A. A. Lancola

384065

A Study of Two-Lane Rural Roadside Accidents

DONALD E. CLEVELAND
Professor of Civil Engineering

and

RYUICHI KITAMURA
Research Assistant

August 1976

Michigan Department of State Highways and Transportation
Contract No. 75-1724 - Amendment to No. 75-1301
Lansing, Michigan

THE UNIVERSITY OF MICHIGAN 1817

Department of Civil Engineering

THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING

Department of Civil Engineering

A STUDY OF TWO-LANE RURAL ROADSIDE ACCIDENTS

Donald E. Cleveland
Professor of Civil Engineering

and

Ryuichi Kitamura
Research Assistant

DRDA PROJECT 384065

under contract with:

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION
CONTRACT NO. 75-1724 - AMENDMENT TO NO. 75-1301
LANSING, MICHIGAN

administered through:

DIVISION OF RESEARCH DEVELOPMENT AND ADMINISTRATION
THE UNIVERSITY OF MICHIGAN

DECEMBER 1976

ACKNOWLEDGEMENTS

The cooperation provided by Michigan Department of State Highways and Transportation employees Maurice Witteveen, William Lebel and Preston Masters is gratefully acknowledged. Mr. Donald E. Orne, Engineer of Traffic and Safety, first specified this problem and provided invaluable assistance.

Mr. Charles Knowles of the Kentucky Highway Department assisted while he was a student at the University of Michigan. The assistance of Ms. Bonnie Fore and Ms.Gail Gray in preparing the tables and text is gratefully appreciated.

DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Michigan State Highway Commission or the University of Michigan.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

SUMMARY OF FINDINGS

This study was directed toward assisting the Michigan Department of State Highways and Transportation (MDSHT) in its program of providing additional safety on state trunkline highways. The type of accident of particular interest is that in which a vehicle sustains damage and passengers may be injured _after_ the vehicle leaves the road. These off-road accidents include most of the so-called _single-vehicle_ accidents as well as those involving _fixed-objects_ located off the road. They also include accidents in which vehicles _overturn_ after leaving the road.

The MDSHT has a program for ameliorating the effects of these off-road accidents on the state's freeway and expressway system. This type of accident on freeways has received much attention (2)*, however, there has been little formal attention to a program for diminishing the effects of these type of accidents on other highway types for which the MDSHT is responsible other than using engineering judgement and allocating some funds specifically for this type of improvement.

In this study, making extensive use of MDSHT accident files and roadway information from sufficiency studies and the photolog, a mathematical model of the frequency and severity of off-road accidents recently developed in an NCHRP project by Glennon (15) and further extended by him (16) has been investigated as a tool for use in Michigan.

---

*Numbers in parentheses refer to references listed at the end of the report.

Data showing the severity of Michigan off-road accidents on rural two-lane trunklines to be used along with Glennon's values have been developed.

Glennon's model does not take into account alignment and assumes that the effect of traffic volume on accidents is proportional to ADT. These elements were given careful study and significant effects identified. The effect of ADT was found to decrease with increasing volume and curved alignment has a large effect on off-road accident occurrence as well as severity.

These effects have been quantified in a number of mathematical formulas which capture their impacts with reasonable accuracy and which should prove helpful in detailed analyses as well as in important policy decisions.

A procedure for immediate implementation of these findings is suggested.

CHAPTER II

BACKGROUND AND APPROACH

Michigan experiences more than 300,000 reported automobile accidents each year and these crashes exact a toll of about 2,000 lives and 150,000 injuries as well as $700 million in property damage.* Of these accidents 110,000 occur on rural roads outside of incorporated areas. These rural accidents are more severe than urban accidents.

The most important segments of the rural road network, those which serve cross state and interstate movements in large numbers, are under the supervision of the Michigan Department of State Highways and Transportation (MDSHT). The total rural state trunkline mileage is 7,968 of the total 97,828 miles of rural road in Michigan. This 8 percent of the mileage carries 38 percent of the rural traffic and suffers 50,000 accidents per year and a total of 600 deaths. Among these accidents a group which has received much attention in recent years is that in which the vehicle leaves the road and suffers damage or injury to its occupants by striking an obstacle or losing its stability as a result of the cross section of the roadside.

These off-road accidents are not exactly characterized by standard accident report coding** although the general nature

---

*Data are general averages of data from the early 1970's developed by the Michigan State Police in _Michigan Traffic Accident Facts,_ an annual publication.

**See Reference (3) in the list of references following this report. Its author, Baker, has an excellent discussion of this problem.

of this type of accident can be found by looking at two main subgroups; those recorded as being involved in a fixed-object accident and those accidents in which the vehicle overturns.

In 1968 Baker (3) presented a comprehensive summary of research findings on single-vehicle accidents. Nationwide, single vehicle accidents resulted in 34% of rural nonfatal accidents. Stonex (39) reported that single-car accident fatalities averaged 42% (16,000) of the total recorded from 1953 to 1962. Reported Michigan rural fixed object accidents average nearly 40,000 per year. Four hundred are killed and 17,000 injured. One hundred of these killed are on state trunklines and 3,000 injured are on this type of road.

Just as in many other types of accidents, steps (or countermeasures) can be taken to reduce the toll from the off-road accident. Obstacles can be removed or moved farther from the road, weakened so as to break away without damaging the vehicle extensively or protected by devices which absorb the vehicle's energy or redirect the vehicle along a safer path. In addition, the ground form created by ditches, embankments and slopes, can be made more forgiving by reshaping it for improved vehicle stability.

It must be recognized that a program of making every mile of the state's system have a "forgiving roadside" would require a tremendous investment in funds and time, if possible at all, and leads one inevitably to the conclusion that the state must invest the limited funds available for roadside improvements in a way that will return safety benefits that fully justify the expenditure. It is also necessary that they be spent in the proper locations, making only improvements which will yield the greatest return from among the many possibilities that exist.

The Michigan Department of State Highways and Transportation (MDSHT) along with most other progressive highway agencies has been very concerned with the off-road accident. For some years attention has been paid particularly to the state's freeway system where the spectacular nature and heavy representation of off-road accidents in the total has caused much attention to be paid to this part of the system. Yet, the MDSHT's responsibilities also include two, three, and four lane undivided highways in both rural and urban areas upon which there is also a significant number of off-road accidents. MDSHT is launched in a program which has as its goal the improvement of the roadside to current state standards on the entire state trunkline system*.

A key step in a roadside safety program is to be able to understand what can be expected to happen when a roadside improvement of a given type is made. If, for example, we eliminate all trees within 20 feet of the edge of the travelled way what will be the average improvement in safety to motorists on Michigan highways; or if we replace old guardrail with more modern designs what will be the reduction in injuries among those vehicles striking the rail? An organized way of developing the necessary understanding is to model the process with accuracy adequate for the

---

*MDSHT, Design Guides for Roadside Safety Improvement Program: Task 1, Lansing, Geometric Standards and Development Unit, Traffic Research and Development Section, Traffic & Safety Division, January 1975, p. 1.

MDSHT investment design process. A useful model must be able to cope adequately with all the possible improvements available to the highway safety engineer. For obstacles this means that the effect of removing as well as moving the obstacle to a different location must be coped with by the model. In addition the reduction or changing the nature of the energy exchange by breakaway devices, attenuators, deflectors, etc. must be also considered.

Unfortunately, the present state of understanding of accident causation is inadequate. However, in recent years sustained efforts in this area have begun (15) and promising results obtained. We now will review these results, indicate some current problems and outline the approach used in this effort to assist the MDSHT in its program for two-lane rural roads.

2.1 Previous Studies

The primary interest in this study ultimately reduces to where the off-road accident occurs and to be able to predict accident frequency and severity using only knowledge of road and traffic conditions. There have been many studies related to this type of task for two-lane rural roads in the past which are relevant to this problem.*

In studies of all accidents, traffic flow (ADT) and alignment have been shown to be important variables which explain part of the accident location phenomenon. Increasing ADT and curved alignment are both associated with higher accident experience.

---

*Excellent summaries are provided in various chapters of Traffic Control and Roadway Elements - Their Relationship to Highway Safety, References 8, 10 & 27.

In an early study, Raff (36) found curvature caused two to four times as many accidents. Gupta and Jain modeled the effect of roadway geometrical elements on the two-lane rural road accident rate in Connecticut (18). Restricted sight distance was the best predictor followed by horizontal curvature. Roadway width played no role in explaining accidents.

There have been several studies of single-vehicle accidents. Recently, Kihlberg and Tharp (24) in studies in three states found that single-vehicle accident experience increased with curvature (4° appeared as a critical boundary), gradient (4%), and presence of structures. Accident experience did not keep pace with increasing ADT. Short lengths of homogeneus road had more accidents per mile than did longer sections, indicating an additional accident increasing effect as the character of the roadway changes. Agent and Deen (1) analyzed 1970-72 Kentucky accidents and concluded that single-vehicle accidents were the most severe (injury plus fatal accident fraction of total accident experience) and that accidents on curves had the highest severity.

In a recent study of 300 fatal Georgia accidents by Wright and Robertson (42) it was concluded that priority should be given to curves with radii less than 1,000 feet (6° , although more serious results begin at 3°), particularly on down-grades greater than 2%. Accidents on curves were overrepresented by a factor of 2.5.

The most extensive reported study of this subject was recently completed by Foody and Long (14). In the first part of their study a large number of road traffic flow characteristics were used to model single-vehicle off-road accidents. In the model with the best ability to describe the phenomenon only 37% of the variance was explained by a linear relationship involving as many as 14 variables. It was concluded that traffic volume, sight distance restriction, road geometry transitions and shoulder width were the most important variables in this explanation.

A second analysis looked at shoulder width and type as well as simply classifying the roadside as good or bad. The importance of shoulder width and surface stability was confirmed. The relative possible improvement resulting from roadside improvements was concluded to be quite small. They concluded that a good quality wide shoulder is more important than any program of providing a clear roadway farther from the road's edge. Studies of severity revealed that the development of a roadside improvement program would not yield adequate returns and that attention should be focused on shoulders and the road itself in Ohio.

The Ohio study did not simultaneously take into account the many possible road elements (for example, alignment),the traffic flow, and the characteristics of the roadside. The existence of interactions among these elements casts serious doubts on the validity of their findings.

Recently Dearing and Hutchinson (10) quoted a study indicating that roadside improvement programs for high design standard roads with ADT less than 400 are not cost effective.

2.2 Modeling Off-Road Accidents - Glennon's Model

Modeling off-road accidents can take advantage of the fact that most of them are single-vehicle accidents and the bulk of these involve the vehicle striking a fixed roadside object. Figure 2-1 breaks this accident into four events; encroachment on the roadside, a trajectory followed by the vehicle, a collision between the vehicle and the object, and the severity of the crash. The relevant elements which control each of these states are shown on the left.

Glennon (15) has used such a concept to develop a mathematical model of this process using the following elements:

H = The Hazard Index (expected number of fatal plus nonfatal injury accidents per year caused by an obstacle).

V = Vehicle exposure (number of vehicles per year passing through a section of L; ADT x 365).

$P(E|L, R)$ = Probability that a vehicle will encroach, E, on the roadside within increment L (encroachments per vehicle). This probability is a function of length of exposure, L, and other environmental variables, R, such as the geometric design of the roadway.

$P(C|E, \Theta, y, s, l, w)$ = Probability of a collision, C, given an encroachment has occurred (accidents per encroachment). This probability is a function of the angle of encroachment, θ, the vehicle's lateral displacement (measured from the right-front corner of the vehicle) y, the lateral placement of the roadside obstacle, s, and the dimensions of the obstacle, ℓ and w. (See Figures 2-2 and 2-3.)

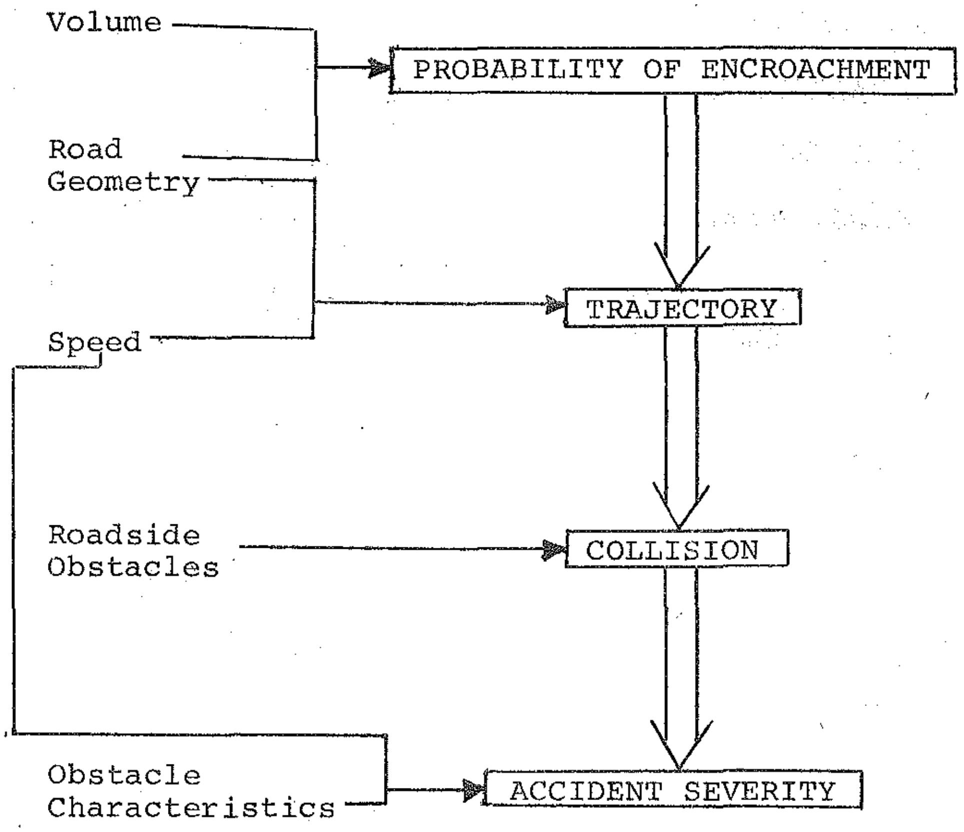


Figure 2-1 THE SINGLE-VEHICLE ROADSIDE ACCIDENT

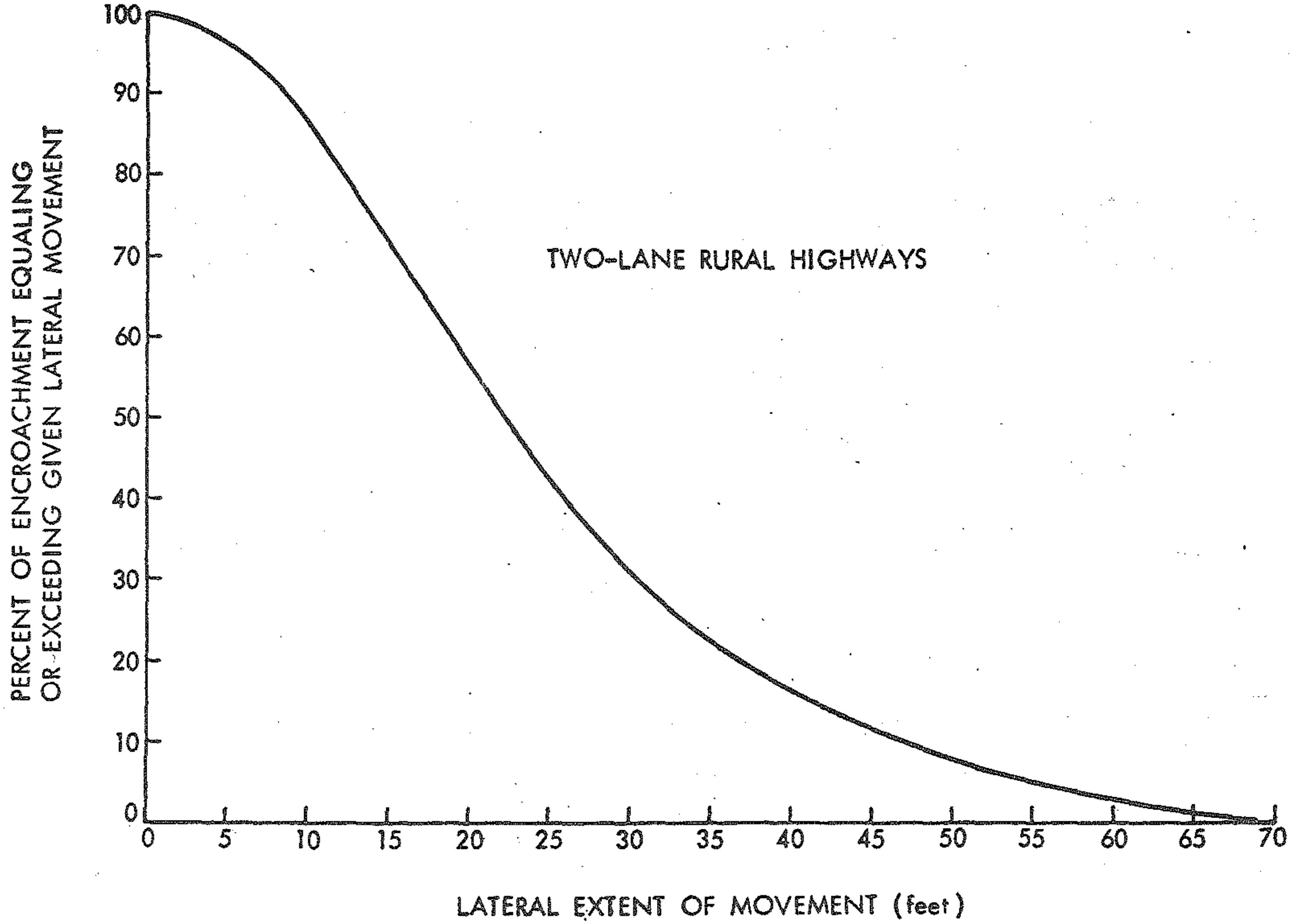


Figure 2-2 Cumulative Distribution of Lateral Displacement of Encroaching Vehicles for Rural Two-Lane Highways

Source: Glennon and Wilton (16)

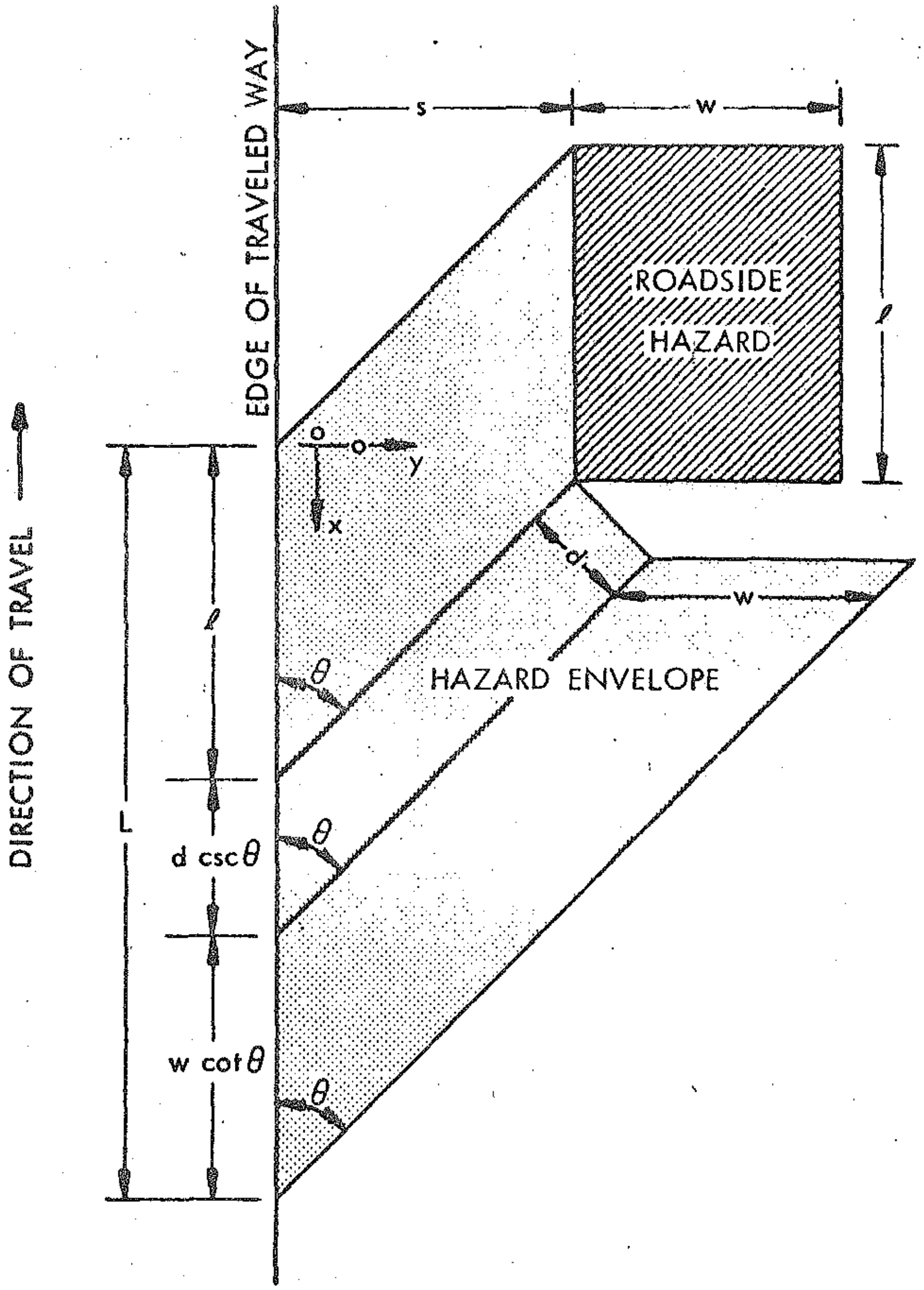


Figure 2-3 Schematic Illustration of Roadside Obstacle and its Relationship to an Encroaching Vehicle

Source : Glennon and Wilton (16)

$P(I|C)$ = Probability of an injury or fatal accident, I, given a collision. (See Table 2-1.)

