate left- and right-angle distributions only made a difference when objects could be hit from just one direction, such as bridge rail ends. It had made the contention that the average angle from the combined distribution worked well enough for objects that could be hit from either side. Neither report mentioned any sensitivity analysis that quantitatively measured the effects of this assumption.

Two components of the model were used to predict severity. The first was the probability that a collision between a vehicle and an object would result in an accident. The second was the probability that an accident would be severe enough to produce a fatal or nonfatal injury. These values were taken from the 1983 Zegeer/Parker study and the 1974 Glennon/Wilton study, respectively. The author noted that the findings of the 1980 Mak and Mason study concerning unreported accidents suggest the Zegeer/Parker values may be too high.

The expected accident rate in the model was replaced with the actual rate from accident data for different combinations of pole density and lateral offset. The three calibration constants were then determined, and statistical analysis provided the optimum values. The three functions for modeling lateral extent distribution offered approximately the same accuracy. The exponential model was recommended, however, for its ease of use and greater sensitivity to lateral offset in regions near the travel lanes.

A preliminary test of general applicability compared the predictions of the model with actual accident rates for extended highway segments typical of those evaluated in a 1982 NCHRP report by Graham and Harwood.[13] When all accidents were considered, the model predictions exceeded the actual rates by up to 160 percent. For accidents that resulted in a fatal or nonfatal injury, the level of over prediction shrank to a maximum of 85 percent. This level of accuracy was said to be reasonably good, considering all the assumptions required to apply the model to the Graham/Harwood data base. The study concluded that it had presented the best encroachment model to date.

APPENDIX B. EXPERIMENTAL PLAN

The experimental plan presented in this appendix was developed as part of a technical work request that focused on two issues related to run-off-the-road accidents. These issues pertain to the rate at which vehicles encroach on the roadside and the percentage of hit-fixed-object accidents involving both small signs/sign posts and utility poles that are unreported. It was hoped that the investigation of these topics, in conjunction with other on-going research, would contribute to a better understanding of the relationship between roadside design and safety. Research on roadside encroachments was documented in the body of this report and elsewhere. Interested readers should consult the original references for more details on these research efforts.

TIMING OF THE EXPERIMENTAL PLAN

Several factors should be carefully considered in determining when to conduct this experimental plan. Perhaps most important is the on-going and proposed research in related areas that will have an impact on the results of this experimental plan. Continuing research in the area of roadside safety is expected to yield a greater understanding of key components of the roadside hazard model, including encroachment angle distributions, effective vehicle swath width, and the distribution of lateral travel as a function of roadside elements. Because the methodology for this experimental plan is based on using the roadside hazard model to back calculate an encroachment rate estimate, the accuracy of the results is necessarily a function of the assumptions on a vehicle trajectory. Thus, it is strongly recommended that the experimental plan be conducted only after this related research has been completed, so the best possible information will be available for use in estimating encroachment rates using this method.

Two other important factors are the availability of computer-based roadside feature inventory data and accuracy of State sign maintenance records. The following methodology assumes that the candidate State will have accurate sign maintenance records in electronic media for comparison with accident data. Thus, the experimental plan should be conducted at a time when sign management systems which include highly accurate data on sign and sign post replacement because of knockdowns by vehicles have advanced to the point where this is possible. Although not absolutely necessary, the experimental plan should also be conducted when the state of the art has advanced and reliable, accurate roadside features inventory data are available in electronic media. This could potentially eliminate the need for a field survey to collect the necessary roadside information. This will reduce the time and cost required to conduct the experimental plan.

OBJECTIVES

The objectives of this experimental plan are to:

(1) Develop improved estimates of the average annual rate of roadside encroachments (expressed in terms of encroachments per kilometer (mile) per year per ADT) on tangent sections for the following types of roads:

- Two-lane rural roads.
- Rural, four-lane undivided highways (excluding freeways).
- Rural, four-lane divided highways (excluding freeways).

These encroachment rate estimates will be developed as a function of ADT and, if appropriate, other variables such as lane width, paved shoulder width, unpaved shoulder width, side slope, and clear zone, to the extent possible within the limitations of available sample sizes.

(2) Develop estimates of the percentage of unreported hit-sign-post and -sign crashes through a comparison of accident data with sign inventory and maintenance data. Estimates will be developed for the following roadway types:

- Two-lane rural roads.
- Rural, four-lane undivided highways (excluding freeways).
- Rural, four-lane, divided highways (excluding freeways).

(3) Develop estimates of the percentage of unreported hit-utility-pole crashes through a comparison of accident data with utility maintenance records. Estimates will be developed for the following roadway types:

- Two-lane rural roads.
- Rural, four-lane undivided highways (excluding freeways).

The primary objective of the experimental plan is to develop reasonable estimates of encroachment rates. Estimating the percentage of unreported accidents is a secondary objective, although it is necessary to improve the accuracy of the encroachment rate estimates. Also, this experimental plan is limited to tangent sections in level terrain. Consequently, the effects of horizontal and vertical alignment on encroachment frequency will not be considered. The estimates of encroachment rates and unreported accidents for four-lane roads will be subject to limitations imposed by available sample sizes. If sample sizes are judged to be too low, then it may not be possible to develop meaningful encroachment rate estimates.

POSSIBLE APPROACHES

Several conceivable methods exist to investigate roadside encroachment frequency. One method would be direct observation of actual encroachments. For example, strategically placed video cameras, triggered by sensors that would detect errant vehicles, could monitor road sections to record roadside encroachments. These video records could then be used to estimate encroachment frequency. They could also be analyzed to determine other encroachment parameters, such as the distribution of encroachment angles and the distribution of the lateral extent of the encroachment. However, the currently available equipment necessary for such an effort is relatively expensive, costing approximately $20,000 for a two-camera, fully-equipped unit to monitor about 305 m (1,000 ft) of roadside. Thus, the number of units required to obtain a reasonable sample in an acceptable time period would be prohibitively expensive. Conversely, it would take a prohibitively long time to collect the necessary sample size using an affordable number of units.

Another possible method, similar to the work conducted by Hutchinson and Kennedy, would be to search for evidence of encroachments. This method would rely on periodic monitoring of roadsides for evidence of encroachments, such as tire tracks and damage to roadside fixed objects. In addition to being highly labor intensive, and therefore prohibitively expensive, it will not be possible to differentiate unintended encroachments from controlled encroachments that are performed in a safe and efficient manner.

The method described in this experimental plan is based on the use of reported accident data to analyze the effects of encroachments (i.e., collisions with roadside fixed objects). To accomplish this, there is a need to rely on relationships that have been developed previously for roadside hazard models. Specifically, probability distributions for the maximum lateral extent of roadside encroachments and vehicle trajectory information will need to be assumed in deriving estimates for roadside encroachments. It must be recognized that at the time this report was prepared research was underway to investigate the sequence of events and the trajectory of vehicles that have run off the road. It is hoped that these research efforts will yield improved understanding of the relationships among roadway cross-section, alignment, roadside design including clear zone and side slope, speed, vehicle type, driver characteristics, and the lateral offset of fixed objects for a wide variety of potential roadside hazards. Until such time that the results of these studies become available, however, it will be necessary to rely on previous relationships that have been documented in the literature. When improved relationships become known, it may be appropriate to revise the analyses that are required for this experimental plan.