An equation is developed and is presented below:

$$H = \frac{E_f S}{10,560} \left\{ \ell P\left[y \geq s\right] + 31.4 \quad P\left[y \geq (s + 3)\right] + \frac{5.14 \ w}{n} \sum_{j=1}^{n} P\left[y \geq \left(s + 6 + \frac{w(2j - 1)}{2n}\right)\right] \right\}$$

where H = Hazard Index for a one-direction roadway

E_f = Encroachment frequency (number of roadside encroachments per mile per year).

S = Severity Index (the number of fatal and non-fatal injury accidents per total accident).

$P\left[y \geq s\right]$ = Probability of a vehicle lateral displacement greater than s.

n = Number of analysis increments for the hazard associated with the obstacle width.

j = The number of obstacle-width increments under consideration starting consecutively with $j=1$ at the increment furthest downstream.

This model estimates the Hazard Index for a particular roadside obstacle independent of other contiguous roadside obstacles. To evaluate the effectiveness of a particular roadside safety improvement, the difference in Hazard Index before and after improvement must be calculated.

With appropriate severity indices, it is possible to calculate H for each roadside hazard. And finally, H (before) - H (after)

= Reduction in number of fatal and non-fatal injury accidents

In a recent paper Glennon and Wilton have considered the rural two-lane road (16). They analyzed Missouri data and reported that the encroachment rate for rural two-lane highways with roadbeds, P, greater than 36 feet was $7.42 \times 10^{-4} \times \text{ADT}$ while for narrower roads it was $12.1 \times 10^{-4} \times \text{ADT}$ (see Figures 2-4 and 2-5). The annual accident rates, A, for single vehicles were as follows:

$$A = \begin{cases} .182 + 1.42 \times 10^{-4} \times \text{ADT} & P > 36 \text{ ft.} \\ .159 + 2.35^{*} \times 10^{-4} \times \text{ADT} & P \leq 36 \text{ ft.} \end{cases}$$

Severity indices for such highways are presented in Table 2-1.

Weaver (41) has recently described the practical use of Glennon's model in Texas, including necessary field inventories.

2.3 Some Comments on Glennon's Model

In Glennon's recent work (16) he raised two questions on the model as presented in the previous section. He believes that encroachments on curves may be higher than on tangents and his final conclusion is that research is necessary to account for hazard sensitive site specific parameters.

This research program commenced before these conclusions were available and the same questions have been raised by this investigation team. In the following paragraphs some parts of Glennon's work are discussed.

---

*Estimated by study researchers.

TABLE 2-1

ROADSIDE OBSTACLE SEVERITY INDICES FOR RURAL HIGHWAYS

Roadside Obstacle	Severity Index
1. Utility Poles	0.45
2. Trees (greater than 6 in. dia.)	0.50
3. Rigid Signposts	
a. Large (6 in. steel post or greater; 10 in. timber post or greater)	0.50
b. Small	0.30
c. Breakaway	0.20
4. Light poles, Traffic Signal Poles, and Railroad Signal Poles	
a. Rigid	0.40
b. Breakaway	0.20
5. Curbs	0.35
6. Guardrails	
a. Short (less than 100 ft)	
(1) Safety end-treatment	0.35
(2) No safety end-treatment	0.45
b. Long (greater than 100 ft)	
(1) Safety end-treatment	0.30
(2) No safety end-treatment	0.35
7. Roadside Slopes	
a. Fill slopes	
(1) 2:1 or steeper	0.60
(2) 3:1	0.45
(3) 4:1	0.35
(4) 5:1	0.25
(5) 6:1 or flatter	0.15
b. Cut slopes	
(1) 1:1 or steeper	0.60
(2) 1.5:1	0.45
(3) 2:1	0.35
(4) 3:1	0.25
(5) 4:1 or flatter	0.15
8. Washout Ditch	0.45

TABLE 2-1 (Concluded)

Roadside Obstacles	Severity Index
9. Culverts (Lateral and Longitudinal)	0.45
10. Raised Drop Inlets	0.45
11. Bridge Abutments and Piers	0.60
12. Roadway Over Bridge Structure	
a. Open gap between parallel bridges	0.50
b. Bridgerail--smooth	0.35
c. Parapet-type bridgerail	0.40
d. Bridgerail end or gore abutment	0.50
13. Retaining Walls and Fences	0.35
14. Fireplugs	0.30

Source: Glennon and Wilton (16)

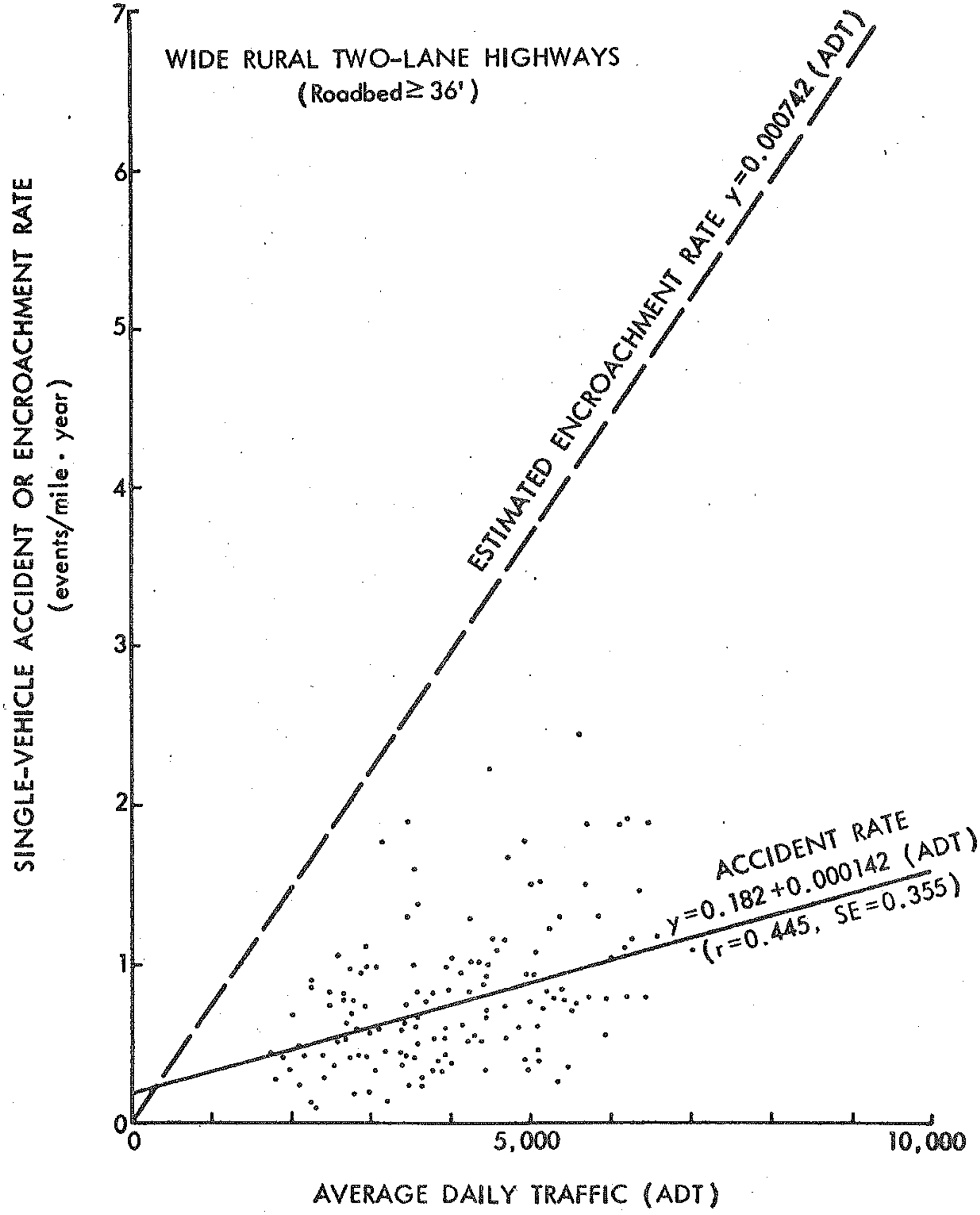
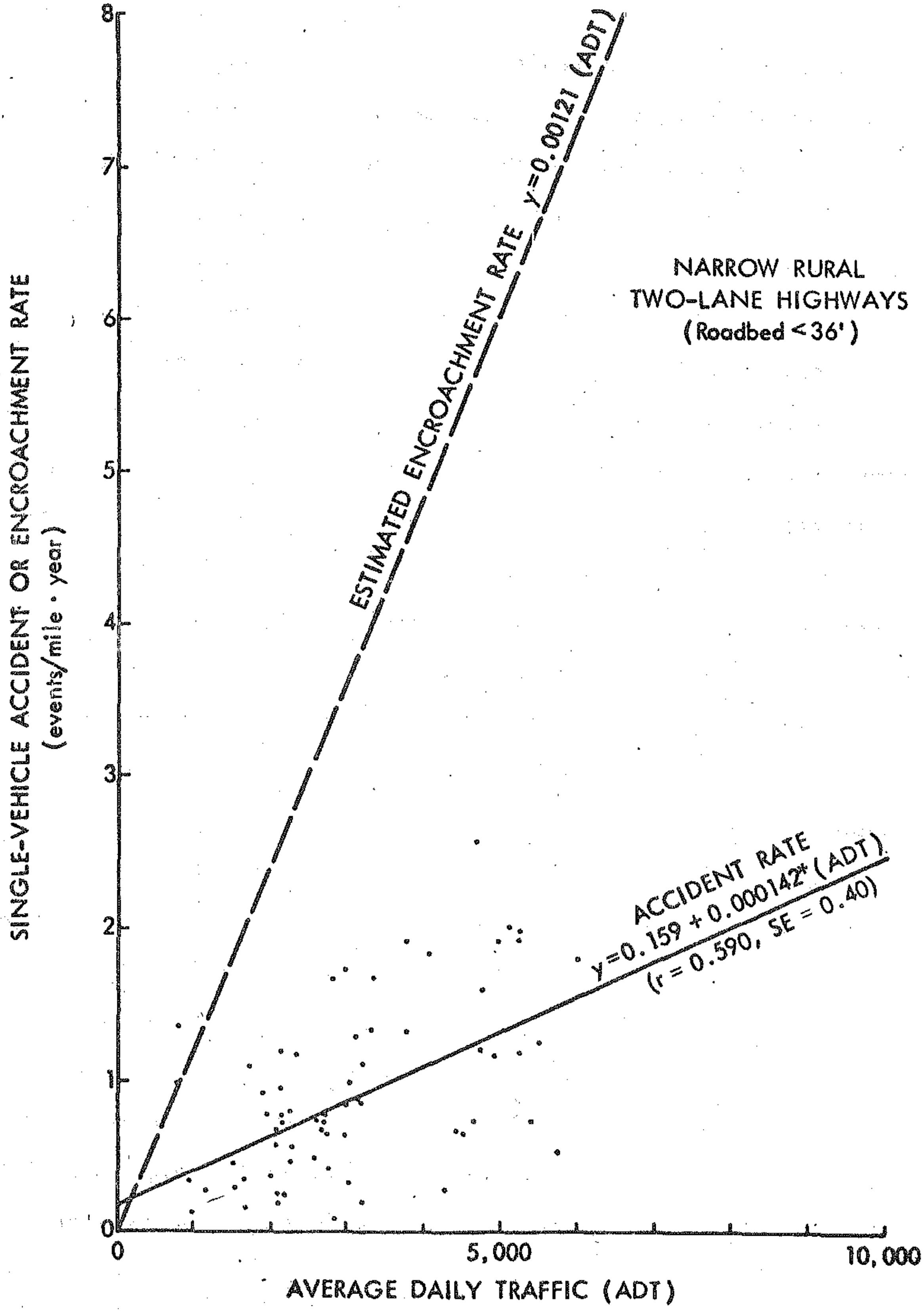


Figure 2-4 Single-Vehicle Accident Rate and Estimated Encroachment Rate for Wide Rural Two-Lane Highways (Roadbed of 36 ft. or Greater)

Source: Glennon and Wilton (16)



*See footnote in text

Figure 2-5 Single Vehicle Accident Rate and Estimated Encroachment Rate for Narrow Rural Two-Lane Highways (Roadbed less than 36 ft.)

Source: Glennon and Wilton (16)

First, there is a question on the assumption of a constant or linear encroachment rate (note that eventually this means a constant accident rate because of the nature of the model) over the entire range of traffic volumes. In other words, in Glennon's model the number of fixed object accidents is directly proportional to traffic volume, for a given environment. As previous studies for single-vehicle accidents have shown, the rate shows a clear decrease as traffic increases. Little information is available to investigate the relationship between fixed-object accident rates and traffic flow. However, judging from the fact that most fixed object accidents are single-vehicle accidents the assumption of a constant accident rate seems quite questionable.

No consideration of roadway geometry (alignment, or cross-section) is included in Glennon's model. The effect of geometry on accidents is not easy to specify. One reason is that no data are easily available to normalize accident experience by the exposure (e.g., by the length of a curve or cross traffic at an intersection). However, accident severity is higher on curved sections than on tangent sections; the existence of curves in a section results in a higher overall accident rate as well as a higher single-vehicle accident rate. These empirical results, together with our intuitive understanding, imply the necessity for the evaluation of the effect of geometry on roadside hazards.

Another comment with respect to the road geometry is the effective "exposure" of an obstacle, its length, ℓ. It can be easily seen that the length of the hazard section, ℓ (determined by assuming that the encroachment angle is constant at all points), varies with the alignment (37). In addition to the change in the length of exposure, the probability of encroachment itself will reasonably be regarded to be affected by the alignment. These discussions suggest that the framework employed by Glennon's study can be developed for the appropriate application to various roadway alignments other than tangent sections.

As has been mentioned, Glennon's model has a structure in which the stages in the accident process are treated as mutually independent. Actually, there are clear interrelationships among variables that affect the occurrence and severity of accidents. Our first point is related to the accident severity. In Glennon's model, the severity has a fixed value for each type of obstacle and other conditions have no effect on the severity. For example, the severity of a collision with a utility pole is, given that a collision has occurred, of the same degree regardless of the location of the pole (10 feet from the roadway, or 50 feet). Actually, the off-road vehicle will gain or lose energy on its path and this will naturally affect the severity of the collision. This process will be highly governed by the cross-section characteristics. Also, the severity is related to the intensity of the collision impact which is not independent of the whole accident process. Although to describe the process of an accident in every detail is impossible, some effective variables could be selected to represent the dynamic effect of the accident process.

Next, in Glennon's model, the probability of collisions is determined by the planar size of the obstacles, their lateral location and orientation and the distribution of lateral vehicle displacements. Here again, one must consider the effect of roadside structure and alignment, especially on the distribution of lateral displacements. A roadside slope may have an influence on the trajectory of an encroaching vehicle and thus on the displacement. The alignment may cause different values of encroachment angles as well as lateral displacements. These dynamic effects are all neglected in Glennon's model.

The preceding comments can be summarized as follows. An off-road fixed-object-accident is a result of an involved process which is conditioned by the roadway geometry, roadside characteristics, and the obstacle as well as the vehicle-driver system. The vehicle encroachment, collision and the resulting severity should be regarded as mutually related phenomenon, whereas, in Glennon's model, they are treated as independent and discussed separately. Roadway geometry and roadside characterization are not taken into consideration to the necessary level. Thus the dynamic aspects of fixed-object accidents is lost from the model. Therefore, the use of Glennon's model with its most recent parameters by the MDSHT may lead to over investments in roadside improvements on high ADT roads, on tangents, on cut sections and less improvements than warranted on roads with lesser ADT values, with curvature, intersections and on embankments.

2.4 Study Approach and Objectives

This study has as its objective the development of a technique to use Glennon's model on the Michigan trunkline system. The Michigan two-lane trunkline system contains many miles with urban type development in both cities and villages. In these areas speed limits vary widely, off-roadway geometry is treated in many ways, obstacles are unusual and intersections have varying designs, movements and controls. These characteristics all combine to make the problem of roadside safety very complex. There has been little reported research on this type of facility and this, combined with their lesser accident experience, and with the concurrence of the MDSHT representatives led to this project's concern being limited to the two-lane rural trunkline system of which there are 6,000 miles, approximately 75 percent of the MDSHT rural mileage. Therefore, the effort is devoted exclusively to the rural system.

As has been discussed, Glennon's model is a microscopic tool in the sense that the development of the hazard index for a length of roadway requires detailed information on each obstacle along the roadway. The primary purpose of this effort is to improve the operational effectiveness of MDSHT procedures in dealing with the off-road accidents on two-lane Michigan trunkline roads. There are two complementary ways in which this can be accomplished. In the first portion Glennon's model itself is tested for direct applicability in Michigan and modifications in calculating the hazard index attempted. Complementary with this is an attempt to aid the MDSHT to identify locations with high off-road accident likelihoods as a by-product of the modelling efforts. This approach will make it possible to identify the sections in which safety improvements are most warranted.

There is another effort which must be explored, that flowing from the energy crisis and the reduced speed limit and ADT. A recent study made at the University of Michigan scales the initial safety effects of the 55 mile per hour speed limit.* In this study it was observed that fatal vehicle accidents on non-freeway trunkline facilities in Michigan declined 41%, a reduction twice as great as that recorded on other parts of the system. (There was a much greater decline in exposure recorded on freeways.) It was also observed that the number of drivers involved in fatal accidents on this type of road declined 46%, indicating fewer single-vehicle fatal accidents as a fraction of all accidents. These effects can be further studied using 1974 accident data.

2.5 Organization of Report

The remainder of this effort is reported in three chapters. In Chapter III key relationships are developed for statewide off-road two-lane rural accidents using aggregations from the individual accident reports in the MDSHT computer file. Chapter IV presents the development of the models recommended for use in two-lane rural situations in Michigan. In Chapter V the procedure recommended for utilization of the model is presented.

---

*James O'Day, et.al, <u>The Effects of the Energy Crisis and the 55 mph Speed Limit in Michigan,</u> Highway Safety Research Institute, University of Michigan, April 1975.

CHAPTER III

OFF-ROAD ACCIDENT CHARACTERISTICS

The purpose of this chapter is to investigate some important characteristics of off-road accidents. Knowledge of these characteristics obtained from individual accident reports provides the starting point for the modelling effort presented in Chapter IV. It assists in the identification of fundamental model variables and in developing a study sampling plan.

3.1 Overview of Fixed-Object and Turnover Accidents on Two-Lane Rural Highways

The definitions of the sub-groups of off-road accidents with which we are concerned in this study are;

> Fixed Object Accident: an accident in which a fixed object is struck by a motor vehicle, regardless of the cause of the collision or the chronological sequence of incidents during the occurrence of the accident. (Turnover accidents are excluded.)
>
> Single-vehicle, Turnover Accident: an off-roadway single vehicle accident where the first incident recorded is the overturning of the accident vehicle.

The accidents are confined to those which occurred on undivided, two-lane, rural (not within city limits) highways.

All accidents meeting the above definitions for the full years 1971, 1972, 1973 and 1974 were extracted from the accident master file maintained by the MDSHT. This accident file contains all accidents reported on the Michigan State Trunkline System; thus this analysis covers the entire two-lane, undivided, rural trunkline system mileage.

Analyses in this chapter are conducted on an aggregated level based on cross-tabulations. These were obtained directly from the above file using MDSHT MALI packages (three-way cross-correlation table, etc.) on both fixed-object and turnover accidents. All accidents falling into the specified categories were treated without discrimination or different weight.

It should be noted that the analyses in this chapter are concerned principally with accident severity rather than the accident rate; primarily because there exist no satisfactory exposure data to normalize the number of accidents for meaningful comparisons at the aggregate level. The effect of roadside features (the location of objects and structures as well as roadside cross-sectional characteristics) is examined in the modelling study using supplementary information on these elements.

The statewide numbers of total off-roadway accidents on free access highways (US and Michigan routes) are shown for the years 1971, 1972, 1973 and 1974 in Table 3-1. The large toll and annual variability is noted. Although not shown in

TABLE 3-1

1971-74 RURAL FREE-ACCESS OFF-ROAD ACCIDENTS BY SEVERITY

	NUMBER OF ACCIDENTS		
YEAR	TOTAL	PROPERTY DAMAGE	INJURY AND FATAL
1971	8297	5146	3151
1972	10175	6521	3654
1973	8762	5541	3221
1974	7875	5041	2834
TOTAL	35109	22249	12860

the table more than 60% of these accidents on rural highways are of the fixed-object and turnover type with which this study is concerned. Also more than 70% of injury accidents are covered in this study. Therefore, it is clear that the above two types of accidents are the dominant type of accident on rural, non-access controlled highways, and it can be reasonably said that this study captures the nature of accidents on rural two-lane highways.

The total mileage of Michigan two-lane rural trunkline highways is 6069.5 miles (1972), about 75% of the state rural trunkline mileage. The 1972 average ADT is 2,500 vehicles/day and the average fixed-object and turnover accident rate is 1.14 per million vehicle miles.

Tables 3-2 and 3-3 show the number of fixed object and turnover accidents by year for five ADT classes, respectively. The stability of annual results is noteworthy. 1973 fixed-object, turnover and both types of accident data are converted into an accident rate (using total annual vehicle-mileage in each ADT class and plotted in Figure 3-1). In all cases it can be seen that roads with ADT less than 2,000 have a fairly high accident rate. The accident rate is generally U-shaped, being highest for the over 8,000 ADT class except for turnover accidents. This is reasonable since the turnover accident is often associated with high speed and therefore with low ADT. This high accident rate for the highest ADT class is probably the effect of roadside development; the roadside on rural highways with high ADT generally has urban type land access

TABLE 3-2

1971-74 TWO-LANE RURAL FIXED-OBJECT ACCIDENTS BY ADT

ADT CLASS	YEAR 1971	1972	1973	1974	TOTAL
≤1,999	788	935	809	815	3347
2,000 - 3,999	1325	1548	1321	1130	5324
4,000 - 5,999	848	1057	948	819	3672
6,000 - 7,999	527	606	536	462	2131
≥8,000	546	684	558	548	2336
TOTAL	4034	4830	4172	3774	16810

TABLE 3-3

1971-74 TWO-LANE RURAL TURNOVER ACCIDENTS BY ADT

ADT CLASS	YEAR 1971	1972	1973	1974	TOTAL
≤1,999	364	374	374	364	1476
2,000 - 3,999	522	625	590	447	2184
4,000 - 5,999	249	279	345	288	1161
6,000 - 7,999	134	144	166	143	587
≥8,000	132	164	181	146	623
TOTAL	1401	1586	1656	1388	6031

?

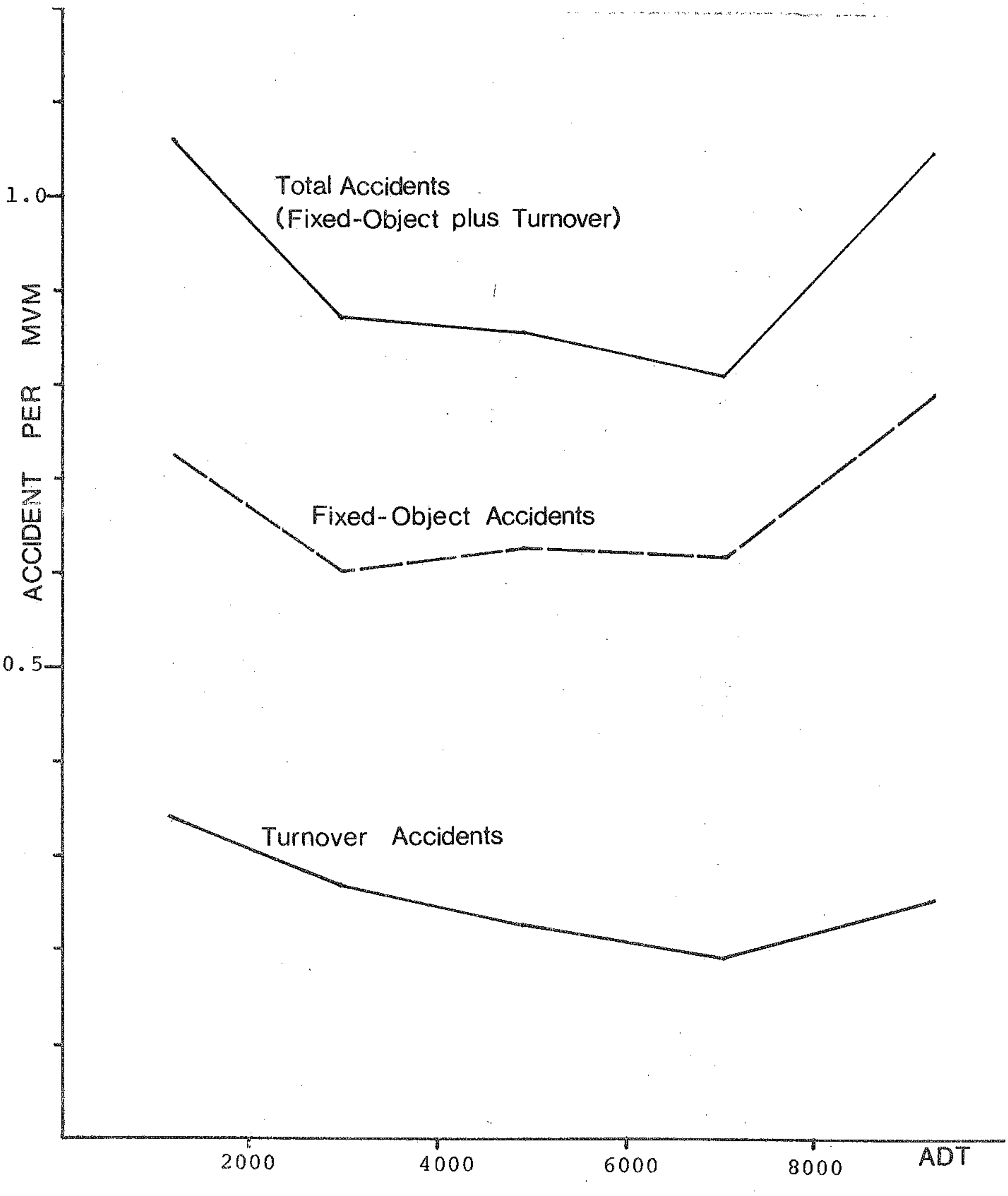


Figure 3-1 1973 OFF-ROAD ACCIDENT RATE AND ADT characteristics. Thus a different mechanism of accident occurrence is probably associated with this ADT class. The lowest ADT exposure probably reflects the nature of the highway alignment and obstacles on these lesser roads.

The number of secondary collisions with fixed-objects by ADT is shown in Table 3-4. Secondary collisions are those in which another vehicle or on-roadway element was hit before leaving the roadway and striking the fixed object. The percentage of the collisions is about 1 percent and therefore, almost all fixed-object accidents on rural two-lane highways are single-vehicle accidents. No relationship with ADT is apparent.

3.2 Factors Affecting Accident Severity

Using analysis of variance and contingency tables, the effects and interrelationships of ADT, Alignment, Object Hit, Impact Code, and Highway Area Type* have been studied. The results are presented for fixed-object and turnover accidents separately, since there are significant and important differences between these two types of accidents.

3.2.1 Fixed Object Accidents

ADT, Alignment and Severity: In this chapter, the term severity refers to the level of suffering from an accident, the injuries and/or fatalities involved, and property damage only. Also Glennon's severity index, the ratio of injury and fatality accidents to the reported total, is used to represent the accident severity.

---

* These variable names are identical to those in the *1975 Coding Manual for Michigan Accidents*, Traffic Safety Division, Michigan Department of State Highways and Transportation.

TABLE 3-4

1971-74 TWO-LANE RURAL SECONDARY FIXED OBJECT COLLISIONS

ADT	YEAR 1971	1972	1973	1974	Percent of Fixed-Object Collisions
0-1,000	4	5	0	3	1.2
1,000-1,999	10	12	2	3	
2,000-2,999	7	10	2	4	1.0
3,000-3,999	6	15	4	4	
4,000-4,999	7	16	0	9	1.1
5,000-5,999	1	4	1	3	
6,000-6,999	5	3	0	1	0.5
7,000-7,999	1	0	0	1	
8,000-8.999	3	3	1	1	1.6
9,000-9,999	5	1	1	0	
10,000-10,999	4	1	0	0	
11,000-11,999	1	2	0	0	
12,000-12,999	3	1	0	1	
13,000-13,999	0	0	0	2	
14,000-14,999	1	0	0	0	
15,000-15,999	0	3	0	1	
≥16,000	0	0	0	3	
TOTAL	58	76	11	36	1.1

This index, the severity ratio is presented against ADT in Table 3-5 and Alignment in Table 3-6 for each of the four years and as an accident weighted average. Annual differences appear small. The decline in severity with increasing ADT can be easily seen in Table 3-5. In Table 3-6 we see a 20% greater index on curves.

Analyses of the interactions with respect to alignment and ADT were made utilizing analyses of variance, ANOVA. Table 3-7 presents fixed object accident data by ADT and alignment jointly. The severity index for ADT and alignment is plotted in Figure 3-2. The result of a three-way ANOVA is presented in Appendix A-3-1 (in this table annual data are pooled). Note that in the analyses of variance of this study, the above defined severity index is not directly examined*. The ANOVA confirms that the joint effect of alignment and ADT on fixed-object accidents shown in the figure is highly significant. A statement of this effect is that while the severity drops with increasing ADT on both tangents and curves the decline is less on curves and more rapid at the lower ADT on tangent sections.

Figure 3-3 presents the fraction of fixed object accidents occurring on curves against ADT. The lowest ADT class shows an extremely high fraction. This is probably the result of higher exposure to curves on highways with lower ADT; i.e.; the result of poor highway geometry on minor two-lane highways.

We have already seen that the roadway alignment is a crucial factor affecting accident severity. At this point, only

---

*A three-way analysis of variance, employing the number of accidents rather than the accident rate and severity rate, is used throughout this study. Further discussions will be found in Appendix A-2.

TABLE 3-5

1971-74 SEVERITY RATIO BY ADT

ADT CLASS	YEAR 1971	1972	1973	1974	Weighted Average
≤ 1,999	.375	.359	.364	.365	.365
2,000 - 3,999	.332	.325	.343	.330	.332
4,000 - 5,999	.346	.324	.286	.313	.317
6,000 - 7,999	.311	.323	.313	.289	.310
≥ 8,000	.310	.292	.302	.285	.297
Weighted Average	.337	.326	.325	.322	.328

TABLE 3-6

1971-74 SEVERITY RATIO BY ALIGNMENT

ALIGNMENT	YEAR 1971	1972	1973	1974	Weighted Average
Tangent	.332	.315	.309	.310	.317
Curve	.364	.382	.392	.378	.380
Weighted Average	.337	.326	.325	.322	.328

TABLE 3-7

TOTAL FIXED-OBJECT ACCIDENTS BY ALIGNMENT, ADT AND SEVERITY

ADT	ALIGNMENT	SEVERITY Property Damage	Injury	TOTAL
≤ 1,999	Tangent	1644	898	2542
	Curved	474	322	796
	Total	2118	1220	3338
2,000-3,999	Tangent	2970	1410	4380
	Curved	582	357	939
	Total	3552	1767	5319
4,000-5,999	Tangent	2166	947	3113
	Curved	343	215	558
	Total	2509	1162	3671
6,000-7,999	Tangent	1253	549	1802
	Curved	216	112	328
	Total	1469	661	2130
> 8,000	Tangent	1416	572	1988
	Curved	225	121	346
	Total	1641	693	2334
TOTAL	Tangent	9449	4376	13825
	Curved	1840	1127	2967
	Total	11289	5503	16792

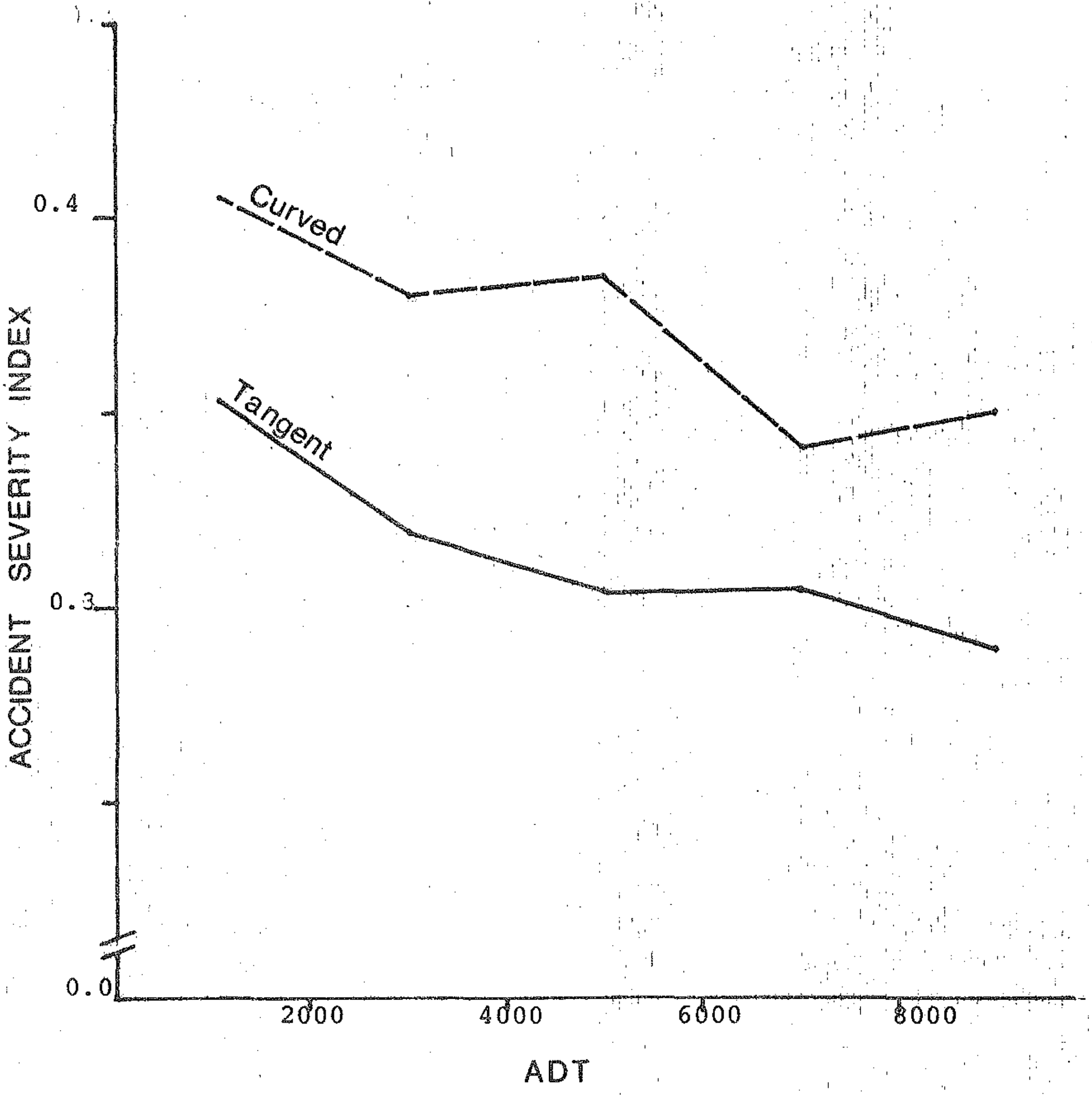


Figure 3-2 FIXED-OBJECT ACCIDENT SEVERITY INDEX BY ADT AND ALIGNMENT

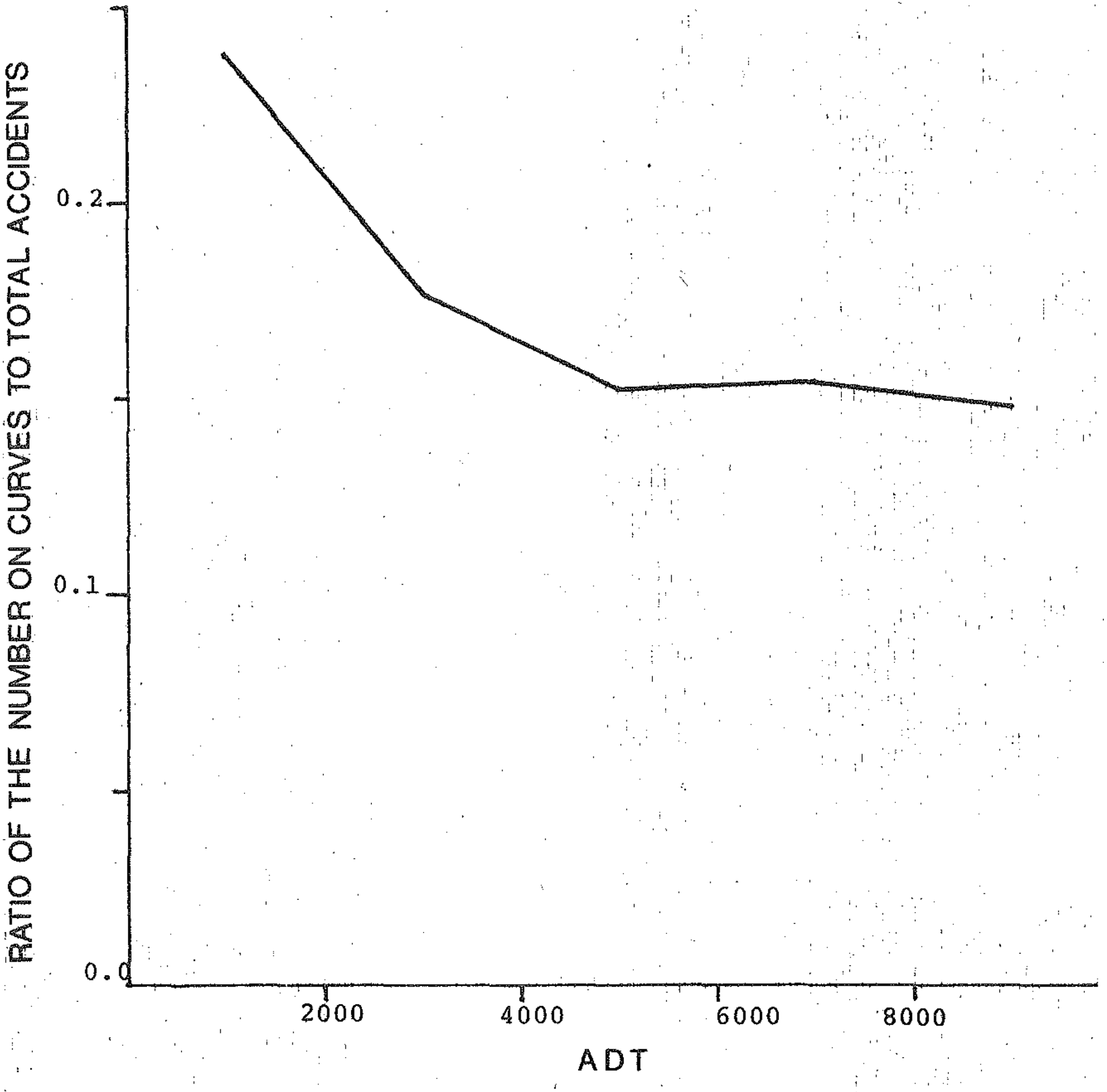


Figure 3-3 FRACTIONS OF FIXED-OBJECT ACCIDENTS ON CURVES BY ADT

ADT and Alignment have been investigated, but the following discussions on other factors will confirm that Alignment is one of the most important factors in accident analysis.