BACKGROUND ON THE BASIC ENCROACHMENT MODEL

The approach for this experimental plan relies on the use of a roadside hazard model, such as that developed by Glennon in *NCHRP Report 148*. This type of conceptual model defines the conditional relationships of events that result in a vehicle impacting with a roadside hazard. The different components of this type of model account for the probability of a roadside encroachment occurring in the hazard envelope of a roadside object, the probability of the encroaching vehicle reaching a lateral displacement necessary for collision with the object, and the probability of the collision resulting in some level of severity. Average encroachment frequency, the focus of this experimental plan, is an important parameter considered by this type of model.

In general, a typical application of this model predicts the number of accidents for an individual fixed object over some time period. The model can be applied to a variety of roadside objects such as sign posts, poles, bridge piers, culverts, embankments, and traffic barriers. The results can then be aggregated to assess the overall hazard with respect to the fixed objects on the roadside. A very basic form of the model can be expressed as follows:

$$A = E * P_{(A/E)} \tag{13}$$

where:

A = Number of expected accidents.
E = Number of roadside encroachments.
$P_{(A/E)}$ = Probability of an accident, given an encroachment.

The number of roadside encroachments, E, represents the fraction of the vehicles passing a given object that encroach while in the hazard envelope of that object. The hazard envelope represents the section of roadway in which a vehicle must have begun its encroachment for a collision with a given object to be possible. Assuming an average encroachment frequency (encroachments/km/yr), the number of encroachments into the hazard envelope of that object during some time period (yr) can be estimated. $P_{(A/E)}$ then represents the fraction of vehicles encroaching in the hazard envelope that are expected to reach a great enough lateral displacement for a collision with the object. It is this number of vehicles that collide with the object that the model predicts. Additional conditional probability distributions, such as severity distributions of typical roadside objects, are applied to consider the results of these collisions. In this way, the cost-effectiveness of safety improvements as a function of the different roadside environments being considered can be analyzed.

The generalized roadside hazard model can be solved algebraically to yield encroachment frequency as a function of accidents and the probability of an accident given an encroachment. For a given highway test section, the expected number of accidents in the model (normally the output of the calculations) is replaced by the number of accidents that actually occurred on those test sections. Thus, knowing the actual number of accidents on a given test section, not just those that are reported by police, is paramount to the success of this approach. This illustrates why this experimental plan concurrently requires investigation of the issue of unreported accidents. The accuracy of the encroachment frequency estimated in this manner is therefore dependent on the accuracy of the estimate of total accidents, which include reported and unreported, can only be as accurate as the accident data used as input.

SCOPE OF WORK

The scope of work for this experimental plan shall be limited to two-lane and four-lane rural roads only. The experimental plan will include the collection of accident data, sign maintenance data, utility pole maintenance data, and roadside information for selected sections of roadway.

WORK PLAN

The proposed experimental plan shall consist of the following task:

Task 1. Review Recently Completed and On-Going Related Research Efforts.

Because there were several major roadside research studies underway at the time that this report was prepared, the contractor will need to contact and determine the most recent developments and findings in the roadside research area. Notably, the contractor should review results associated with NCHRP Project 22-9, "Improved Procedures for Cost-Effectiveness Analyses of Roadside Safety Features," Project G17-11, "Recovery Area Distance Relationships for Highway Roadsides," and in-house research conducted for the Design Concepts Research Division of FHWA's Office of Safety and Traffic Operations Research and Development.

Task 2. Assess the Adequacy of State Data Bases and Select States.

The contractor should contact the candidate States and inquire about the availability and quality of data from their State traffic/accident/roadway records systems, especially with respect to recent improvements and changes for roadside, traffic, accident, sign maintenance, and utility inventory data. The contractor shall determine the suitability of the States for the purposes of this experimental plan.

Selection criteria should consider the availability and quality of computerized roadside features inventory data, computerized crash records, sign maintenance records, sign inventories, videologs, digital mapping, consistently applied police accident reporting thresholds, traffic records, roadway geometric and features files, among others.

Criteria to Select States

The candidate State will need to specifically identify hit-sign post on their traffic accident report forms, as opposed to grouping these types of accidents together under a general category of hit-fixed object. To facilitate data collection and analyses, the candidate State's accident reporting system should be in the form of a computer data base that allows easy extraction of pertinent information. The focus of this experimental plan is on hit-sign-post and hit-utility-pole accidents. However, it will be advantageous to acquire an extract file of information for all accidents that occurred on the study sample of roads during the time period to be considered by the experimental plan. Three years is an appropriate time period to be considered. Longer time periods will increase the uncertainty of the present roadway and roadside features compared to those that existed for the corresponding dated accident data.

Thus, the candidate State for this experimental plan will necessarily have:

(1) An accurate, computerized sign maintenance records system that explicitly identifies the location and type of maintenance work done as a result of motor vehicle damage.

(2) Cooperative utility companies that maintain accurate maintenance records that explicitly identify the location and type of maintenance work done as a result of motor vehicle damage.

(3) An accurate, computerized accident reporting system that explicitly identifies hit-sign-post and hit-utility-pole accidents. In addition, the accident data base should contain data on sequence of events, direction of travel, and whether the vehicle ran off the road to the right or left.

(4) Reasonable, accurate, and complete historical data on ADT for all rural roads. Data on truck ADT's and distribution of travel by lane would be desirable, although not necessary.

(5) A Roadway Inventory File that includes data on number of lanes, lane width, paved shoulder width, and other cross-section variables.

In addition, the cost to conduct this experimental plan could be greatly reduced if an appropriate State could be identified that also maintains the following:

(1) A sign inventory system data base that includes accurate data on lateral offset for all signs on rural roads.

(2) A computer data base that contained roadside information, such as side slope, clear zone, and longitudinal and lateral location for guardrail and other roadside features.

(3) A computer data base on roadway alignment characteristics for rural roads.

(4) Computer-based videologs with random access selection of its highway system that could be used for the purpose of this study.

(5) A computer data base that contains information on intersection locations.

This information will otherwise need to be collected by a manual field inspection and data collection effort. This labor intensive effort will significantly increase the cost to conduct this experimental plan.

The eight States that comprise the Highway Safety Information System (HSIS) provide a good starting point to begin identification of appropriate candidate States. The HSIS is a safety data base that contains accident, roadway inventory, and traffic volume data for the following States:

- Illinois
- Maine
- Michigan
- Minnesota
- Utah
- California
- Washington
- North Carolina

These States were selected based on the quality of their data, the range of data available, and their ability to merge data from various files. The HSIS is used by FHWA staff, contractors, university researchers, and others to study current highway safety issues, direct research efforts, and evaluate the effectiveness of accident countermeasures. One or more of these States may be potentially suitable for implementation of the experimental plan, based on the availability and quality of their data and anticipated improvements or changes to their data management systems for roadside traffic, accident, sign, and utility data.

Task 3. Collect Available Data.

As outlined in the objectives and scope, this plan will focus on two-lane rural roads and include four-lane divided and undivided roads if adequate sample sizes can be developed, with the exception of using utility poles for studying encroachments on rural, four-lane, divided highways. Previous research has shown encroachment frequency to be a function of traffic volume. Thus, the experimental plan is structured so that, for each road type, road sections are stratified by ADT intervals. In general, the smaller the traffic volume interval the better, but the implemented experimental plan is likely to be dictated by budgetary constraints. Given the finite resources available, it is suggested that a minimum of four traffic volume intervals be considered for two-lane rural roads:

(1) Very low volume paved roads — Defined to be those carrying less than 2,000 vehicles per day, but greater than 500 vehicles per day.

(2) Low volume paved roads — Defined to be those carrying between 2,000 and 4,000 vehicles per day.

(3) Moderate volume paved roads — Defined to be those carrying between 4,000 and 6,000 vehicles per day.

(4) Higher volume paved roads — Defined to be those carrying more than 6,000 vehicles per day.

For four-lane rural roads, two volume intervals should be considered:

(1) Lower volume — Defined to carry less than 10,000 vehicles per day.

(2) Higher volume — Defined to carry more than 10,000 vehicles per day.

Traffic volume data will need to be available for the candidate State, both to select appropriate road sections and for subsequent input to the roadside hazard model. If it appears that the available sample size for a specific combination of ADT interval and highway type will be inadequate, then that group should be excluded from the analysis.

It should also be noted that there are several other variables of interest that have not been included in roadside hazard models to date but would be useful additions. These include lane width, paved shoulder width, unpaved shoulder width, side slope, and clear zone. It is not suggested that roadway samples be selected based on these factors. However, these data could be collected along with the other required data, and there may prove to be a sufficient amount of information for some or all of them to be included in a statistical model.

Desirable Minimum Sample Size and Road Selection Criteria

In Mak's 1992 study, a methodology for determining minimum sample sizes for this type of experimental plan was presented. He noted that the underlying assumption for this approach was that the extent of unreported accidents for the fixed objects is very low or can be estimated with reasonable accuracy. He specifically mentioned utility poles, which previous studies have estimated to have approximately a 90-percent reporting level. For sign posts, the assumption of this experimental plan is that the true number of sign knockdowns can be determined with a reasonable degree of accuracy from sign maintenance records, even if most of these accidents are not in a State-reported accident data base.

Based on an initial encroachment rate estimate of 3.73 encroachments per million veh-km (6 encroachments per veh-mi), Mak's 1992 study estimated the total required exposure for an experimental plan of this type. Based on this assumption, the minimum required sample is 18.92 million vehicle-km (11.76 million veh-mi) per highway/volume category. Using the same initial encroachment rate estimate, there would be approximately 71 encroachments expected for this exposure. The suggested, rounded-off sample was 75 encroachments to be monitored for each highway sample.

The number of objects to be sampled can be estimated from the required exposure. For example, a group of roadway sections with a weighted ADT of 3,000 vehicles per day, corresponding to the low volume category listed above, equates to:

$$\frac{(18.92 \text{ x } 10^6 \text{ veh-km})}{(3{,}000 \text{ veh/day} * 365 \text{ day/yr})} = 17.28 \text{ km-yr } (10.74 \text{ mi-yr}) \text{ of exposure.}$$

Dividing the required exposure by the time period to be considered by the study yields the total length of hazard envelopes for a given type of object. Thus, for a study using 3 years of accident data, the sample would need to consist of 5.76 km (3.58 mi) of hazard envelopes for sign posts. That is, the sum of each of the individual hazard envelopes for sign posts in the sample should total at least that length. Dividing the total sample length by the length of an average hazard envelope yields an approximation of the number of objects that can be expected to be in the sample. Depending on the existing encroachment parameters assumed for this estimation, the hazard envelope for a 10-cm by 10-cm (4-in by 4-in) wooden sign post ranges from 13.7 to 18.3 m (45 to 60 ft). Therefore, the number of objects to be sampled will be between 315 and 420 sign posts.

Using utility poles to independently corroborate the results derived from sign post knockdowns requires an equal number of encroachments to be monitored. Considering the same 3-year study period, the sample of hazard envelopes for utility poles would also need to consist of 5.76 km (3.58 mi). Approximating an average utility pole as a 25-cm by 25-cm (10-in by 10-in) rectangle yields a hazard envelope of 15 to 20 m (50 to 60 ft). Therefore, the number of objects to be sampled, for a group of road sections with a weighted ADT of 3,000 vehicles per day, will be between 290 and 380 utility poles.

Mak suggested that the roadside objects to be monitored should be located close to the edge of the travelway laterally to minimize the number of encroachments in the study area that do not result in a collision with the fixed objects in question. However, it may not be feasible, using accident data and maintenance records, to directly identify road sections within a certain ADT range that have a high density of fixed objects that are close to the edge of the travelway but not shielded by guardrails or other roadside features. In general, those data currently do not exist. However, the current roadside hazard model can be used to estimate the number of accidents that would correspond to the 75 encroachments cited earlier, for road sections with fixed objects at typical offsets. Thus, the number of sign knockdowns in the sign maintenance records can be used to ascertain whether candidate road sections will have a sufficient number of unshielded sign posts located relatively close to the edge of the travelway. Similarly, the number of hit-utility-pole accidents in a State-reported accident data base can be used to assess whether candidate road sections will have a sufficient number of unshielded utility poles close enough to the edge of the travelway.

The average lateral offset for sign posts found by the pilot study for this experimental plan was approximately 5 m (16 ft). Existing estimates for the probability of an errant vehicle in the adjacent lane reaching this lateral displacement range from about 30 percent, for the AASHTO 80 km/h (50 mi/h) design speed, to about 70 percent for Glennon's curve. The probability for a vehicle in the opposing lane on a two-lane road, or the left lane on a four-lane road, ranges from about 12 percent to about 33 percent. Depending on the lateral extent probability value used, 75 encroachments in the hazard envelopes of sign posts would result in 16 to 39 collisions. The higher value is suggested for use as it will result in the selection of road sections that more likely have the required number of sign posts to satisfy the minimum sample. Thus, there should be at least 39 sign knockdowns during the 3 previous years in the sign maintenance records for the initial selection of candidate road sections. This applies to each traffic volume and road type category.

For utility poles, the average lateral offset found by the pilot study for this experimental plan was approximately 7 m (22 ft). Thus, as estimated above for sign posts, 75 encroachments would result in an expected 10 to 28 hit-utility-pole collisions. Once again, to be conservative, 28 hit-utility-pole collisions should be used. Assuming that approximately 90 percent of hit-utility-pole accidents are reported, based on current estimates, the initial selection of candidate road sections for each traffic volume and road type category should have at least 25 hit-utility-pole accidents reported during the 3 previous years.

It should be remembered that these estimates for sign knockdowns and reported hit-utility-pole accidents are to be used strictly as an aid in the selection of road sections. They should not be confused with the actual sample size requirement, which is based solely on the minimum number of objects to be sampled. That is, if the roadside data collection reveals that there are still an insufficient number of objects for the selected road sections, additional road sections must be included until the minimum sample size has been satisfied. Conversely, a sufficient number of objects may be attained for a traffic volume and road type category before the complete sampling of the initially selected candidate road sections. The estimates are merely a guide to minimize the possibility that chosen road sections will have an insufficient number of unshielded sign posts and utility poles close enough to the edge of the travelway. Furthermore, it should be noted that these estimates apply only to tangent sections within the overall road sections selected for the sample. This experimental plan is intended to determine the encroachment rate for tangent sections only. Obviously, a State data base containing horizontal alignment will greatly facilitate this selection. Otherwise, the horizontal alignment will be unknown until the roadside data collection is conducted, possibly resulting in an insufficient number of appropriate objects on tangent sections to satisfy the minimum sample requirements. Also, it will be advantageous, if possible, to select a sample of road sections that satisfies the minimum number of both types of fixed objects. This will minimize the roadside data collection effort.