Object Hit: The type of object hit is another important factor that greatly affects accident severity and, as Glennon's model shows, also affects the probability of collision. Since we have no means of normalizing the number of accidents by the exposure to each object, only accident severity can be used as a measure in our investigation at this point.

First, we explore the distribution of objects hit. Table 3-8 presents the number of accidents and different types of objects hit on two-lane, rural trunkline highways and on all rural roadways for the year 1974 (from Michigan State Police data). The leading object struck on rural two-lane trunklines is the ditch followed by guardrails, trees, highway signs and mail boxes. These 5 object types account for more than 78 percent of the accidents. This pattern is somewhat different from that for all rural highways in which ditches, trees, guardrails, power poles and mail boxes are the main objects struck. The last column of the table shows the variation around the 12.2 percent that trunkline rural highway accidents are of the total. Guardrails, culverts and highway signs are struck relatively more frequently and fences and trees relatively less frequently on the trunkline system. The reasons for these differences are probably accounted for by the roadside improvement on trunklines as well as differences in roadside development on different types of rural roads.

TABLE 3-8

OBJECTS HIT
ALL RURAL AND TRUNKLINE 1974
FIXED-OBJECT ACCIDENTS

Object Hit	Trunkline No.	Trunkline %	All Rural No.	Percentage on Trunkline of All Rural %
Guardrail	575	15.2	3148	18.3
Highway Sign	448	11.9	2622	17.1
Power Pole	280	7.4	2806	10.0
Culvert	82	2.2	423	19.4
Ditch	965	25.6	7803	12.4
Bridge Abutment/Pier	27	0.7	300	9.0
Bridge Railing	43	1.1	382	11.3
Tree	556	14.7	6085	9.1
Highway or Railroad Signal	15	0.4	102	14.7
Building	32	0.9	360	8.9
Mailbox	402	10.7	2737	14.7
Fence	128	3.4	1544	8.3
Island/Curb	17	0.4	195	8.7
Concrete Barrier	12	0.3	328	3.7
On-Road Object	90	2.4	1250	7.2
Other Off-Road Object	80	2.1	689	11.6
Overhead Object	19	0.5	90	21.1
Unknown	3	0.1	149	2.0
	3774	100.0	31013	12.2

The severity indices for each object are shown for ten major objects in Table 3-9. The object severity index varies from a low of 0.191 for mail boxes to a high of 0.559 for culverts. Trees and bridge piers or abutments also have an index exceeding 0.5. These values are consistent with our intuitive understanding of the magnitude and nature of energy exchange between the vehicle and an object during a collision.

Table 3-9 and Figure 3-4 also show the object severity indices by Alignment (curved or tangent). The severity index on curves is higher than that on tangent section for all 10 types of fixed objects. The differences are greatest for trees, power poles and culverts, all rigid point hazards. These results suggest a need for separate treatment of fixed objects on curves in the analysis and estimation of the accident severity.

The last column of Table 3-9 presents the ratio of curve to tangent accidents for each obstacle. Although the exposure of the objects is unknown it seems as if some objects are over represented in their accident involvement.

A three-way ANOVA table with the factors Severity, Object Hit and Alignment is shown in Appendix A, Table A-3-2. The analysis was made for the seven objects out of the ten that had at least 100 accidents in each cell. The Severity-Object Hit interaction was highly significant with its dominant estimated variance. Further, the Severity-Alignment interaction is as well highly significant. The implication of this is that, although

TABLE 3-9

FIXED-OBJECT ACCIDENT SEVERITY INDEX BY OBJECT HIT

Object	Alignment	Object - Alignment Severity Index	Total No. of Accidents	Average Object Severity Index	Accident Ratio (Curve/ Tangent)
Guardrail	T.	.253	2050	.259	
	C.	.289	539		.263
Highway Sign	T.	.188	1595	.198	
	C.	.238	442		.277
Power Pole	T.	.377	1134	.399	
	C.	.589	284		.250
Culvert	T.	.539	306	.559	
	C.	.688	48		.157
Ditch	T.	.359	3519	.362	
	C.	.382	646		.184
Bridge Abutment or Pier	T.	.504	121	.515	
	C.	.667	9		.074
Bridge Rail	T.	.341	126	.348	
	C.	.417	12		.095
Tree	T.	.492	1792	.521	
	C.	.646	413		.230
Mailbox	T.	.180	1495	.191	
	C.	.282	177		.118
Fence	T.	.241	573	.244	
	C.	.259	108		.188
SUB TOTAL	T.	.320	12711	.334	
	C.	.402	2678		.211
OTHER MISCELLANEOUS	T.	.279	1114	.287	
	C.	.318	289		.259
TOTAL	T.	.317	13825	.328	
	C.	.380	2967		.215

T: Tangent
C: Curve

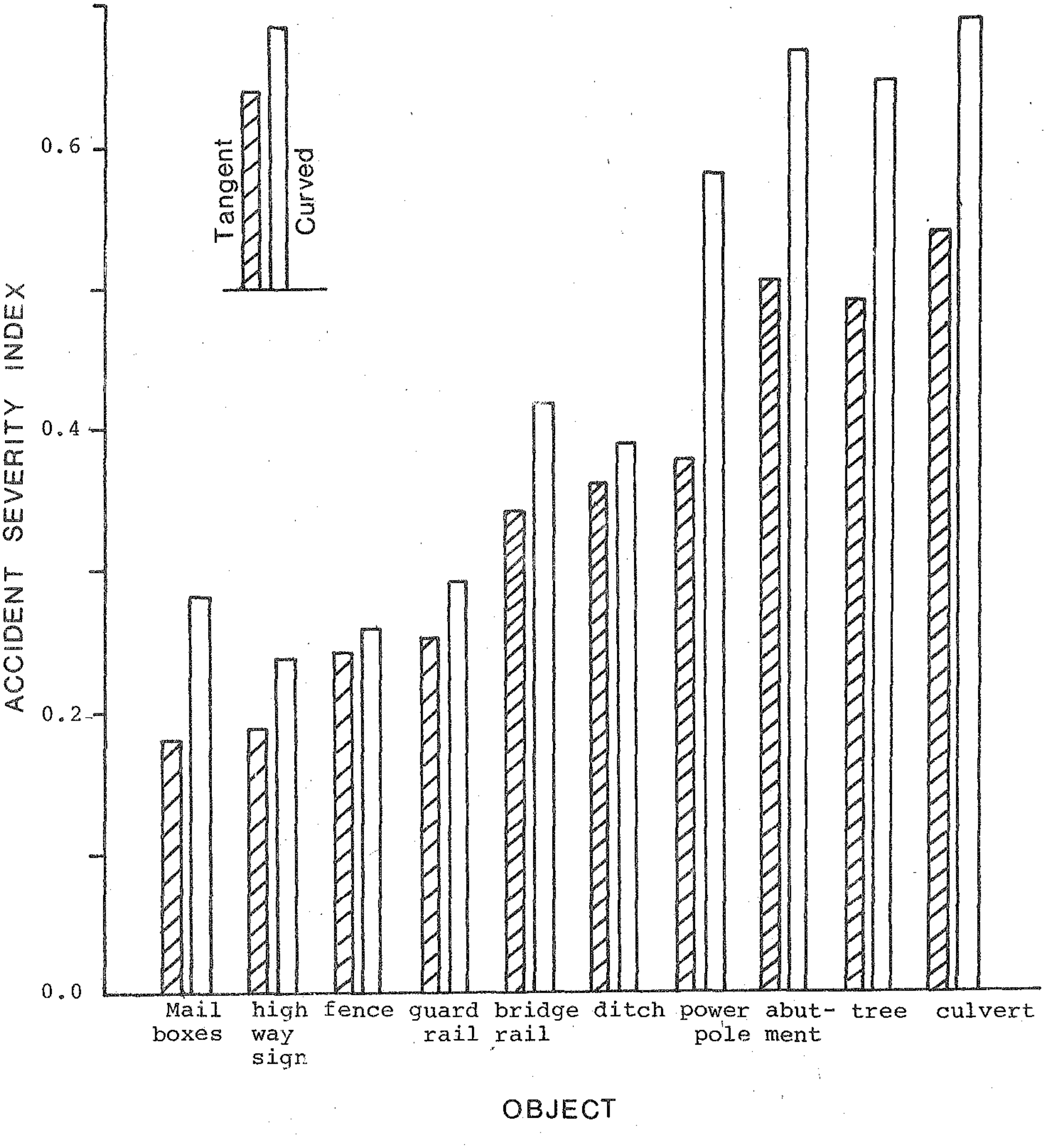


Figure 3-4 ACCIDENT SEVERITY INDICES OF MAJOR OBJECTS BY ALIGNMENT

a significant interaction exists between the type of objects and highway alignment, the alignment itself still has a certain effect on the accident severity. This result is crucially important in the sense that it suggests the severity index is not inherent to the object itself, but also depends on other factors, particularly the highway alignment.

Impact Code: The original code for the collision impact type for the vehicle has ten categories, which are here reduced into four types, rollover, front, side and rear. Table 3-10 shows the total number of accidents for each impact type by severity for 1971 through 1974. Seventy-two percent of the total accidents have impacts on the front, 16% on the side, 11% on the rear and 2% are vehicle rollovers. The severity ratio differs significantly by impact; 0.35 for front impacts, 0.30 for side hits, 0.19 for the rear and 0.62 for the rollover. This variation in the severity index is quite meaningful in the light of a kinetic view of fixed-object accidents. The severity of an accident is a function of the energy exchange between the vehicle and the object, and a side or rear impact will usually involve some rotation which dissipates a significant portion of the vehicle's kinetic energy, thus lessening the severity for side or rear impacts.

Further analyses are carried out to see the relative effect of Impact on accident severity compared to Alignment and Object Hit. Table 3-11 gives the contingency table of Impact and Alignment with rollover accidents excluded. These two factors are concluded to interact. Further examination of the table

TABLE 3-10

FIXED-OBJECT ACCIDENT IMPACT POINT BY SEVERITY

	IMPACT POINT				
SEVERITY	Front	Side	Rear	Rollover	Total
Property Damage	7061 (69.3)	1699 (16.7)	1313 (12.9)	108 (1.1)	10181 (100.0)
Injury & Fatality	3819 (75.9)	719 (14.3)	315 (6.3)	176 (3.5)	5029 (100.0)
TOTAL	10880 (71.5)	2418 (15.9)	1628 (10.7)	284 (1.9)	15210 (100.00)
Severity Index	.35	.30	.19	.62	.33

( ); Percent

TABLE 3-11

FIXED-OBJECT ACCIDENT IMPACT POINT BY ALIGNMENT

ALIGNMENT	FRONT	SIDE	REAR	TOTAL
Tangent	8953 (8980)	1974 (1994)	1393 (1346)	12320
Curve	1918 (1891)	441 (421)	236 (283)	2595
TOTAL	10871 (10871)	2415 (2415)	1629 (1629)	14915

( ); expected

$\chi^2 = 11.06$, d.f. = 2, $\chi^2_{.05,2} = 5.99$

by means of the individual contribution of each cell to the overall chi-square value shows that the frequency of the rear impact is significantly lower on curves and that this is the main interaction.

The independence of Object-Hit and Impact was examined by a contingency table summarized in Table 3-12. The results show a strong differential effect. For ditches the frequency is higher for the front impact and lower for the side impact compared to the expected number. This is because of the geometrical and structural differences of ditches. Note that guardrails, the same "continuous"objects, do not show this type of difference. The relative effects of Object Hit and Impact on the severity ratio (excluding rollover) are shown in Table 3-13 (see also Appendix Table A-3-3*). The effects of both Impact and Object are highly significant, and judging from the estimated components of variance, it can be concluded that Object Hit has a much higher effect on the severity. Supplemental analyses involving other factors showed similar results.

These discussions support the following conclusion: The collision impact has a significant effect on the accident severity and has correlations with the alignment and the type of objects. However, the joint effect of the impact and the alignment or the type of objects results in almost no effect on the accident severity on an aggregated level; thus the effect of impact can be regarded practically to be independent of other factors. Thus we have evidence that the

---

*To ensure enough numbers of accidents in each cell, only six objects are employed in the ANOVA.

TABLE 3-12

FIXED OBJECT ACCIDENT IMPACT POINT BY OBJECT HIT

	IMPACT POINT			
OBJECT	Front	Side	Rear	Total
Guardrail	1911	366	260	2537
Highway Sign	1352	421	223	1996
Power Pole	956	277	163	1396
Culvert	283	35	28	346
Ditch	3023	471	419	3913
Bridge Abutment/Pier	100	13	16	129
Bridge Railing	110	10	15	135
Tree	1555	394	232	2181
Mailbox	1074	347	209	1630
Fence	516	84	63	663
TOTAL	10880	2418	1628	14926

$\chi^2 = 194.1$, d.f. = 18, $\chi^2_{.05,18} = 28.9$

TABLE 3-13

SEVERITY INDEX BY OBJECT AND IMPACT POINT

OBJECT	IMPACT POINT Front	Side	Rear	Total
Guardrail	.269	.254	.146	.255
Highway Sign	.217	.143	.112	.189
Power Pole	.404	.422	.313	.397
Ditch	.384	.291	.198	.353
Tree	.543	.536	.345	.521
Mailbox	.204	.179	.077	.182
TOTAL	.346	.299	.195	.322

accident severity can be captured by predictable factors such as ADT and Alignment without being troubled with the collision impact, which is a difficult to predict microscopic factor.

Intersections; Intersections have quite different characteristics from simple traffic ways. This naturally can cause differences in the characteristics of fixed-object accidents at these locations. Our concern here is concentrated mainly on the effect of intersections on the accident severity, although some attention will be paid to the accident rate.

First, the number of intersectional accidents is explored with respect to Alignment and ADT. Table 3-14 shows the number of accidents by Highway Area Type (interchanges, intersections and non-intersectional areas). About one fixed-object accident out of four occurs at an intersection or interchange and annual differences are insignificant. Table 3-15 is a 2x2 contingency table representing the number of fixed-object accidents by Highway Area Type and Alignment. It is concluded that the accident rate at intersections does not depend on the alignment. Further, ANOVA of the number of accidents (log-transformed) against Highway Area Type, Alignment and ADT shows (Appendix Table A-3-4) that the number of accidents in intersectional areas tends to increase with ADT. This is presumably due to higher exposure to intersections and traffic movements on high ADT highways.

Although the accident rate at intersections does not appear to have a clear relationship with the alignment, the severity may be affected by the alignment. In Figure 3-5, the severity ratio is shown for Highway Area Type and Alignment. It can be seen that the ratio is lower at both intersections

TABLE 3-14

1971-74 FIXED-OBJECT ACCIDENTS BY HIGHWAY AREA TYPE

	HIGHWAY AREA TYPE			
YEAR	Interchange	Intersection	Other	Total
1971	43 (1.1)	1055 (26.2)	2936 (72.7)	4034 (100)
1972	53 (1.1)	1242 (25.7)	3535 (73.2)	4830 (100)
1973	48 (1.2)	1112 (26.6)	3012 (72.2)	4172 (100)
1974	47 (1.2)	976 (25.9)	2751 (72.9)	3774 (100)
Total	191 (1.1)	4385 (26.1)	12234 (72.8)	16810 (100)

TABLE 3-15

1971-74 FIXED-OBJECT ACCIDENTS BY INTERSECTION AND ALIGNMENT

HIGHWAY AREA TYPE	ALIGNMENT Tangents	 Curves	Total
Intersection	3758	814	4572
Other	10057	2153	12210
Total	13815	2967	16782

$\chi^2 = 0.07$, d.f = 1, $\chi^2_{.05,1} = 3.84$

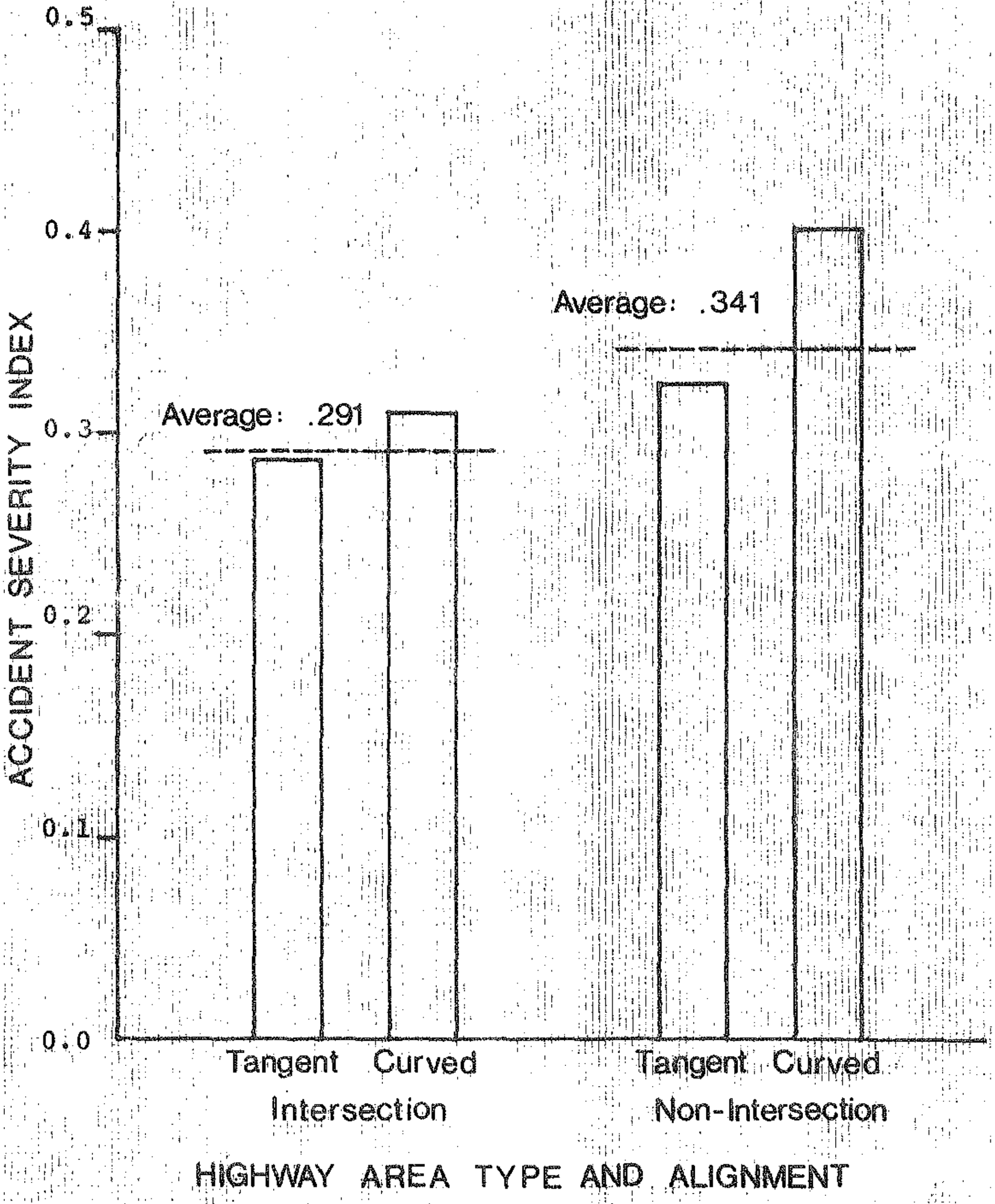


Figure 3-5 ACCIDENT SEVERITY INDEX AND ALIGNMENT BY INTERSECTION

and on tangent sections. It appears as if there is a greater increase in severity as one moves from tangents to curves when there are not intersections present than when there are.

Looking at separate contingency tables for intersections and other areas, we obtain the result that the severity of accidents at intersections does not depend on the alignment. See Table 3-16. That the alignment is a crucial factor on the accident severity is reconfirmed in this table. We can conclude that the effect of the alignment on non-intersectional areas is more dominant than we have seen, while its effect on intersectional accident severity can be ignored.

From Table 3-17, it is apparent that the distribution of objects hit differs significantly by the highway area type. An ANOVA using the severity index showed that Highway Area Type has an effect on the severity index of each object, although the effect of Object Hit is still dominant.

The relative effects of these two factors, Highway Area Type and Object Hit were further examined by means of expected severity ratios. The expected severity in intersections was estimated employing the overall severity index for each object and the distribution of Object Hit for intersectional areas. Then the resulting expected number of injury and fatal accidents was compared against the actual figures. It was found that the reduction in severity cannot be attributed solely to the differences in the distribution of objects, since the expected number of injury and fatal accidents deviates more from the actual number of intersectional areas than from the average for

TABLE 3-16

NUMBER OF FIXED-OBJECT ACCIDENTS BY INTERSECTION, ALIGNMENT AND SEVERITY

INTERSECTION:	ALIGNMENT Tangent	 Curve	 Total
Property Damage	2679 (2663)	561 (577)	3240
Fatal & Injury	1079 (1095)	253 (237)	1332
TOTAL	3758	814	4572

( ); expected

$\chi^2 = 1.85$

OTHER:	ALIGNMENT Tangent	 Curve	 Total
Property Damage	6764 (6625)	1279 (1418)	8043
Fatal & Injury	3293 (3432)	874 (735)	4167
TOTAL	10057	2153	12210

$\chi^2 = 48.46$

$\chi^2_{.05,1} = 3.84$

TABLE 3-17

ACCIDENTS BY OBJECT HIT AND INTERSECTION

	TOTAL ACCIDENTS	
OBJECT	Non-Intersection	Intersection
Guardrail	1885	704 (703)
Highway Sign	1092	949 (407)
Power Pole	938	478 (350)
Culvert	287	78 (107)
Ditch	3082	1088 (1150)
Bridge Abutment or Pier	102	28 (38)
Bridge Railing	102	16 (38)
Tree	1850	356 (690)
Traffic Sign	33	13 (12)
Building	95	67 (35)
Mialbox	1405	266 (524)
Fence	526	154 (196)
Curb	38	41 (14)
Jack Knife	37	7 (14)
Other Off-Road	445	199 (166)
TOTAL	11917	4444 (4444)

( ); Expected

other highway area types. Although the distribution of Object Hit significantly differs between intersectional areas and other places, the severity indices of objects themselves are significantly reduced in intersectional areas. Also, judging from the components of variance and the discussion on the expected severity, less severity at intersections is to be attributed to the Highway Area Type itself than the difference in the distribution of objects.

Factoring Glennon's Model: Many tables showing the severity indices can be used to modify Glennon's model for its use in Michigan, which will be suggested in Chapter V of this report. The analyses above have shown that the roadway alignment greatly changes the severity index for each object. Table 3-9 can be used along with Glennon's model to account for the effect of alignment. The effects of ADT and intersections can be incorporated by developing severity weighting factors from Trables 3-5 and 3-16.

The effects of these severity contributing factors on the collision probability are not explored in this chapter. Following analyses in Chapter IV are concerned with the accident occurence in two-mile roadway sections. Our view on the accident rate is that the encroachment probability in Glennon's model should be captured in relation to the characteristics of roadway over a certain length, thus our view is to assign an equal encroachment rate for those objects along the roadway segment. The distributions of encroachment angles and lateral displacement should be further explored considering site specific feautres, but this is beyond the scope of this study.

Summary; Through a series of analyses of variance, several factors have been examined as to their effects on the severity of fixed-object accidents. The investigation here is not exhaustive in the combination of factors, and at most only three factors have been examined simultaneously. Thus the analyses here are not to be taken as having completely revealed the interrelationships among variables and their interactions. Rather they give the apparent importance of each factor based on, though limited in the above sense, statistical inferences. The principal findings of this subsection are as follows:

Highway alignment appears to greatly affect accident severity. In all cases except the analyses involving intersection and non-intersection comparisons, its effect on the severity has turned out to be dominant, with higher severity indices on curves. Definitely the alignment must be one of the key factors in the Chapter IV analysis.

The type of object struck is confirmed to be another important factor. Its independent effect on the severity has been confirmed against the effects of the collision impact point and intersection presence. An important finding here is that the severity indices of objects are not inherent to the objects, but are affected by the highway alignment, thus conflicting with Glennon's view. It may be necessary that the type of object and its mix will not be possible in the general accident predicting model. However, it can be treated at later stages in practical analysis.

Judging from the fact that one accident out of four occurs in intersectional areas, it is suspected that the existence of intersections is related to the accident rate adding to its certain effect on the severity. Further, it has been found that the alignment has no effect on the severity of intersectional accidents in spite of its highly significant effect on non-intersectional areas.

ADT is highly related to the alignment and the highway area type, and certainly will play an important role in the modeling effort. However, its isolated effect on the severity is not fully determinable because of the above mentioned deficiency in simultaneously incorporating many variables.

3.2.2 Turnover Accidents

Alignment, ADT and the Accident Rate; Since the traffic exposures of turnover and fixed-object accidents are identical, the accident rates of these two types of accidents can be compared by using the number of accidents to represent the effects of factors involved in the comparison. This is done by means of ANOVA of the number of accidents (log-transformed) against ADT, Alignment and the type of accidents (fixed-object and turnover). Figure 3-6 shows these values. The resulting ANOVA table (Appendix Table A-3-5) shows that all interactions are significant at the 95% level with relatively similar components of variance estimated. The implication of these interaction terms can be seen clearly in the figure. The upper sketch shows that the ADT-Alignment interaction is principally associated with the lowest ADT class, with a much

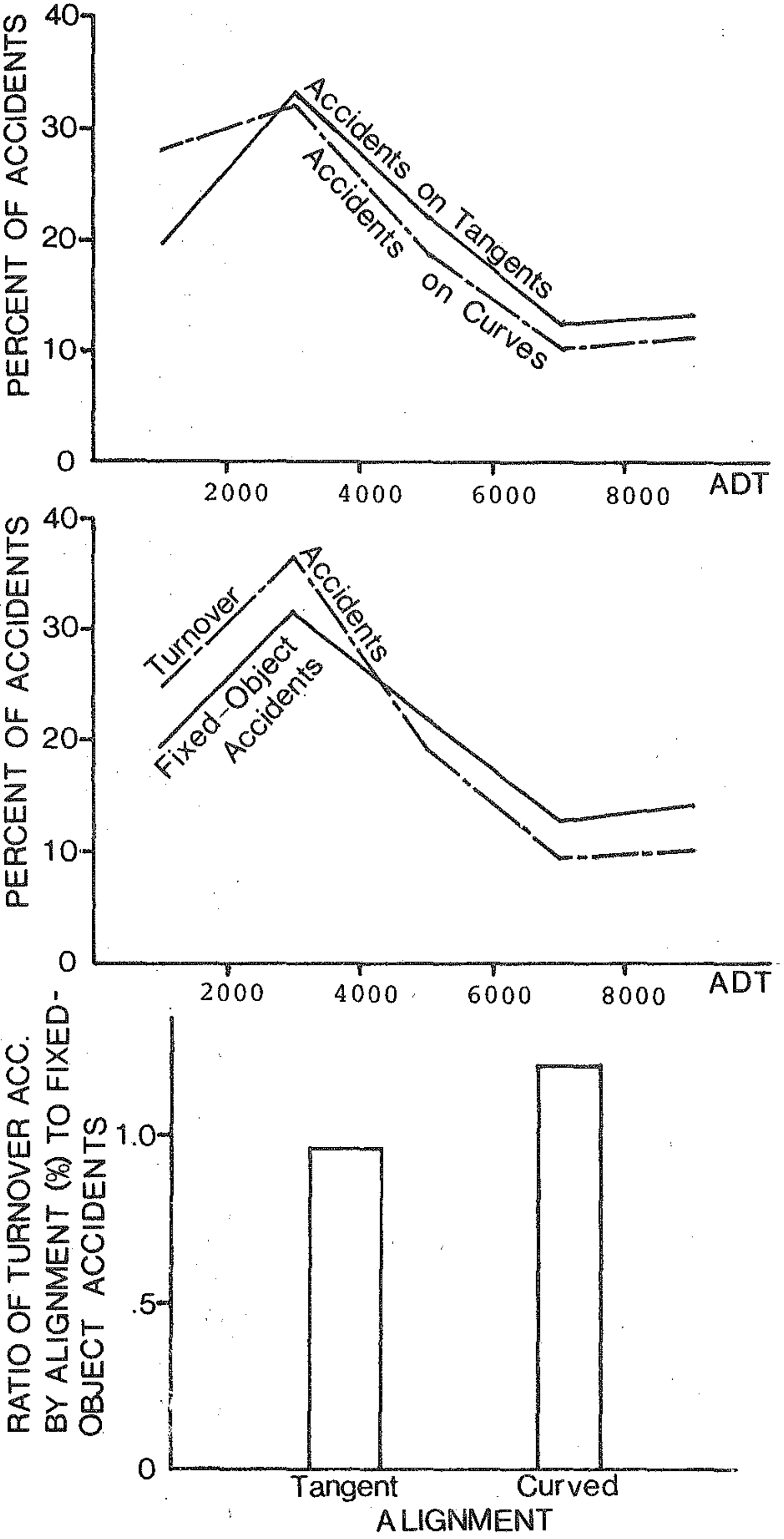


Figure 3-6 INTERACTIONS AMONG ACCIDENT TYPE, ADT AND ALIGNMENT

larger number of accidents on curves. The middle sketch clearly shows the difference in the accident rate between these two types. The turnover accident shows higher accident rate in lower ADT classes and lower rates in higher ADT classes. The lower sketch indicates higher accident rate of turnover accidents on curves, which is quite reasonable. Thus it can be concluded that ADT and the roadway alignment will have greater effect on the accident rate of turnover accidents, the validity of which will be investigated in the modelling study. (Compare Figures 4-2 and 4-3)

<u>Accident Severity</u>; The principal factors, ADT and Alignment are examined through their effect on the severity of turnover accidents. The ANOVA table (Appendix Table A-3-6) demonstrates the high significance of all interactions involved. The Alignment-Severity interaction turns out to have the largest component of variance among other interaction terms, showing the dominant effect of the roadway alignment on severity. Though its interaction term is significant, the effect of ADT on the severity would be said to be less influential judging from the estimated variance of the interaction term. Comparing the table with the corresponding one for fixed-object accidents, it can be noticed that the relative effect of the Alignment-ADT interaction is much less in the current table. This suggests the existence of some complex interaction of these factors affecting the accident occurrence, but definitely in different ways for the respective types of accidents.

Intersections; The rate of intersectional turnover accidents among the total is about 19%, which is much less than the value of 27% for fixed-object accidents. In an ANOVA with factors, Highway Area Type, Alignment and ADT, the Alignment-ADT interaction turned out to be insignificant, contrary to the case with fixed-object accidents, but consistent with the above discussion. The only significant interaction term, ADT-Highway Area Type, is obvious and not of much interest. Thus for turnover accidents, the presence of intersections does not seem to play any important role.

3.3 Speed Limit - Volume Effect

The year 1974 began with a reduced speed limit (65 down to 55) and decrease in the volume on roadways as results of the oil crisis. In this section possible effects of these changes are explored based on the data tabulated in this study.

Figure 3-7 compares both types of off-roadway accidents for 1974 to the 1971-73 average by ADT. Reduction in the number of accidents is apparent in every ADT class and type of accident. The reduction in the ADT range 2,000 to 3,999 is especially noticeable. On the whole, fixed-object accidents show more reduction rates throughout the ADT range (13.2% in total), but reduction in the turnover accidents in high ADT is less noticeable. The total reduction in the off-road accident is 12.4%.

Table 3-18 shows average overall severity indices for 1971-73 and 1974 by ADT. It can be concluded that no change in the accident severity for 1974 off-road accidents occurred.

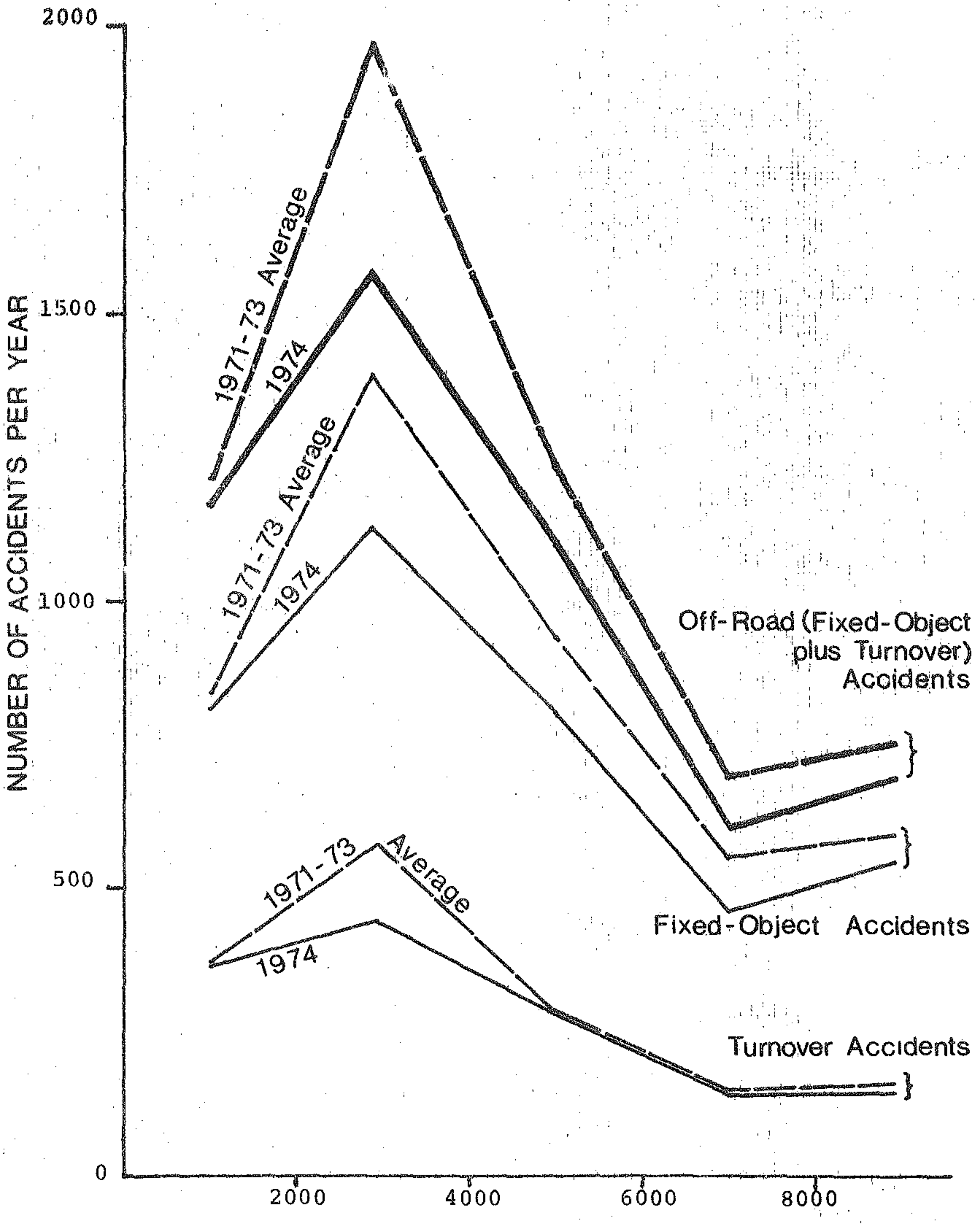


Figure 3-7 1974 OFF-ROAD ACCIDENTS VS. 1971-73 AVERAGE

TABLE 3-18

OFF-ROAD ACCIDENT SEVERITY INDEX BY YEAR AND ADT

	SEVERITY INDEX		
ADT	1971-73	1974	1971-74 TOTAL
1,999	.426	.432	.428
2,000 3,999	.402	.391	.400
4,000 5,999	.384	.401	.388
6,000 7,999	.376	.354	.371
8,000	.362	.363	.362
TOTAL	.395	.395	.395

3.4 Measures of Accident Severity

Throughout this study, Glennon's severity index (the ratio of accidents involving fatalities and/or injuries to the reported total) is only presented as a measure of accident severity. Althouth this index is statistically more reliable when compared to other measures employing only fatalities, it has some defective aspects which could cause biases in the analysis and prediction of accident costs: The fatality rate may not be proportional to the severity index, in which case the latter is not appropriate as a measure in comparing expected costs of accidents among different types of objects; The inclusion of minor injuries in the severity index may tend to lessen distinctions among degree of hazard of roadside objects; And reporting level of accidents may plausibly be associated with accident severity,which could further reduce the severity variances among objects. In this sub-section, these possible defects are discussed for the current data set, and alternative measures are examined.

Table 3-19 shows the number of accidents by three categories of severity; property damage only, involving injuries and involving fatalities. Two alternative measures of severities are also shown for each object along with the severity index found in this study;the fatality rate (the ratio of fatality accidents to the reported total) and the fatality-injury rate (the ratio of fatality accidents to the non-property-damage-only accidents).

First, it should be noticed that the fraction of fatal accidents is very low, about 1.3 percent of all reported

TABLE 3-19

MEASURES OF ACCIDENT SEVERITY

OBJECT	NUMBER OF ACCIDENTS				SEVERITY MEASURE		
	PROPERTY DAMAGE	INJURY	FATALITY	TOTAL	GLENNON'S SEVERITY INDEX	FATALITY RATE	FATALITY INJURY RATIO
Guard Rail	1915	646	28	2589	.26	.011	.042
Sign	1637	395	9	2041	.20	.004	.022
Tx Pole	851	548	17	1416	.40	.012	.030
Culvert	156	182	17	355	.56	.048	.085
Ditch	2659	1490	21	4170	.36	.005	.014
Abut/Pier	63	58	9	130	.52	.069	.13
Bridge Rail	90	43	5	138	.35	.036	.10
Tree	1057	1055	94	2206	.52	.043	.082
Traf.Signal	25	21	0	46	.46	------	------
Building	99	62	1	162	.39	.006	.016
Mail Box	1353	308	11	1672	.19	.007	.035
Fence	515	162	4	6801	.24	.006	.024
Curb	54	25	0	79	.32	------	------
Jack knife	38	7	0	45	.16	------	------
Other off-road	459	183	2	644	.29	.003	.011

accidents. This causes some difficulties in evaluating the fatality rate for those types of objects that have very few or no fatal accidents.