Roadside Data Collection

The roadside hazard model requires additional information concerning the roadside and the fixed objects to be considered. Determining the number of hit-utility-pole and hit-sign-post accidents, adjusted for those that are not reported, accounts for only part of the input to the model. The description of the roadside corresponding to those accidents, with respect to the objects included in the study, is equally important. The availability of this information in the form of an existing computer data base will greatly facilitate this experimental plan and reduce the cost. Some of this information may be contained in the sign inventory system or the utility inventory system, or could possibly be collected using a videolog of the States highway system, if one exists.

Table 5 shows the minimum sample size requirements as described above. These samples apply to each of the three road types considered by this experimental plan.

Table 5. Estimated sample size required to meet the minimum sample requirements.

ADT Group (Veh/Day)	Average Section ADT*	Exposure (Km-Yr) over 3-Yr Time Period	Sample Size Required**	
			Sign Posts	Utility Poles
< 2,000	1,250	13.83	755-1,010	700-910
2,000-4,000	3,000	5.76	315-420	290-380
4,000-6,000	5,000	3.46	190-255	175-230
> 6,000	8,000	2.16	120-160	110-140

* Assumed average of section ADTs within that group.
** Estimate based on assumed average for ADT group and existing values for encroachment angle and vehicle swath width.

To apply the roadside hazard model, the location and dimensions of every sign post and utility pole in the study sections are necessary. The dimensions of each object are needed to calculate L_i, the length of each hazard envelope. The location of each object is also essential. In particular, the lateral offset of each object is used to determine the probability of an accident, P_i, given a lane departure in the hazard envelope of the object. The longitudinal location of each object will serve to identify it for the purpose of analyzing the sign maintenance, utility maintenance, and reported accident records. It can also be used to investigate the extent of shielding in the sample. This occurs when hazard envelopes overlap, such that one object is fully or partially prevented from being struck because of the location of one or more other roadside objects.

Data will be collected for all sign posts and utility poles within approximately 12.2 m (40 ft) of the roadway that could possibly be struck by an errant vehicle. Posts and poles located behind guardrails, up a steep embankment, or beyond a nontraversable ditch will not be included. The following information will necessarily be collected for sign posts and utility poles in the study sections:

- Object type: Data will be collected for wooden utility poles, wooden sign posts, metal sign posts, metal signs, and guardrails. Object markers (yellow background with black diagonal striping) will be classified as metal signs, rather than metal sign posts, because they are located so close to the ground. The sign panel, not the sign post, would be struck in this case. For all other signs, the vertical clearance is generally such that an errant vehicle would strike the post, not the panel.

- Object size: Utility poles — The approximate diameter of utility poles will be recorded to the nearest 25.4 mm (1 in) during the data collection. Because the hazard model was developed for objects with a rectangular cross section, however, all utility poles will be approximated as a rectangle to simplify the analyses.

- Sign posts: The length and width of rectangular wooden sign posts and metal U-channel posts will be measured to the nearest 12.7 mm (0.5 in). The actual dimensions of these objects will be used in the analyses. Metal sign posts with a circular cross section will be approximated as rectangles.

- Kilometer (mile) point location: Object kilometer (mile) points will be determined, accurate to approximately 1.525 m (5 ft).

- Lateral offset: Lateral offsets represent the distance between the near-side of the object and the edge of the travel lane. For small signs, the near side of the object will be taken to be either the edge of the sign or the sign post, depending on which one a vehicle would be likely to strike. In the model, the width of the adjacent lane will be added to the lateral offset for calculating the probability of a collision caused by a far-side encroachment. This accounts for the extra lateral displacement a vehicle must reach to strike an object on the far side of the road.

- Sign description: A description of each sign, including the legend and MUTCD code, will be recorded as part of the data collection effort. This will be helpful in matching a particular sign post to maintenance or accident records.

While the above information is the minimum necessary to use the existing roadside hazard model, additional roadside information should also be collected for the study sections. This additional information can be used to either take advantage of future refinements in the lateral extent probability distributions or be used to develop adjustment factors to modify the roadside hazard model. This information includes:

- Lane width: This should be measured to the nearest 0.1 m (4 in).

- Paved shoulder width: This should be measured to the nearest 0.1 m (4 in).

- Unpaved shoulder width: This should be measured to the nearest 0.1 m. (4 in).

- Guardrail: The location, terminal treatment, and type need to be measured.

- Sideslope: The slope and width of foreslopes and backslopes at the location of each sign and utility pole need to be measured.

- Clear zone: The distance to potential fixed roadside objects in the vicinity of each sign and utility pole should be measured to the nearest 0.1 m (4 in).

Task 4. Estimate the Percentage of Unreported Hit-Sign-Post Accidents.

The method for estimating the percentage of unreported hit-sign-post accidents will be based on a comparison of reported accident records with sign maintenance records. The underlying assumption of this method is that because of the breakaway design of most unprotected small sign supports within the clear zone, nearly all motor vehicle collisions with a sign post will result in some type of maintenance activity. Therefore, for a given roadway section, it is assumed that the sign maintenance records can be used to estimate the actual number of hit-sign-post accidents. Thus, the candidate State for this type of analysis will need to have an accurate data base of its sign maintenance activity. Additionally, the data base will have to identify the reason for maintenance. This will permit the separation of work done as a result of motor vehicle damage from maintenance performed for other reasons, such as vandalism, normal aging, and so forth.

Additional information is necessary to identify those signs in the study sample that required maintenance because of motor vehicle damage during the time period to be considered. The following information, as a minimum, will be part of the candidate State's sign maintenance records:

- Type of sign, including legend.
- Longitudinal location of the sign, including route number and milepost.
- Lateral location (highly desirable though not absolutely necessary).
- Description of work performed on the sign.
- Reason the work was performed.
- Date the work was performed.

This would yield a factor by which police-reported accident rates can be adjusted to reflect unreported accidents for a better estimate of the true accident rates.

Comparison of Sign Maintenance Records with Reported Accidents

Sign maintenance records will be compared with accident records for the road sections for which roadside data is collected. This comparison can be used to estimate the percentage of unreported hit-sign-post accidents. It should be noted that for the pilot study, which was documented earlier in this report, there were a few reported hit-sign-post accidents for which a corresponding sign maintenance record could not be located. Unless there were inaccuracies with either the sign maintenance or the accident records system, this finding implies that it may be possible that some signs are not replaced or, if they are, they are reinstalled at a different location. The contractor should consider this during the conduct of this plan.