Both the fatality rate and the fatality-injury ratio have much higher variation compared to Glennon's severity index; the highest of the fatality rate is 0.0692 for the bridge abutments or piers, and the lowest is 0.0031 for the other off-road objects; the ratio of these two is 22.3. The fatality rate is further examined by plotting it against Glennon's severity index for Michigan accidents (Figure 3-8). The figure suggests a discontinuity that results in extremely high fatality rates for some objects of higher severity indices. For objects of lower severity indices, the variation in fatality rates is relatively small. It appears that the fatality rate is an effective measure to distinguish objects of very high severity, but their relative values are rather unreliable due to the small sample size. For example, for the abutment and pier ($N=130$, $\hat{p}=9/130 \cong 0.07$), the 95 percent confidence limits are 0.03 and 0.13 (about 400 percent variation) assuming a binominal distribution for the number of fatality accidents.

The fatality-injury ratio is less affected by the accident reporting level. From Table 3-19, this measure will also be seen to have high variation. Similarly, this measure is plotted against Glennon's severity index in Figure 3-9. A similar pattern as in Figure 3-8 is found here, although the previous discontinuity is somewhat lessened; generally the fatality-injury ratio is higher when Glennon's severity index is higher, although the relationship is not very strong.

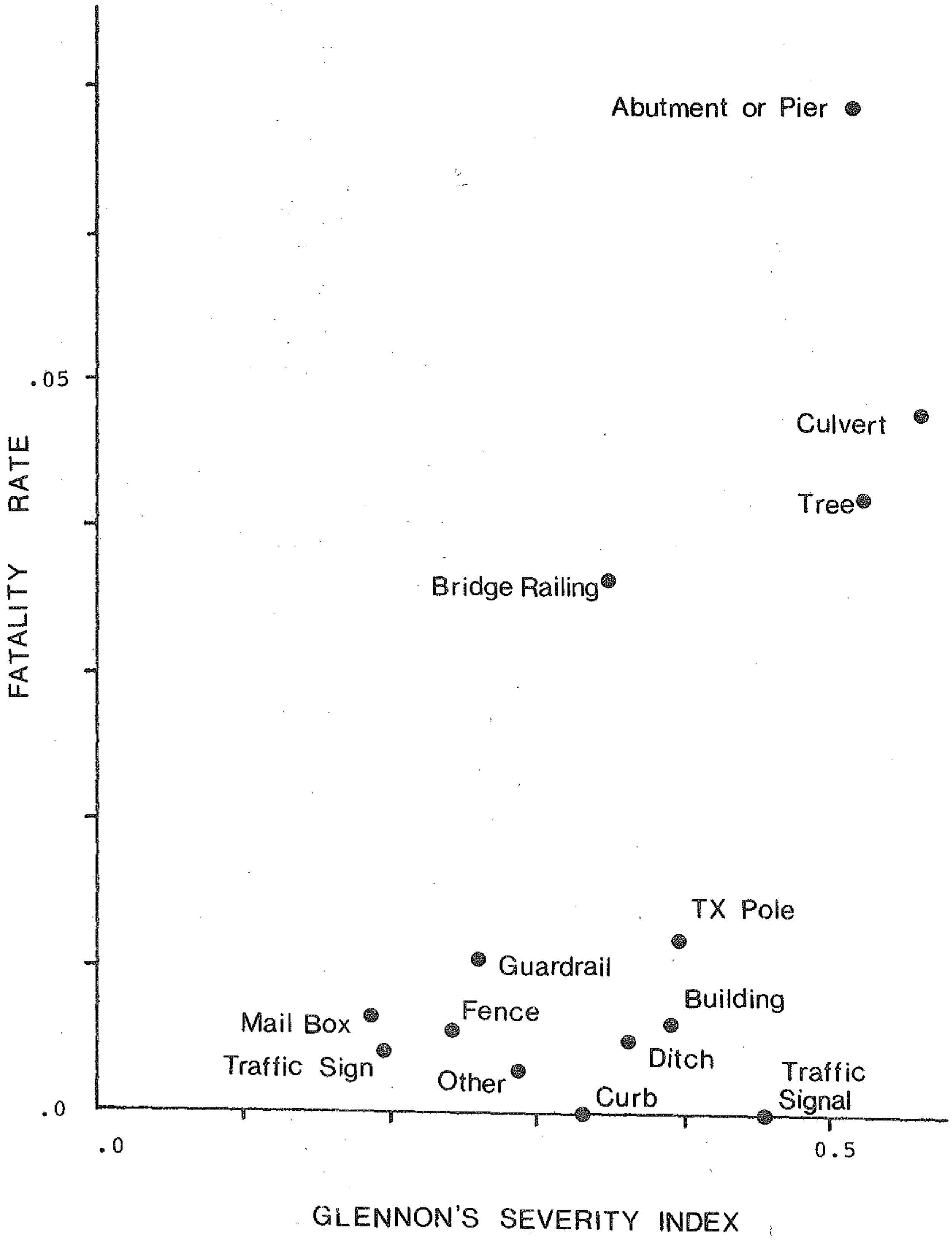


Figure 3-8 Fatality Rate Against Glennon's Severity Index

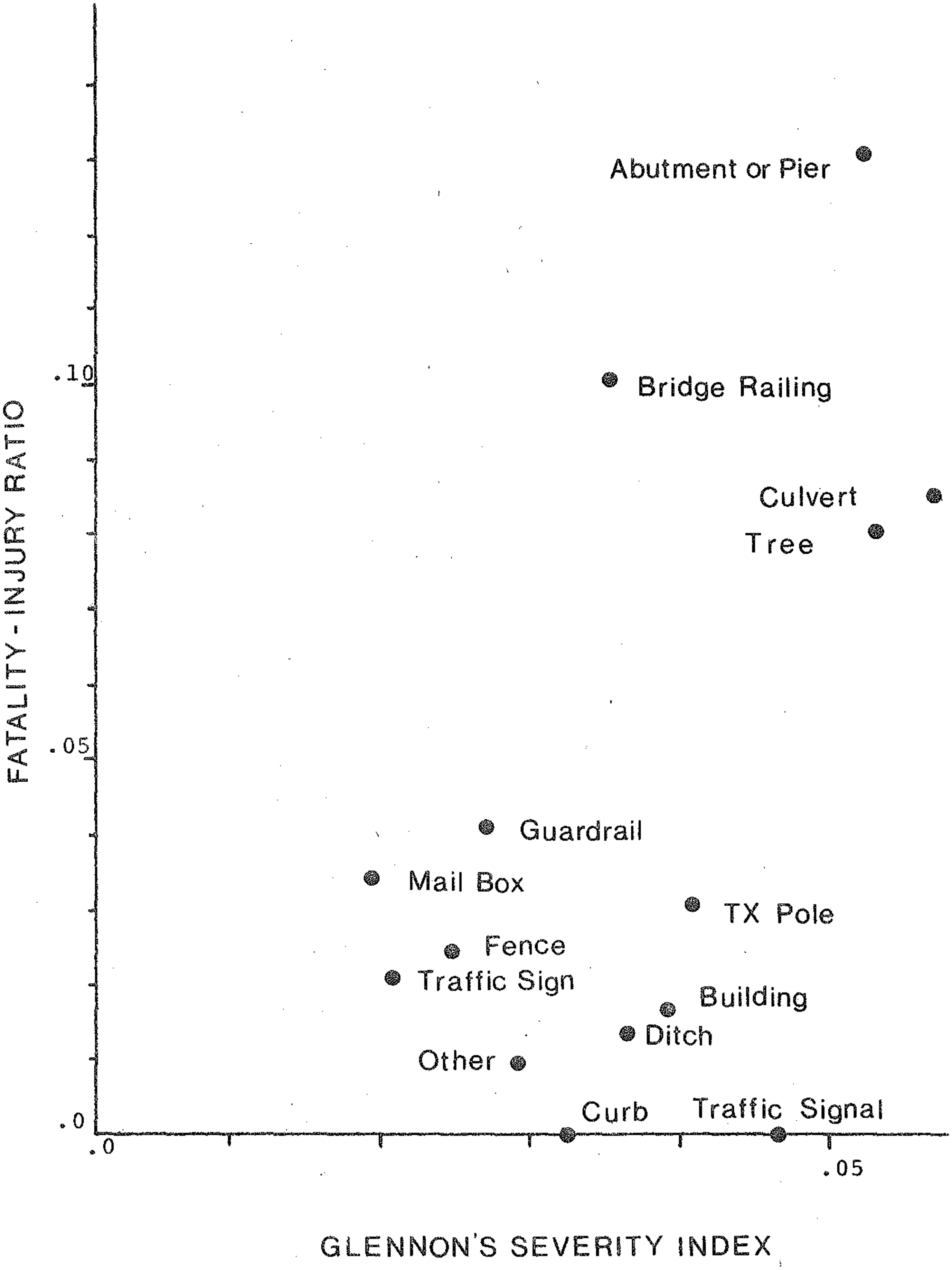


Figure 3-9 Fatality-Injury Ratio Against Glennon's Severity Index

It should be understood that the variance of the estimates of this measure is larger even than the previous fatality rate, thus reliability of the estimate is further reduced.

The above two figures have shown that; Glennon's severity indexes have less variation over objects than the other two measures, which could cause under-representation of highly hazardous objects; The ratio of fatalities to the non-property-damage-only accidents is not constant over objects, thus the Glennon's index is not a good representative measure of the accident cost expected for each object; The fatality ratio may be a good measure in distinguishing objects of very high hazard, but does not look very effective for those objects of relatively low hazard (note that guardrail is one of the highest* among those lower hazard objects, almost as high as telephone pole). It is not reliable for objects with low frequency of accident involvement. The fatality-injury ratio is a good measure in the sense that it is least affected by the accident reporting level. But the measure itself is not directly related to the expected accident cost of objects. Thus the measure has difficulties in applying it in engineering decision making. We have no other means to investigate the effects of the reporting level on estimates of severity measures.

One advantage of Glennon's severity index is its statistical reliability due to the increased number of observations. This is especially true in a case where accident severity is explored in a multivariate context, as it is in this study. Therefore it can be justified to employ the number

---

* This figure may be biased by the accident reporting level.

of injury plus fatality accidents as a dependent variable in multivariate analyses to identify the factors affecting accident severity. Note that the severity index (ratio) itself is not directly used in the statistical analyses throughout this study. Also note that the principal purpose of this chapter is to identify those factors affecting accident severity which is defined above according to this objective.

Efforts are not intensively exercised in this study to develop an effective measure of the accident severity associated with each type of object. Rather, possible defects of the currently used measure are just pointed out. Thus in practical applications of the results, another severity measurement may be developed according to the specific object of the application. The above two figures involving the fatality will assist in such development.

3.5 Chapter Summary

The characteristics of off-road accidents on rural two-lane highways were investigated in this chapter as the basis for the modelling study of this effort. The analysis here is based on accident data that includes all reported fixed-object and turnover accidents on these highways along the Michigan trunkline system. The principal results and findings of the analysis on this aggregate data in this chapter are as follows:

Most of the off-roadway accidents on rural two-lane highways are single vehicle accidents, among which 75% are fixed-object accidents; the rest are turnover accidents. Approximately one-third of fixed-object accidents and three-fifths of turnover accidents involve injuries or fatalities.

The accident rate of these off-road accidents decreases as the ADT increases, except for very high ADT highways. This is even more notable in turnover accidents.

The roadway alignment has a dominant effect on the severity of off-roadway accidents resulting in a higher rate of injury accidents on curves. Also, judging from a result that the alignment has different effects on the accident rates of fixed-object and turnover accidents, it is concluded that the alignment is also related to the accident rate on two-lane rural highways.

The type of object is another factor that is highly related to accident severity. However, its effect on severity is not only inherent to the object itself, but also interacts with the roadway alignment.

The severity of fixed-object accidents tends to be less in intersectional areas, but this effect of the intersection is not seen in turnover accidents. Though positive statements cannot be made since no exposure data are available, the presence of intersections is suspected to be related to the accident rate as well, judging that a large portion of fixed-object accidents occur in intersectional areas.

CHAPTER IV

OFF-ROAD ACCIDENT MODELS

The analysis of aggregated fixed-object and turnover accidents and their severity described in Chapter III showed that there are important and different effects of many factors in adequately describing off-road accidents as was hypothesized in Chapter II. The analysis showed that there were also important and complex interactions among these variables. As a result it became necessary to consider that Glennon's model of calculating the hazard index would have to incorporate a number of site-specific features (as he speculated in reference (16)) in order to achieve an explanation for the very great differences in accidents which are found on various sections of the system.

This establishes a need for a multivariate approach in which a section of a highway with a particular set of important characteristics can have its accident and/or injury potential quantified. Such an approach is possible using multivariate methods and requires the development of a mathematical model which accepts highway characteristics as input and gives an expected predicted number of accidents and/or injuries for a period of time as its output. Since the input data for an operational model would be developed by the MDSHT as a part of its safety program and since the ultimate measure of effectiveness will be the reduction in accident experience as recorded in MDSHT files, it is best to turn to MDSHT accident and highway information for the data needed to develop, and estimate the needed parameters and to validate the model.

4.1 General Approach

The approach to be used in this effort to explain the occurrence of accidents on Michigan two-lane rural trunkline highways must cope with the problem that there is a tremendous difference in the accident experience total over a several year period for different sections of the highway (for example, see Figure 4-11 presented later in the chapter). The approach must also cope with the fact that accident occurrences are the results of a complex of causal features and that the ability to predict accident experience will ultimately be limited by variability in the factors involved as well as factors which cannot be described.

The outputs of prime interest in this study are of course the total off-road as well as the off-road injury accident experience. It is possible to model this in two ways. One can make use of the fact that the characteristics of fixed-object accidents are somewhat different from the characteristics of turnover accidents, model each of these separately, and develop the total accident experience by adding the component results of the two separate models. Since the samples of the types of accident will necessarily be limited and if there is little difference in the two models it may also be that a single direct model can be developed which predicts the total accidents or injury accidents equally well. In this chapter we explore both direct and component models.

A major decision in the modelling process is concerned with the way in which individual roadside obstacles and geometric forms are treated. Because of the great diversity of obstacles, their many possible locations and the interaction with highway features it is impossible (within the limits of the resources of this study) to treat obstacles as identifiable units at this stage of the process. It is believed that the microscopic Glennon analysis as described in references (15) and (16) and utilizing techniques described in reference (41) can be applied to individual sections of roads following the identification of the problem location by the first-stage modelling effort developed in this chapter.

It should be noted that this study concentrates on the occurrence of <u>accidents</u> not the <u>accident rate</u>. This of course, implies that the MDSHT program is a social one that is directed toward minimization of off-road total accidents, not one which attempts to make the risk for individual motorists the same or below a certain level. As a result safety investments will be made more often on higher ADT roadways than lower ADT roadways.

An important decision involves the necessity to deal with a finite length of highway since many of the characteristics of a route can only effectively be captured by summing over a length of route. Accordingly, this modelling effort is based upon the accident experience recorded over a fixed (and uniform) highway section length.

The approach used in the analysis described in this chapter is to identify a list of reasonable and directly measurable or calculable hypothesized variables, to obtain information on these variables for a carefully drawn sample of two-lane rural trunkline roadways in Michigan, to obtain information on total accident and injury accident experience for both fixed-object and turnover accidents by location for several years, and to use appropriate multi-variate techniques to develop a useable and adequate model. In the following sections of this chapter we describe the selection of variables, acquisition of data and the analysis, presentation and discussion of the effectiveness of the models which are developed.

4.2 Variables and Data Acquisition

As has been indicated in previous sections of this report the characteristics which have a major effect on off-road accidents include average daily traffic volume (ADT), horizontal alignment, the presence of intersections and some characteristics of roadside obstacles. The first task as a part of this modelling effort involved the identification of relatively easily obtainable data on variables which can be expected to have a high likelihood of causing or being associated with the occurrence of off-road accidents of various types in each of these categories described above. The variables which were used in this analysis are listed in Table 4-1. They are presented in the ways in which they are

TABLE 4-1

LIST OF VARIABLES IN THE ORIGINAL COMPUTER FILE

VARIABLE NAME	REMARKS
CASE NO.	Sample section number prepared in this study
C.S. NO.	MDSHT Control Section Number
P.O.B.	The Point of Begining of the Two-Mile Sample Section
AREA	Area code (1 = upper peninsula, 2 = middle peninsula, 3 = lower peninsula)
PAVE. W.	Pavement width (1 = 20 ft., 2= 22 ft., 3 = 24 ft.)
SHOULDER W.	Shoulder width in feet.
PSR	Percent sight restriction.
PSR-CODED	Percent sight restriction coded into 22 classes.
ROLLING	Terrain (1 = level, 2 = rolling)
ADT	ADT divided by ten.
ADT-CODED	ADT coded into 25 clases
ADT-LOG	ADT, logarithmitic transform
ADT-QUAD	ADT quadratically transformed, divided by 10^{+4}.
NC	Number of curves in the two mile section.
CL	Curve length in the two-mile section.
CL-CODED	Curve length coded into 22 classes.
INTER-N	Number of non-channelized intersections in the two-mile section.
INTER-C	Number of channelized intersections.
INTER-CU	Number of intersections on curves.
INTER-TA	Number of intersections on tangents.
INTER-TOTAL	The total number of intersections.

TABLE 4-1 (Continued)

VARIABLE NAME	REMARKS
DITCH OFFSET	Dominant ditch offset in feet.
DITCH COND.	Ditch Condition (1 = good, 2 = fair, 3 = hazard).
TREAT.	Shoulder treatment (1 = treated, 2 = gravel).
STIFF	Existence of unyielding object (1 = non-existence within 14 feet, 2 = existence).
OB-ST-6 OB-ST-10 OB-ST-14 OB-ST-20 OB-ST-30 OB-Oc-6 OB-OC-10 OB-OC-14 OB-OC-20 OB-OC-30 OB-IC-6 Ob-IC-10 OB-Ic-14 OB-IC-20 OB-IC-30 OB-IN-6 OB-IN-10 OB-IN-14 OB-IN-20 OB-IN-30	Object exposure length (in five feet) by alignment and object off-set. Alignment (indicated by middle two letters) ST: Tangent OC: Outside Curve IC: Inside Curve IN: Intersection Area Offset (Indicated by last two digits) 6: $x \leq 6$ 10: $6 < x \leq 10$ 14: $10 < x \leq 14$ 20: $14 < x \leq 20$ 30: $20 < x \leq 30$ The exposure is not cumulative, but for those objects falling in each category.
OB-6FT OB-10FT OB-14FT OB-20FT OB-30FT	Total exposure length (in five feet) to objects in each offset category, not cumulative.
FO. 71-3	Number of fixed-object accidents, 1971-73 total.
FINJ. 71-3	Number of fixed-object accidents involving injuries or fatalities, 1971-73 total.
FO. 74 FINJ. 74	Corresponding 1974 values
TO. 71-3	Number of turnover accidents, 1971-73 total.
TINJ. 71-3	Number of turnover accidents involving injuries, 1971-73 total.

TABLE 4-1 (Concluded)

VARIABLE NAME	REMARKS
TO. 74	Coresponding 1974 values.
TINJ. 74	
ACC. 71-3	Number of off-road accidents, (fixed-object and turnover total), 1971-73 total.
INJ. 71-3	Number of off-road accidents involving injuries, 1971-73 total.
ACC. 74	Corresponding 1974 values.
INJ. 74	
FO. 71-4	1971-74 total.
FINJ. 71-4	
TO. 71-4	
TINJ. 71-4	
ACC. 71-4	
INJ. 71-4	

found in the original computer file which was developed for each of the sample segments (See Appendix B-3). Traffic flow was represented by the 1971-73 average of ADT data. Variables which could be expected to be associated with alignment include the percent of a section in which the passing sight distance was restricted, a characterization of the terrain as rolling or level, a count of the number of curves in a given section, broken down also by the presence or absence of intersections on the curves, and the total length of curved road in a given section. Measures associated with the roadside include the width of the pavement as a possible measure of the propensity of a vehicle to leave the travelled way, the width of the shoulder and the type of stability provided by the shoulder treatment, the distance to drainage ditches and the description of the cross-sectional abruptness of these ditches, the existence of obstacles within a variety of distance ranges from the edge of the roadway, and an abstraction of the degree of yielding associated with those obstacles within 14 feet of the edge of the roeaway. In addition,the injury and total accident experience on two-mile segments* classified by fixed-object or turnover and by 1974, 1971-73, and the four years taken together, were the sources of measures of dependent variables.