In the pilot study, the comparison of State-reported accident data and sign maintenance data did not bear out the expected results. As described previously, the fundamental assumption of this method is that every motor vehicle collision with a sign post should result in maintenance activity. It was expected that all reported accidents would have a matching sign maintenance record. Any unmatched sign maintenance records would then be considered unreported accidents. However, none of the reported hit-sign-post accidents within the overall study sample, including both curves and tangents, could be matched to a corresponding sign maintenance record.

To further investigate this issue, the pilot study analysis considered a portion of the sample for more detailed investigation. All types of reported accidents on this subsample were compared to the sign maintenance records for the corresponding road sections. The speculation was that possibly some reported accidents involving a hit-sign post were just not being coded as such. In this case, however, even with generous consideration for both the time lag from accident occurrence to maintenance activity and the inaccuracy in the reported location of accidents, not a single accident record could be matched with a sign maintenance record. Consequently, the contractor should contact, through the State liaisons, a sample of highway agency district personnel and police officers who complete the reports about the disposition of signs knocked down.

The unexpected results of the pilot study necessitated a somewhat modified methodology that may be necessary for the experimental plan as well. The total number of accidents was taken to be the sum of the reported accidents (2) and the number of sign knockdowns according to the maintenance records (14). The percentage of unreported hit-sign-post accidents was then expressed as the ratio of the unreported sign knockdowns determined from sign maintenance records (i.e., all of them) to the total number of hit-sign-post accidents as follows:

$$\text{\% Unreported Hit-Sign-Post Accidents} = \frac{(16 - 2)}{(16)} = 87.5 \text{ percent}$$

A similarly determined factor for each combination of roadway type/ADT interval considered could be used to adjust reported hit-sign-post accident rates for the roadway sections in the selected group. Depending on the quantity of data to be analyzed, it may be more desirable to determine the total number of hit-sign-post accidents on each roadway section rather than adjust the number of reported accidents. As in the pilot study, this would be the sum of the matching accident and maintenance records, unmatched accident records, and unmatched maintenance records for each roadway sample traffic and volume category. If feasible, this would be more accurate than adjusting the reported accident rate.

Task 5. Estimate the Percentage of Unreported Hit-Utility-Pole Accidents.

To corroborate the encroachment rate estimate derived from the sign post analysis, this experimental plan will consider utility poles as well. For the same types of roadway and roadside conditions, the encroachment rate estimate derived for signs should be in reasonable agreement, as the encroachment rate will not vary according to the roadside (i.e., a vehicle is no more or less likely to encroach on the roadside in the presence of a sign post than in the presence of a utility pole). As reported earlier in this report, it was estimated that approximately 15 percent of vehicle-utility pole collisions are unreported, based on an analysis of the 1985 NASS cases. A 1980 study by Mak and Mason determined that approximately 11 percent of all vehicle-utility pole collisions are unreported. Based on the available documentation, Mak and Mason derived this estimate from a comparison of utility pole maintenance records and police-reported accident data. However, in a later work, Mak contended that the 11-percent estimate may be low because there are impacts that do not result in the need for utility maintenance. Additionally, in appendix E to TRB Special Report 214, *Designing Safer Roads: Practices for Resurfacing, Restoration, and Rehabilitation*, Deacon indicated that Zegeer and Parker had found that 10 percent of all hit-utility-pole crashes are unreported. (A review of the final technical report prepared by Zegeer and Parker could not confirm this finding.)

At this time, it is suggested for subsequent tasks of this proposed experimental plan that the contractor assume 15 percent of hit-utility-pole crashes are unreported. It should be kept in mind, however, that continuing research in this area may shed new light on this issue. If results for these other research projects are available to the contractor at the time that this experimental plan is conducted, then the contractor should use the latest and best available estimates of unreported hit-utility-pole accidents, in subsequent tasks of this proposed experimental plan.

Task 6. Estimate Encroachment Rates for Three Types of Highways Based on Small Sign Crashes.

The following description of the analytical method uses, as an example, departure angles and lateral extent probabilities that were developed previously by others. These encroachment parameters, developed by Hutchinson and Kennedy, Glennon, Cooper, and others, are the best available at the time that this report was prepared. However, as with the percentage of unreported accidents, continuing research may provide more appropriate and possibly additional parameters.

Estimating Encroachment Frequency from Accident Data

The pilot study developed an approach for estimating encroachment rate from accident data, based on the use of Glennon's roadside hazard model presented in *NCHRP Report 148*.[1] In general, this model is typically used to predict the number of accidents for an individual fixed object over some time period, based on the following:

- An average encroachment frequency.
- An average angle of encroachment.
- The dimensions of the fixed object.
- The lateral offset of the fixed object.
- The distribution of lateral displacements of encroaching vehicles.
- An average vehicle width.

For the purposes of the experimental plan, the general form of the model is expressed as:

$$A_{ij} = T * D * ADTL_j * L_{ij} * P_{ij} \qquad (14)$$

where:

A_i = Number of accidents in which vehicles traveling in a given $lane_j$ impact i^{th} object during the time period, T.

T = Time period, in years, considered by the experimental plan. (3 yr)

D = Lane departure rate per lane, to one side, with units of lane departures per kilometer (mile) per year per ADT.

$ADTL_j$ = Traffic volume for the $lane_j$ being considered.

L_i = Length of the hazard envelope, in kilometers, associated with the i^{th} object for vehicle traveling in $lane_j$ (mile).

P_i = Probability of an accident, given a lane departure from $lane_j$ in the hazard envelope of the i^{th} object.

This equation is used to predict the number of accidents with the i^{th} object from one lane of travel. Thus, this equation would be calculated individually for each lane of traffic from which an errant vehicle could possibly strike the object in question. Thus, for a two-lane road, the above equation would be calculated twice: once for the adjacent lane of travel and once for the opposing lane.

The equation will also be calculated at least twice for a four-lane undivided road: once for each lane adjacent to the fixed object. However, the probability is greatly reduced for an errant vehicle from the opposing lanes to cross both adjacent lanes of traffic and continue a sufficient distance onto the roadside to reach or exceed the lateral offset of the fixed object. Depending on the state of knowledge concerning lateral extent probability distributions at the time this experimental plan is conducted, the contractor shall determine the utility of considering the opposing traffic flow for this type of roadway. In making that determination, the contractor shall review available accident data to determine the incidence of this type of cross-multi-lane roadway crash involving an object on opposite the roadside.

It is highly unlikely that an errant vehicle on a four-lane divided road will cross the median, both opposing traffic lanes, and continue a sufficient distance onto the roadside to reach or exceed the lateral offset of the fixed object. Thus, it is expected that the above equation will only be calculated twice for these types of roads: once for each adjacent lane of traffic.