These data were acquired from MDSHT accident file as described earlier in this report and through an extensive photolog study by research project personnel. This study is described in detail in Appendix B-2. Appendix B-3 presents

---

* The length of the sample section is fixed to two miles. Further discussions can be found in Appendix B-4.

information on the development of the computer file information on the variables.

The next step involved drawing a sample of roadway sections in Michigan for study and the procedure in this process is described in Appendix B-4. At the conclusion of this step information was available on 270 two-mile segments of the Michigan two-lane rural trunkline highway system, approximately 9 percent of the mileage. It was these 270 sections which provide information used in the analysis described in the remainder of the chapter.

4.3 Variable Importance and Interactions by AID

4.3.1 General Description of AID; Automatic Interaction Detection (AID) is a multivaliate analysis method that reduces the unexplained variation of a dependent variable by splitting an entire sample sequentially into sub-groups based on the best explanatory variable at each split. "A one-way analysis of variance technique is used" in the sequential splitting to explain as much of the variance of the dependent variable as possible.*

The most common and easy-to-understand method to represent the result of an AID analysis is through a branch diagram, from which one can see the way that explanatory variables interact as well as the importance of variables in the explanation of variation.

---

*The interested reader will find a full description of AID in; Sonquist, J.A., et.al., Searching for Structure, Institute for Social Research, University of Michigan, Ann Arbor, 1971.

The most advantageous aspect of AID is that it identifies those interactions that do not affect the entire sample, rather some specific sub-groups. This is a phenomenon which is very difficult to discover by other methods of data analysis. This is especially true for such a phenomenon as traffic accidents where many intercorrelated factors affect the accident and where there are differing interaction effects of the variables.

The 19 explanatory variables (predictors) employed in the AID analyses are listed in Table 4-2 together with their modifications in the regression analysis described later in this chapter. As is described in Appendix B-3, object exposure is in a cumulative form representing the exposure length (in percent) to objects within each offset that a variable carries. The area is a nominal variable with three categories; upper peninsula, middle (MDSHT Districts 3 and 4) and lower (Districts 5-8 and Metropolitan).

Since the model of off-road accidents can be built by combining the model for fixed-object accidents with that for turnover accidents, or directly for all off-road accidents, for both total accidents and accidents involving injuries or fatalities, in the following sections we explore each of these possibilities. Another analysis is directed toward the need to explore 1974 experiences against 1971-73 data for any differences in causal variables attributable to the energy crisis and speed limit change occurring early in that year.

TABLE 4-2

VARIABLES USED IN ANALYSES

VARIABLE	ABBREVIATION
Area	AREA
Pavement Width	PAVE. W.
Shoulder Width	SHOULD. W.
Percent Sight Restriction	PSR**
Rolling	*
Number of Curves	NC**
Curve Length	CL**
ADT	ADT
Number of Intersections on Curves	NIC**
Number of Intersections on Tangent	NIT**
Total Number of Intersections	NITO**
Shoulder Treatment	*
Ditch Condition	DITCH
Object Stiffness	STIFF
Percent Exposure Length to Objects within 6 ft.	OB6
Percent Exposure Length to Objects within 10 ft.	OB10
Percent Exposure Length to Objects within 14 ft.	OB14
Percent Exposure Length to Objects within 20 ft.	OB20
Percent Exposure Length to Objects within 30 ft.	OB30

*These variables did not appear in the analyses results.

**Following versions of these variables were employed in the regression analysis. They are not necessarily accompanied with changes in abbreviations.

VARIABLE	ABBREVIATION
100% Sight Restriction (a dummy variable)	PSR100
0% Sight Restriction (a dummy variable)	PSR0
Number of Curves per Mile	NC
Non-existence of Curves (a dummy variable)	NC0
Percent Curved	PCL
Number of Intersections per Mile of Curve	IC
Number of Intersections per Mile of Tangent	IT
Number of Intersections per Mile	ITO

4.3.2 Comparison of 1974 Off-Road Accidents with 1971-73 Experience

Fixed-Object Accident: The 1974 fixed-object AID diagram was compared with that for 1971-1973 (see Figures 4-1 and 4-2). In both cases ADT was the prime predictor. For ADT values lower than 1500 alignment was the prime secondary factor, in both cases. For sections in the 1500-4000 ADT range the percentage of length with objects 20 feet or less from the edge of the pavement, the next factor in 1971-73, was replaced by the number of intersections in 1974. For the high ADT rates the 1971-73 factor of next importance, percentage of road with objects closer than 20 feet was replaced by the same variable with distances of 10 feet.

While there is much variability in the data there is some indication that in the long run at lower speed the importance of object location is of lesser importance. Additional experience will be necessary to confirm or deny this possibility.

Turnover Accidents; In Figure 4-3, the AID branch diagram for 1971-74 turnover accidents, the primal factor is again ADT. In the low and high ADT classes, curve length appears as a good discriminator of the frequency of this type of accident. The presence of curved roadway is a strong determinant of turnover accidents. The variance explanation of turnover accidents is low, only 42 percent being captured in the nine classes presented in the figure.

---

*In all AID's described, the following criteria of splitting were used:
Reducibility (minimum ratio of the variance explained to the total required for a split to be made)=0.025,
Minumum number of cases (sections) in a subgroup = 5
However, AID branch diagrams presented in this report do not always show all sub-groups thus created.

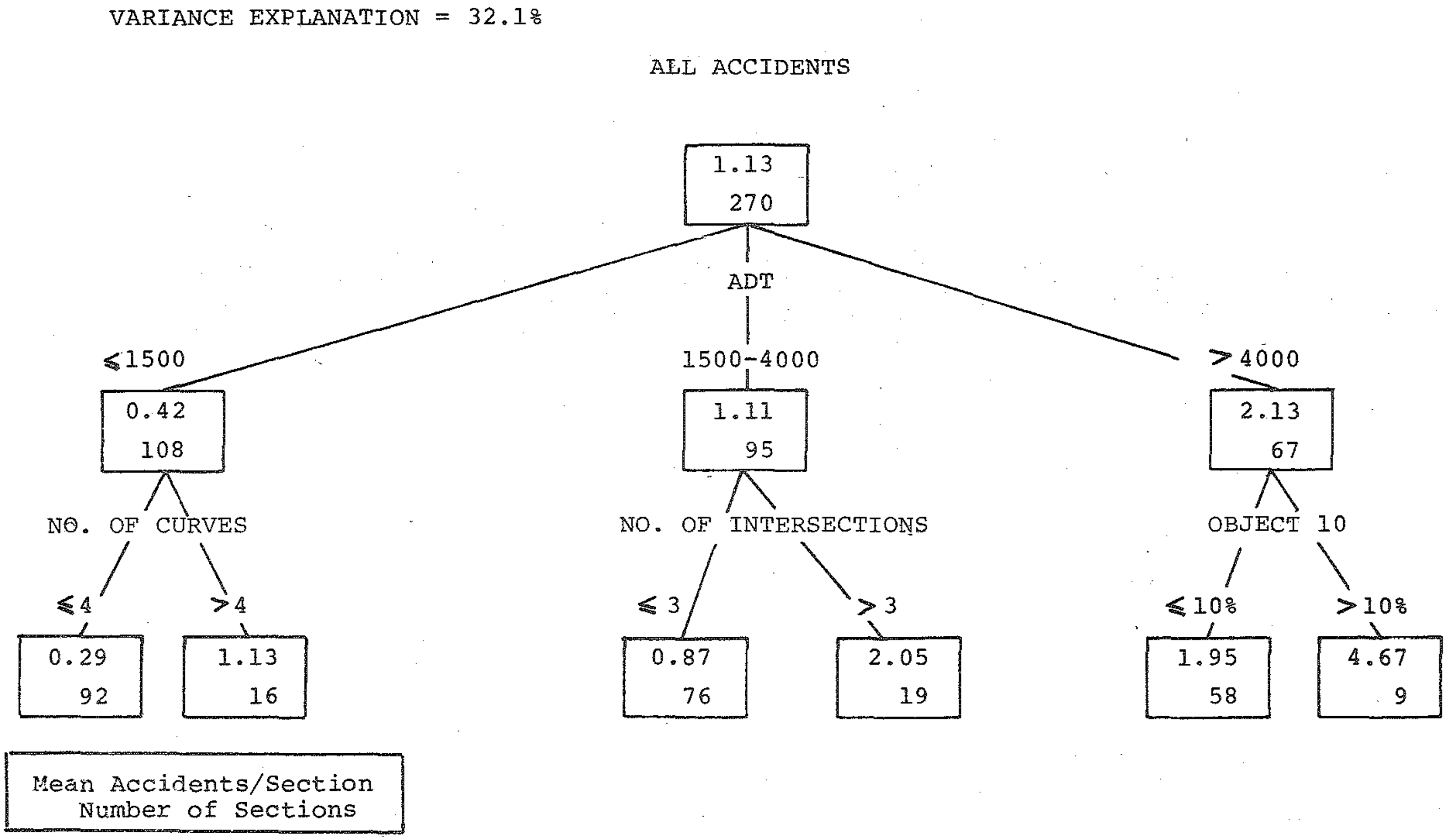


FIGURE 4-1 AID BRANCH DIAGRAM: 1974 FIXED-OBJECT ACCIDENTS

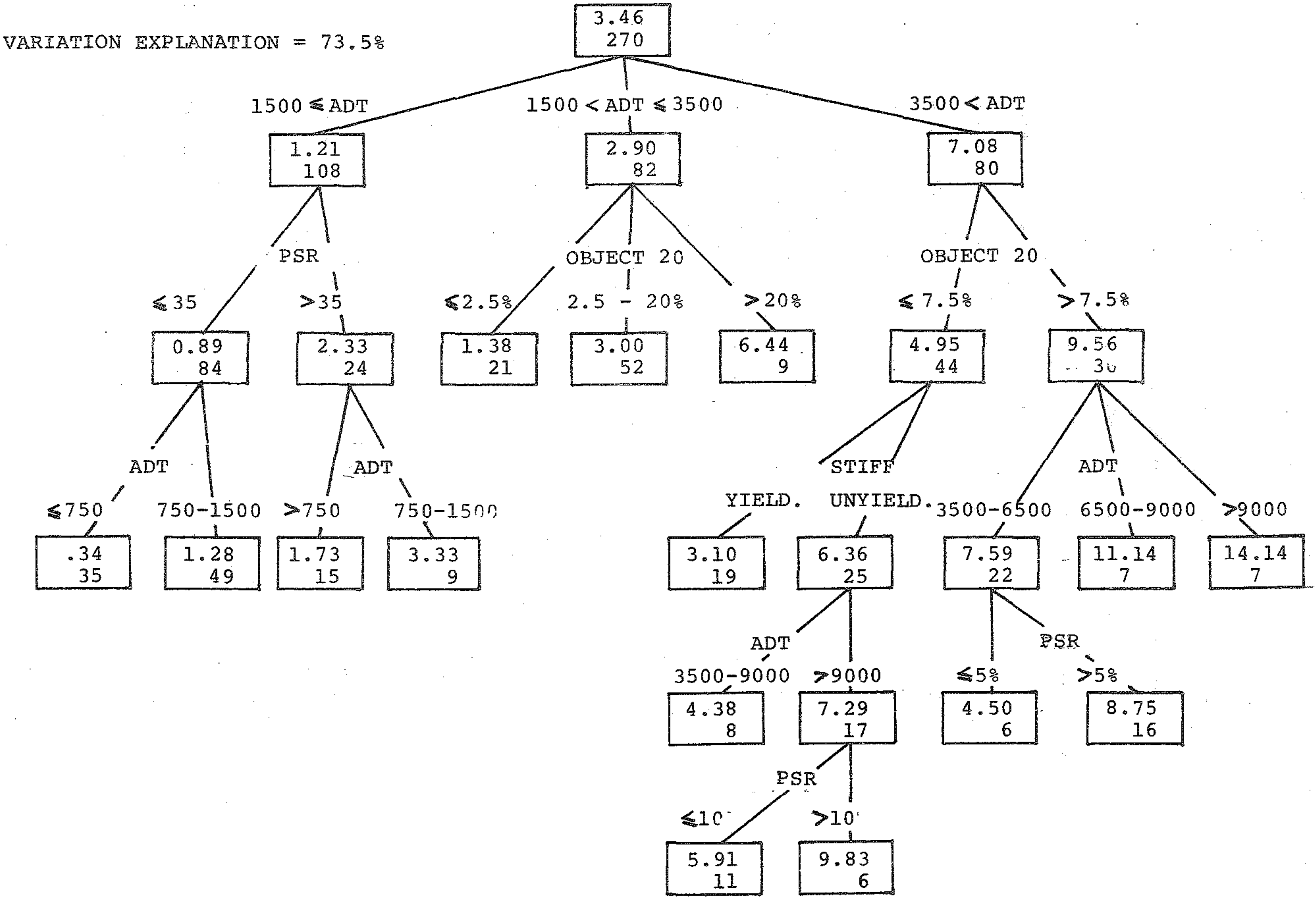


FIGURE 4-2 AID BRANCH DIAGRAM: 1971-73 FIXED-OBJECT ACCIDENTS

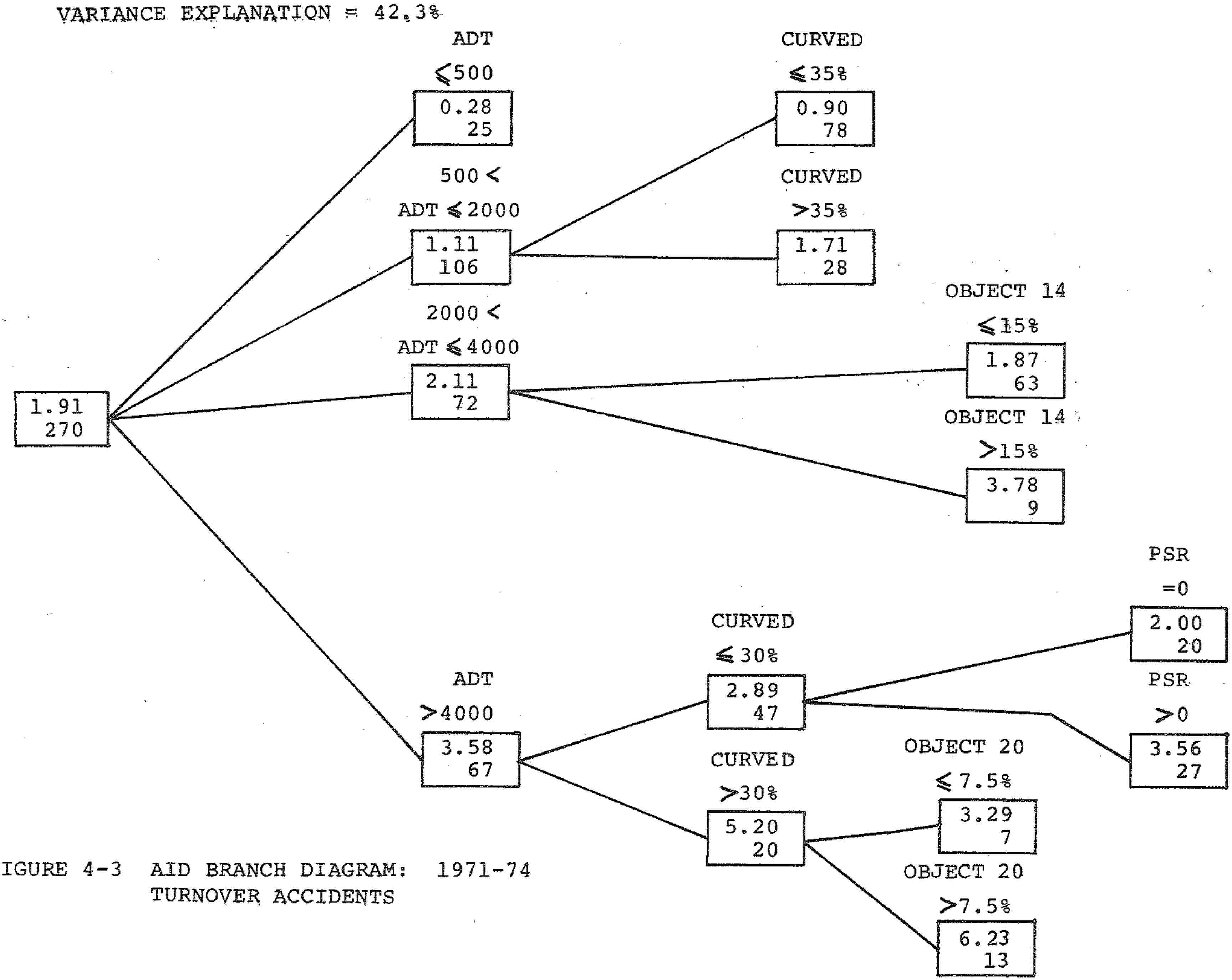


FIGURE 4-3 AID BRANCH DIAGRAM: 1971-74
TURNOVER ACCIDENTS

The 1974 turnover accident AID is shown in Figure 4-4. The total number is down almost 30 percent from the 1971-73 average and the smaller sample makes a lesser level of discrimination inevitable. However, the same variables appear in the majority of splits in both cases and hence, no reason can be seen at this time to believe that the speed limit change has changed the causal description of the turnover accident in Michigan.

4.4 Accident Estimation Model

In this section practical estimation models are developed for total and injury accidents. In the following sub-section, general principles in the model building effort are described with the main focus on the regression analysis. In 4.4.2, total accident estimation models are developed based on the result of AID. Injury accident estimation models are described in 4.4.3. In both sub-sections, results of AID and their interpretation are presented first. Discussions on the estimation models follow in detail.

4.4.1 General Description of Model Building Process

Multiple regression is the basic tool employed here to develop these models. The basic objective of our model building is to provide a practical model for the estimation of the off-road accident experience of a roadway section. Reasonable variation explanation with a small number of independent and obvious causal variables is set as a target. Data acquisition ease and reasonable parameters are also viewed as important.