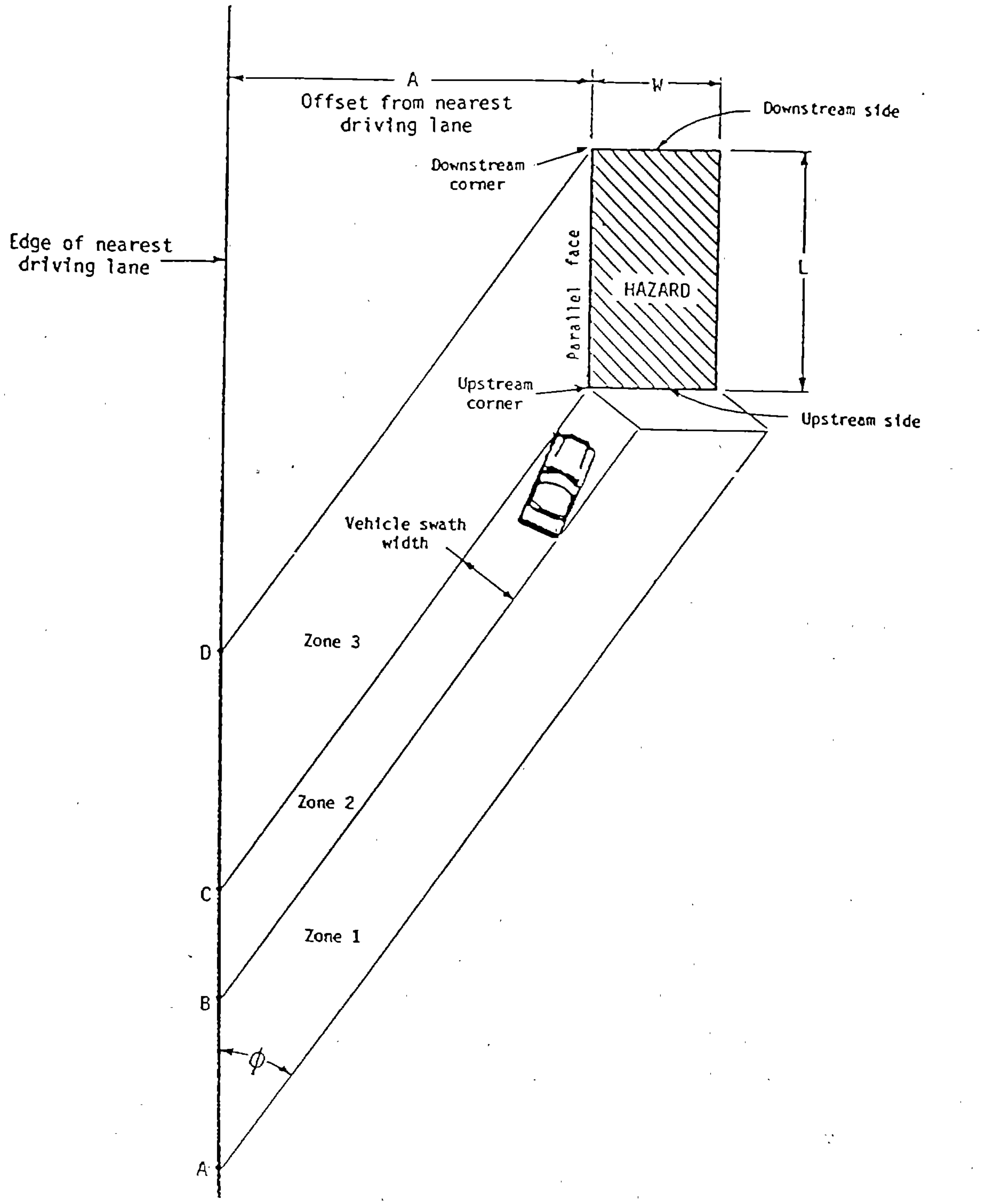
It should be recognized that for each calculation of the above equation, vehicles from different lanes of traffic have different probabilities of an accident given an encroachment in the hazard envelope of a fixed object. This is due to the fact that they are not the same distance from the fixed object at the beginning of the encroachment (i.e., when they errantly leave their respective travel lane). Also, each lane can carry different traffic volumes. For example, while the traffic volume per lane on a two-lane road is usually approximately equal (i.e., half the total volume is in each direction), the same is not necessarily true for a four-lane road. Although the traffic volume for a given direction is not expected to be evenly distributed across the two directional lanes, the simplifying assumption that the directional volume is evenly distributed can be made in the absence of this data. Furthermore, depending on the encroachment parameters used to conduct this analysis, the length of the hazard envelope will not be the same for near-side versus far-side encroachments. These reasons highlight why the above equation must be calculated individually for each lane of traffic from which an errant vehicle could possibly impact a given fixed object.

From Glennon's roadside hazard model, the total length of the hazard envelope for an individual object is comprised of three contiguous sections. The different sections correspond to the different points on the object that the errant vehicle would strike, depending on which section of the hazard envelope the vehicle was in when it began to encroach. Given a sufficient lateral displacement while in the hazard envelope of a roadside object, an encroaching vehicle will strike either:

- The face of the object perpendicular to the roadway.
- The near side, upstream corner of the object.
- The face of the object parallel to the roadway.

Figure 12 shows the relationships between a vehicle, a roadside object, and the three sections of the associated hazard envelope for a near-side encroachment. A similar hazard envelope is

Θ = Angle of encroachment.



Source: *Reference 1*

Figure 12. Geometry of an encroachment assumed by the roadside hazard model.

defined for far-side encroachments. The total length of a hazard envelope, L_i, is calculated as follows:

$$L_i = L_o + \frac{W_v}{\sin \Theta} + \frac{W_o}{\tan \Theta} \qquad (15)$$

where:

L_i = Length of the hazard envelope for the i^{th} object, in meters (feet).

L_o = Length of the i^{th} object, parallel to the roadway, in meters (feet).

W_v = Width of the vehicle, in meters (feet).

W_o = Width of the object, in meters (feet).

The probability of an accident, P_i, given a lane departure in the hazard envelope of the i^{th} object, is determined from the distribution of lateral displacements of errant vehicles. This represents the fraction of lane departures that are expected to reach a lateral displacement greater than or equal to the lateral offset of the i^{th} object. The lateral extent probability distribution presented by Glennon in *NCHRP Report 148* for divided freeways, which was based on the data Hutchinson and Kennedy collected, is used in the following example. Glennon's values for the additional encroachment parameters are used as well. These are:

Near-side encroachment angle	=	6.1°
Far-side encroachment angle	=	11.5°
Effective vehicle width	=	1.83 m (6.0 ft)

Considering a road in which two lanes contribute to the accident potential, solving equations (14) and (15) for D, the lane departure rate, yields the following equation when summed over all of the objects in the sample:

$$D = \frac{\Sigma A_i}{T * [ADTL_1 * \Sigma(L_{i1} * P_{i1}) + ADTL_2 * \Sigma(L_{i2} * P_{i2})]} \qquad (16)$$

If an additional lane or lanes are determined to contribute to the accident potential (e.g. the inside or outside opposing lanes of a four-lane undivided road), additional terms can be added to the denominator of equation (16) to account for this situation. The numerator of equation (16) is equal to the total number of observed accidents (i.e., reported and unreported) with the objects in the sample during the time period being considered. As described previously, 3 years is an appropriate time period. The summation in the denominator can be determined from the roadside inventory data, based on the above discussion concerning hazard envelopes and lateral extent probabilities.

The result of these calculations, D, is the lane departure rate to one side for one lane. A lane departure occurs when a vehicle errantly leaves its lane of travel. On a two-lane road, this occurs when the vehicle crosses either the near-side edge line or the center line. On four-lane divided roads, only the lane departures to the right will be considered (unless accident data supports a different assumption), and these occur when a vehicle in the left lane errantly enters the right lane or a vehicle in the right lane crosses the near-side edge line. For four-lane undivided roads, these same lane departures to the right are also considered. Whether the corresponding lane departures to the left are considered (i.e., vehicle in the right lane enters the left lane or a vehicle in the left lane crosses the center line) will depend on the results of the accident investigations by the selected contractor, as described above.

Assuming that an errant vehicle is equally likely to depart to the left or right, the total number of lane departures per lane is equal to twice the result of the above calculation. This does not, however, equal the roadside encroachment frequency. A roadside encroachment occurs when an errant vehicle crosses an edge line and travels onto the shoulder (if one exists) or beyond. For a two-lane road, this is the result of a vehicle crossing the near-side edge line, or traversing the adjacent lane and crossing the far-side edge line. Similarly, on four-lane divided roads, this is the result of vehicles in the right lane crossing the near-side edge line or vehicles in the left lane crossing the right lane and continuing onto the shoulder or beyond. On four-lane undivided roads, this primarily occurs as with four-lane divided roads. Although on rare occasions, a vehicle may cross the centerline and both lanes of adjacent traffic and continue onto the shoulder or beyond.

The roadside encroachment rate for a road in which vehicles from two lanes would likely reach the roadside, is estimated as follows:

$$Ef_{rs} = D * [(ADTL_1) + (ADTL_2 * P_{s>w})] \quad (17)$$

EF_{rs} = The roadside encroachment frequency, per side. (roadside enc/km/yr)

D = The lane departure rate to one side, per lane. (lane dep/km/yr/ADT)

$ADTL_1$ = The traffic volume for the lane directly adjacent to the roadside.

$ADTL_2$ = The traffic volume for a lane that neighbors the lane directly adjacent to the roadside (i.e., the opposing lane on a two-lane road or the left lane in a given direction on a four-lane road.

$P_{s>w}$ = The fraction of errant vehicles expected to reach a lateral displacement, s, greater than the adjacent lane width, w, according to the lateral extent probability distributions.

From this equation, it can be seen that the roadside encroachment rate is comprised of all encroachments to the right from the adjacent lane and the fraction of encroachments from the neighboring lane that are expected to reach a lateral displacement greater than or equal to the adjacent lane width. This reasoning can be extended to estimate the roadside encroachment frequency for any lateral displacement beyond the edge line. Also, if appropriate, additional terms may be added to this equation to account for vehicles from additional traffic lanes, such as with four-lane undivided roads.

Example Application of the Encroachment-Based Roadside Hazard Model

To estimate encroachment frequency using the data collected for sign posts, the number of hit-sign-post accidents as determined by the method described earlier becomes the value for ΣA_i in the numerator of equation (16). For this example, a sample of road sections on which a total of 40 hit-sign-post accidents occurred over the 3 previous years (i.e., reported plus unreported) was considered.

The value of T in the denominator of equation (16) is 3 years, which corresponds to the time period for which sign maintenance records and accident records would be reviewed. The remainder of the denominator is the sum of the individual values of $L_i * P_i$, for each of the sign posts in the sample of road sections. For the purpose of this example, assume:

- A two-lane roadway with a total weighted ADT of 3,000 vehicles per day.
- A sample of 400 10-cm by 10-cm (4-in by 4-in) wooden sign posts spaced so that their hazard envelopes do not overlap.
- All sign posts are located 5 m (16 ft) from the near edge of the travel lane and are not shielded by guardrails, ditches, etc., from being struck by errant vehicles.

From Glennon's encroachment parameters listed previously, the near side hazard envelope is approximately 18.3 m (60 ft) long and the far side hazard envelope is approximately 9.8 m (32 ft) long. Thus, using these values in equation (16) yields:

$$D_{1500} = \frac{40 \text{ acc}}{3 \text{ yr} * [(1{,}500)(400)(18.3/1000)(0.70) + (1{,}500)(400)(9.8/1000)(0.33)]}$$

$$\mathbf{D_{1500} = 0.00139 \text{ lane dep/km/yr/ADT}}$$

This lane departure rate (to one side) can also be expressed per HM vehicle kilometers, as defined in the Hutchinson and Kennedy report, as:

$$D_{1500} = \frac{(0.00139 \text{ veh-lane dep/km/yr/day}) * (100 \times 10^6 \text{ km/HM km})}{(365 \text{ day/yr})}$$

$$\mathbf{D_{1500}} = \textbf{380 lane dep/HM veh km} \text{ (lane departures to one side, per lane)}$$

Another way to express the above lane departure rate (to one side), as a frequency, is as follows:

$$D_{1500} = (0.00139 \text{ lane dep/km/yr/ADT}) * (1{,}500 \text{ veh/day})$$

$$\mathbf{D_{1500}} = \textbf{2.08 lane dep/km/yr} \text{ (lane departures to one side, per lane)}$$

Of course, an actual example will have sign posts and utility poles of different sizes and, therefore, different lengths of hazard envelopes. They will also be located different distances from the edge of the travel way, resulting in different probabilities of being struck given an encroachment in their hazard envelope. Also, the traffic volume per lane may not necessarily be equal, particularly for four-lane roads. For this reason, the terms in the denominator will need to be calculated individually for each object in an actual sample.

It should also be noted that this analysis has been simplified somewhat, in that it used a single probability of an accident given a lane departure in the hazard envelope of an object. A more rigorous application of the model would have considered the varying lateral displacements of the vehicle that would correspond to collisions with different points along the object. The hazard envelope would have been split into a number of subsections, with the length of each subsection multiplied by the probability that a vehicle would reach or exceed that particular lateral displacement. As an approximation, this example used the overall length of the envelope multiplied by the probability that a vehicle would reach a displacement greater than or equal to the lateral offset of the near side of the object. Given the uncertainty associated with the available lateral extent probability distributions, this is an acceptable simplification. However, on-going research in this area may provide lateral extent probabilities such that an appropriate refinement would be to analyze the hazard envelope more in depth, as described.

Table 6 shows the length of the hazard envelope for near- and far-side departures, based on the values for encroachment parameters listed above (i.e., encroachment angles and vehicle swath width). These values should be used in the absence of more appropriate data applicable to the specific signs and or utility poles present. In addition, the length of the hazard envelope for objects having other dimensions can be calculated through the use of the equations presented above and basic geometry.

Table 6. Hazard envelope lengths for typical objects.

Object	Size	Near-side hazard envelope length	Far-side hazard envelope length
Sign	10.2 cm x 10.2 cm (4" x 4")	18.1 m (59.4 ft)	9.7 m (31.8 ft)
	15.2 cm x 15.2 cm (6" x 6")	18.7 m (61.3 ft)	9.9 m (32.5 ft)
	5.1 cm circular dia	17.7 m (58.1 ft)	9.4 m (30.8 ft)
Utility Pole	25.4 cm x 25.4 cm (10" x 10")	19.8 m (64.9 ft)	10.5 m (34.4 ft)
	30.5 cm x 30.5 cm (12" x 12")	20.4 m (66.9 ft)	10.7 m (35.1 ft)
	38.1 cm x 38.1 cm (15" x 15")	21.2 m (69.5 ft)	11.1 m (36.4 ft)

Task 7. Compare Encroachment Rates and Develop Base Encroachment Rates for Use in Roadside Hazard Models.

The lane departure values determined by this experimental plan represent the rate at which errant vehicles are expected to leave their lane to one side. All rates determined from this experimental plan (i.e., for each traffic volume category for each road type) should be compared directly with the single-base encroachment rate presented in the AASHTO *RDG* for all traffic ranges on all types of roads.

The lane departure rate from this experimental plan should then be used to estimate the roadside encroachment rate. For a four-lane divided road, this value could be compared directly with the value presented by Glennon in *NCHRP Report 148*. His cost-effectiveness analytical method for divided highway roadsides used a modified form of Hutchinson and Kennedy's data for median encroachment frequency. Glennon reasoned that the encroachment frequency for the combined roadsides was the same as the median encroachment frequency. That is, half the median encroachments were expected to come from each side of the divided highway. Furthermore, for a given side of the highway, he assumed an equal number of encroachments onto the roadside as into the median. It would be expected, however, that if the right lane in a given direction carried more traffic, then there would be more roadside encroachments. Conversely, if the left lane carried more traffic there would be more median encroachments expected. Thus, his apparent simplifying assumption was that traffic was distributed equally among the lanes for there to be the same number of median and roadside encroachments.

If the experimental plan explicitly considers traffic distribution by lane, this traffic distribution can be used with the resulting lane departure rate to estimate a median encroachment rate in a manner similar to that described for estimating a roadside encroachment rate. This can then be compared directly to what Hutchinson and Kennedy determined empirically. The reasoning is that if the lane departure rate adequately predicts median encroachment rates, as determined by comparison with Hutchinson and Kennedy's data, it will also suffice for predicting roadside encroachments. It should be recognized, as described in the report for the pilot study of this experimental plan, that Hutchinson and Kennedy's data may be skewed because of their data collection techniques. Therefore, their results probably do not reflect true encroachment rates, as they readily conceded in their own report; however, it is one of the few empirical data sets that exists for comparison.

Task 8. Prepare Draft and Final Reports.

ANTICIPATED COST AND SCHEDULE

It is projected that this experimental plan will take approximately 28 months to conduct and cost approximately $275,000. This estimate assumed that:

- No undue delays are encountered in the collection of accident, roadside, sign maintenance, and utility maintenance data.

- A minimum of three States can be identified that have all of the required information in the form of readily-accessible data bases or videologs, including the roadside information that would otherwise have to be collected as part of a field survey. This necessarily includes lateral offset to fixed objects and any factors that would influence the probability that the objects could be struck, such as location of guardrail, non-traversable ditches, or steep embankments. Other desirable information includes lane width, paved shoulder width, unpaved shoulder width, side slope, and clear zone, which would be used either directly in developing additional factors for the roadside hazard model or indirectly through the use of future lateral extent probability distributions that consider these elements.

If no appropriate State can be identified that has the information listed above in the form of computer data bases or videologs, then a roadside data collection effort will be necessary. Based on the roadside data collection effort conducted as part of the pilot study, it is estimated that this would add an additional $90,000 to the cost of the experimental plan, for a total cost of approximately $365,000. This assumes that sufficient data will be collected to estimate the encroachment rate for the four traffic volume categories suggested previously for two-lane roads, four-lane divided roads, and four-lane undivided roads. Additional traffic volume categories (e.g., narrower range of traffic volumes, and consideration of higher traffic volumes) will increase the cost further. Conversely, focusing on fewer traffic volume categories or considering fewer road types will reduce the cost of the experimental plan.

The cost for collecting roadside information is based on the results of the pilot tests that were conducted in Idaho. A two-person team collected detailed information on both small roadside signs and utility poles along 80 km (50 mi) of two-lane rural roads in Idaho as part of this research effort. As is the case with many States, no paper or computer files containing data on the longitudinal or lateral location of roadside signs and utility poles existed. Consequently, the data had to be collected to manipulate the roadside hazard model to estimate encroachment rates from accidents. Data were collected for utility poles and small roadside signs that were on both sides of the two-lane rural roads, but not located behind guardrails. In addition, an effort was made to exclude poles and signs mounted on the back sides of drainage ditches that were deemed to be non-traversable. Data elements included the following:

- The milepoint location, which was recorded using a distance-measuring instrument.
- Whether the object was a small sign or a utility pole.
- The lateral offset of the object, measured from the edge of the travelway to the face of the object. For roadside signs, the lateral offset was measured to the face of the sign post, not the edge of the sign, if it was judged that a typical sedan vehicle could pass under the sign without hitting it. In most cases, conventional warning and regulatory signs were mounted at the MUTCD-recommended vertical minimum height of 2.1 m (7 ft).
- The type of standard, if the object was a roadside sign.

Because alignment data were not available before the data collection trip, it was expected that a certain percentage of the roadway mileage would be curvilinear or on grade. Because the scope of this effort was devoted to primarily level, tangent sections, only 56 km (35 mi) of the 80 km (50 mi) of two-lane rural roads inventoried could be used. It took approximately 3 weeks of effort for two people to collect the data in the field and reduce the data into a meaningful data base, which equates to 240 person hours of effort. It can therefore be calculated that on the average, it took approximately 4.3 person hours of effort per kilometer (6.9 person hours of effort per mile) to collect, reduce, and process data pertaining to utility poles and small roadside signs which were located on both sides of two-lane rural road tangents. Assuming a fully-loaded labor rate of $28/hr for the data collectors, the average data collection and reduction cost is approximately $124/km ($200/ mi) to collect the data.

For the purposes of this proposed experimental plan, it is estimated that the minimum desirable sample size would be 1,845 small signs and 1,660 utility poles for each of three roadway types, based on the high estimate described previously in the section of the experimental plan entitled "Desirable Minimum Sample Size and Road Selection Criteria" in the description of Task 3. Consequently, the total desirable sample would be 5,535 small signs and 4,980 utility poles. Furthermore, it can be assumed that utility poles are placed typically on one side of the road, whereas small signs are placed on both sides of the road.

Based on the data collected in Idaho, the average density of small signs and utility poles on tangent sections of two-lane rural roads was found to be 9.4 signs per km (15 signs per mi) and

10.9 utility poles per km (17.6 utility poles per mi). Assuming these average densities and the practice that utility poles are placed on only one side of two-lane roads while small signs are placed on both sides, it can be estimated that the total minimum desirable length of tangent, two-lane rural road sections would be 295 km (185 mi) for small signs and 457 km (283 mi) for utility poles. Consequently, the labor cost to collect roadside data, if roadside data inventories are not available, could be as high as $57,000, which would pertain to approximately 1,960 person hours. The costs to equip one vehicle with a distance-measuring instrument, which would be required for accurate location identification, would be less than $1,000. It is expected that videotapes, film, processing, video camera rental over a 5-month period, and the rental of a notebook computer over a 5-month period would cost approximately $3,500.

Assuming one-quarter of the data collection sites do not require overnight lodging, then the estimated number of per diem days would be 184 person-days (i.e., .75 * 1,960 person hours / 8 hrs per day). The costs for per diem assuming $75/day would be on the order of $13,800. Additional transportation costs for airfare, car rental, and mileage could be as high as $4,000. Assuming a contingency factor of 15 percent, the total costs for roadside data collection could be slightly more than $91,000.

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