VARIANCE EXPLANATION = 36.0%

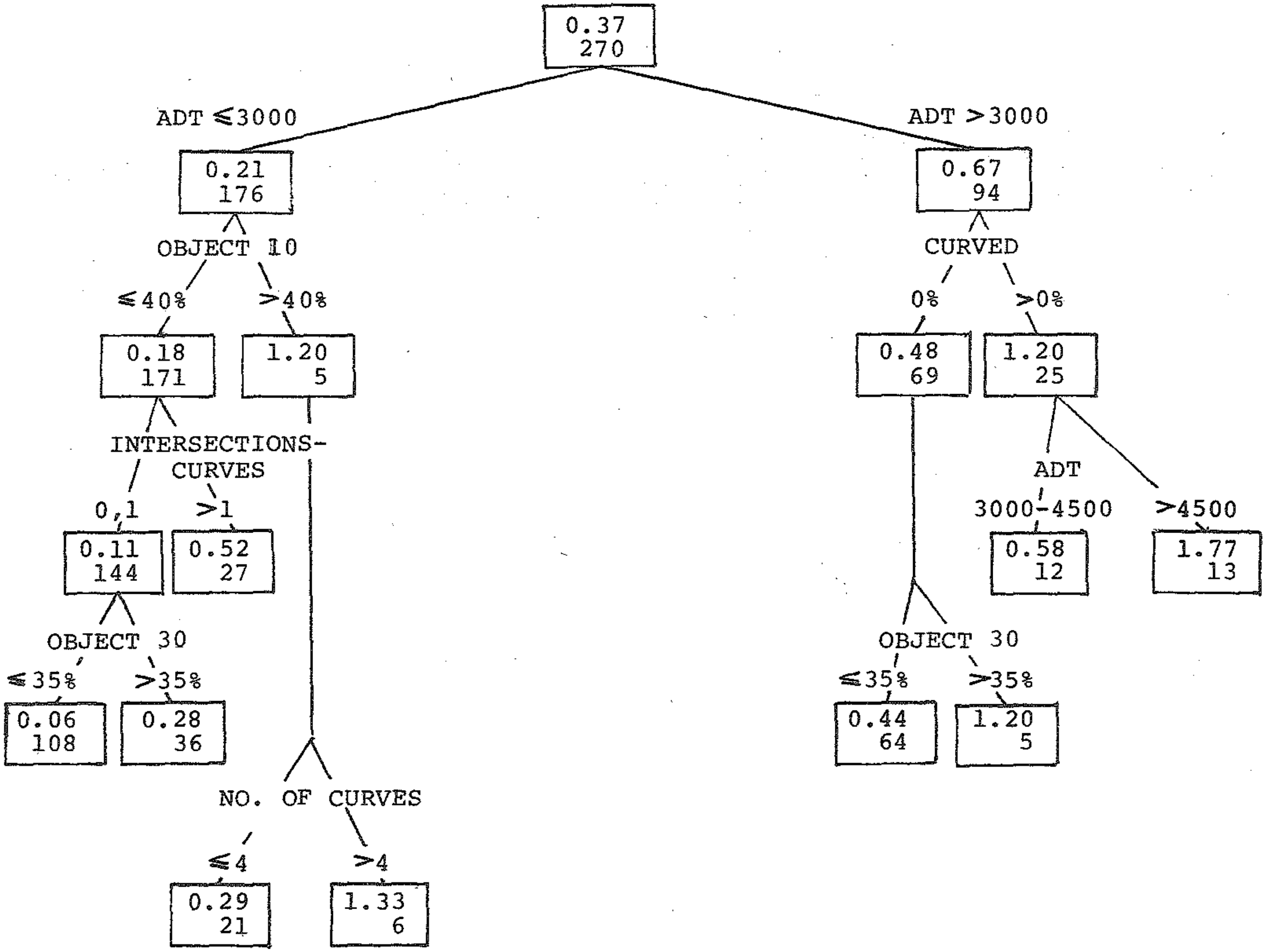


FIGURE 4-4 AID BRANCH DIAGRAM: 1974 TURNOVER ACCIDENTS

The macroscopic analysis presented in Chapter III and the AID results to be described in following sub-sections provide the basic information for model building. A maximum use of a computer terminal is made in model developing to consider simultaneously these analyses in different phases and the regression results.

AID analyses give the researcher a clear view of the interactive behavior of variables. One method employed here to represent the interaction that affects only a sub-group of the entire sample is to develop a model for each of these sub-groups. Further discussion of this treatment of interactions will be found in 4.4.2.

Two forms of models are used in the regression analysis; linear and mulitplicative. The multiplicative model has an inherent capability of representing the interaction, and has the same structure as Glennon's model. On the other hand, the linear model adequately describes the independent effect of a variable making an additive contribution. Thus, both models are developed in almost all cases, and generally result in similar power of variance explanation.

Adding to the result of the Chapter III macroscopic study and AID, analysis of residuals is used to determine an appropriate variable to be taken into the model. A stepwise regression is occasionally used for this purpose, although its direct result is seldom satisfactory.

An important question in the modelling process for a demonstrably complex phenomenon such as off-road accidents is the following:

At what point in the regression modelling process should one cease adding new variables and interactions to the model?

It must be recognized that one could continue to add terms and with their appropriate choice continue to capture a better description of the phenomenon in terms of reducing the variance of the data around the estimated value.

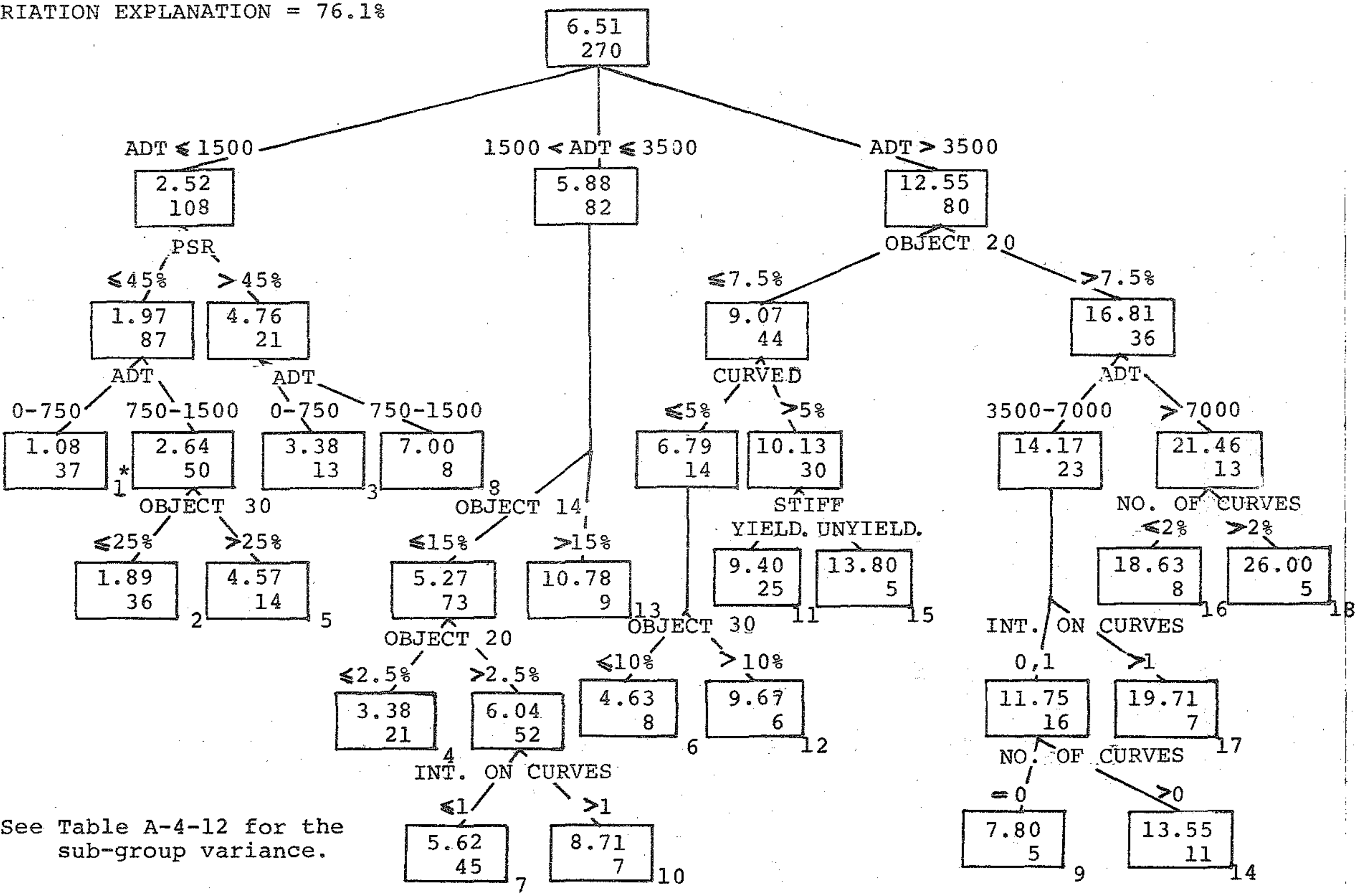
To assist in this decision use was made of the often observed accident characteristic of a homogeneus sections, namely that the accident frequency variation from year to year can be well explained by a Poisson distribution. In the Poisson distribution the unexplainable or fundamental variance is equal to the mean. Accordingly, as a data set was used in the model development process the reduction in the variance toward the mean was closely followed and served as a measure of when additional terms in the model were likely to prove spurious in replicated studies.

An example will be found in Appendix Table A-4-12, where the variance and mean of each AID sub-group (See Figure 4-5) are listed. The Poisson Index, (sample variance)/(mean) varies from 0.44 to 3.09 taking a weighted mean of 1.41. It can be seen that sample variance within each sub-group approaches a Poisson variance.

4.4.2 Total Accident Estimation Models

AID; A major AID analysis involved the more than 1750 1971-74 off-road accidents in the sample file. Figure 4-5 shows

VARIATION EXPLANATION = 76.1%



*See Table A-4-12 for the sub-group variance.

FIGURE 4-5 AID BRANCH DIAGRAM: 1971-74 TOTAL ACCIDENTS the major structure of a branch diagram that accounts for 76 percent of the variation in total accidents in only 18 classes of descriptor variable combinations. The average number of accidents per class ranges from 1.08 for low ADT roads with good passing sight distance (class 1) to 26.00 for curved sections with objects within 20 feet of the surface and ADT's more than 7000 (class 18). See also Table A-4-12.

It is clearly seen that the first stage of the split is dominated by ADT, resulting in three major ADT groups. In the below 1500 ADT group, the next split is the percent passing sight distance restriction (PSR) and then again by ADT. That the effect of PSR on this class of ADT is dominant can be seen by comparing the average accidents of corresponding ADT groups shown in the third row of the diagram. Since PSR is a generalized measure representing horizontal and vertical roadway alignment, it can be concluded that the poor alignment of low ADT roadways is the main explanation for the high accident frequency adding to the ADT exposure rate.

The middle ADT class ($1500 < ADT \leq 3500$) is quite sensitive to object exposure and the initial splits in the class are based on this. The intersection density on curves appears in the diagram in an interactive way.

In the high ADT class ($ADT > 3500$), the first split is on the object exposure within 20 feet which is followed by splits indicating interactions among the variables, ADT (as split at 7,000), number of curves or curve length, intersections on curve density and object stiffness.

It should be noticed that a sub-group with a very high average number of accidents (26.00, an average of more than 3.2 accidents/mile-year) is identified through the splits: high ADT (ADT $>$ 7,000), high object exposure (exposure length to object within 20 feet $>$ 7.5% of the section) and bad alignment (number of curves $>$ 1/mile). This is an example of the way in which AID can be practically employed to identify sections with particularly high accident potential.

Naturally, factors associated with the roadway alignment (number of curves, curve length, percent sight restriction) play a great role in the diagram, as well as object exposure. This result further clarifies the importance of alignment on the accident total adding to the earlier result of this study on the importance of alignment on severity.

Factors related to cross-sectional features, such as pavement width and shoulder width and condition whose effects were found to be dominant in the Ohio study (14), did not appear in major splits at all. Thus the relative importance of their effect on Michigan accidents is questionable.

It is of great importance that those variables appearing in major splits are different in the ADT sub-groups. This indicates a need for the development of individual models for respective ADT sub-groups to best capture the interactions of these affective factors with ADT.

Total Accident Models by ADT Sub-Groups*; As mentioned earlier, one method used here to account for the above different interaction effects by sub-group is to develop regression models for each ADT sub-group respectively. The entire sample is split into four ADT sub-groups whose dominant effect on the variation explanation has been confirmed. The ranges of these ADT sub-groups are; $ADT \leq 750$, $750 < ADT \leq 1500$, $1500 < ADT \leq 3500$, and $3500 < ADT$. These ranges are consistent in all AID runs on total accidents regardless of explanatory variables involved. The final forms of eight equations are found in Table 4-3. In the multiplicative models, variables, except for ADT, must have e (= 2.718) added before being raised to the power. For ANOVA tables, refer to Appendix Tables A-4-1 through A-4-4. Also refer to a note on these ANOVA tables on the first page of Appendix A.

In the lowest ADT class ($ADT \leq 750$), it should be noticed that more than 50 percent of the variation is explained by a simple linear model which uses only two variables developed from passing sight restriction. It is quite noticeable that the dummy variable representing the 100% sight restriction is highly significant with a coefficient exceeding 6. This shows that low ADT roadwary with very poor alignment average an excess of more than 3 off-road accidents per mile per four years. The multiplicative model also shows the im-

---

*All accident estimation in this study is for a four year period, and for a two-mile section of roadway, unless otherwise mentioned.

TABLE 4-3

LINEAR AND MULTIPLICATIVE TOTAL ACCIDENT ESTIMATION MODELS BY ADT SUBGROUPS

ADT $\leqq$ 750	$\hat{y} = 0.03117\ \mathrm{PSR} + 6.235\ \mathrm{PSR100} + 0.6476,\ R^2 = .529$
	$\hat{y} = 0.1880 \times (\mathrm{ADT})^{.6475} \times (\mathrm{PSR})^{.2472} - 1,\ R^2 = .365$
750 $<$ ADT $\leqq$ 1500	$\hat{y} = 0.05137\ \mathrm{PSR} - 1.596\ \mathrm{PSR0} + 2.874\mathrm{L}$ $R^2 = .267$
	$\hat{y} = 1.5821 \times (\mathrm{PSR})^{.3115} - 1,\ R^2 = .246$
1500 $<$ ADT $\leqq$ 3500	$\hat{y} = 0.1910\ \mathrm{OB14} + 0.03646\ \mathrm{OB14} \times \mathrm{IC} + 4.526,\ R^2 = .310$
	$\hat{y} = 0.006121\ (\mathrm{ADT})^{.7434} \times (\mathrm{OB20})^{.4094} \times (\mathrm{PCL})^{.08420} - 1,\ R^2 = .323$
3500 $<$ ADT	$\hat{y} = 0.5504 \times 10^{-3} \times \mathrm{ADT} \times \mathrm{NC} + 12.441,\ R^2 = .367$
	$\hat{y} = .03672 \times (\mathrm{ADT})^{.4646} \times (\mathrm{NC})^{.8696} \times (\mathrm{OB20})^{.2874} - 1,\ R^2 = .480$

For notation see Table 4-2.

portance of sight restriction as an off-road accident predictor.

Fluctuation in the numbers of accidents is much higher in the second class of ADT ($750 < ADT \leq 1500$), which caused difficulties in building a good-fit model for this class. As is shown in Table 4-3 only percent sight restriction (PSR) is employed as an explanatory variable in both linear and multiplicative models. Addition of any other variables did not yield markedly better results.

Therefore, for roads with ADT less than 1500 vehicles per day the inclusion of variables other than passing sight distance restriction is pointless. This indicates that percent sight restriction can be employed alone as a good measure for off-roadway accident prediction on these roadways.

The third class ($1500 < ADT \leq 3500$) is quite sensitive to object exposure as is shown in the result of AID. Actually new variables representing object exposure and curves are introduced in the models, and percent sight restriction (PSR) has dropped. Similar variables appear in the models for the highest ADT class (3500 ADT). In the linear model, one variable, an interaction term involving ADT and curve density, accounts for 37% of the variation. The variation explanation of the multiplicative model is significantly greater, 48%, as the length of road with objects closer than 20 feet is introduced.

Two figures present the multiplicative model for the lowest ADT class (ADT$\leq$750) given in Table 4-3. The first figure, (Figure 4-6)*, shows the model equation against ADT for four different values of percent sight restriction (PSR), and the second one (Figure 4-7) against PSR for four ADT values. The first figure shows the diminishing slope of the ADT effect even in this small range of ADT. The interaction of ADT and PSR is seen by the difference in the slope of each line and the distances between the lines. In Figure 4-7 it can be seen that there is a rapid change in the estimated number of accidents in the lower range of PSR. In this ADT sub-group, the multiplicative model can produce negative values. However, no Michigan data combinations were found in this range.

The variation explained by these models for individual ADT sub-groups is not usually very high. This illustrates the overwhelming importance of traffic volume. Also, the fluctuation in the accident frequency is very high for the middle range of ADT. In spite of this, the above modelling effort has confirmed the following conclusion through the regression analysis and makes a significant contribution to future studies: Factors and interactions affecting off-roadway accidents are very different among ADT sub-groups.

---

*In Figures 4-6 and 4-7, the models are plotted only within the range of observed variable values.

P S R
Percent Sight Restriction

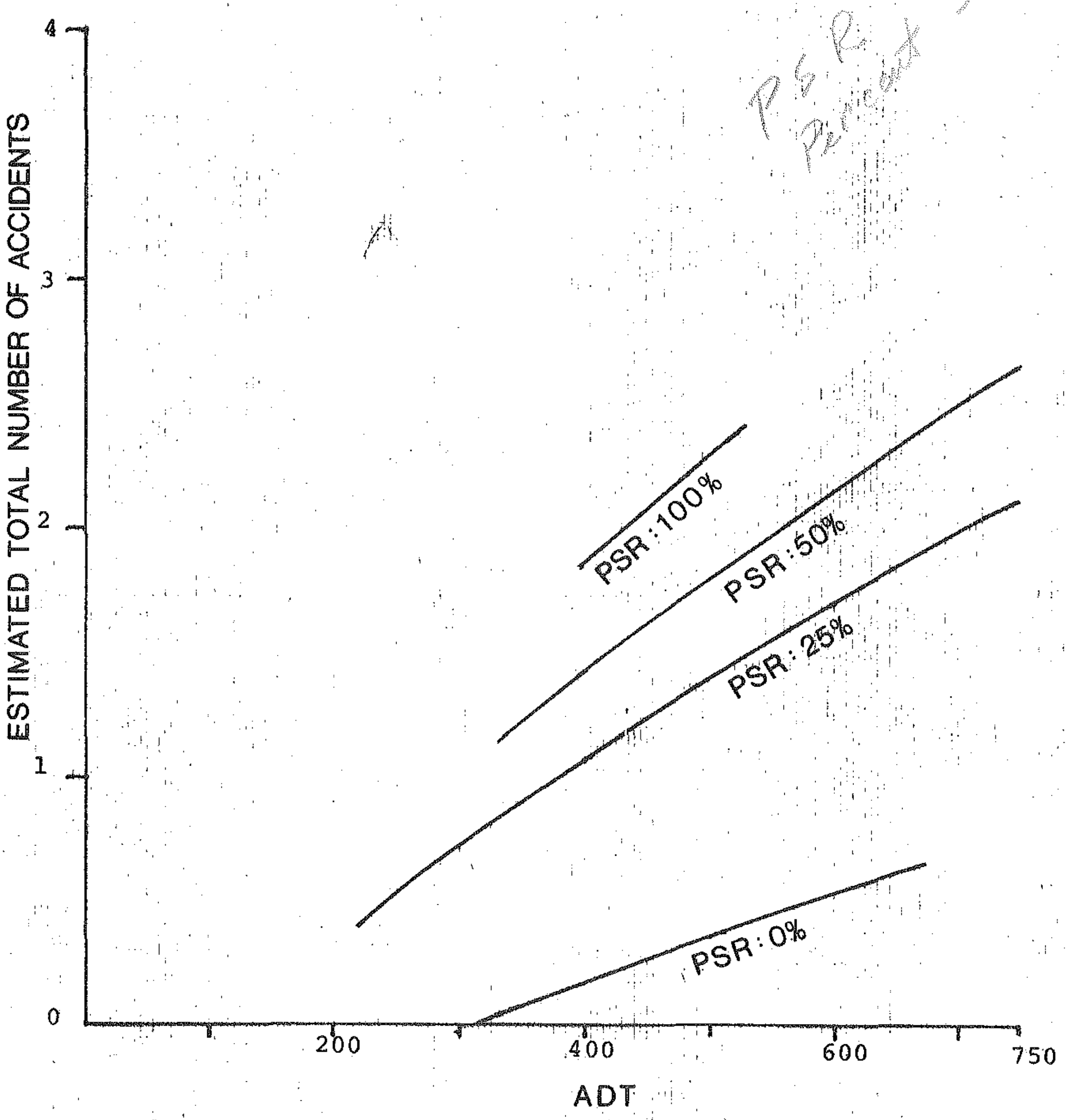


FIGURE 4-6 MULTIPLICATIVE TOTAL ACCIDENT PREDICTION MODEL: ADT AND PSR

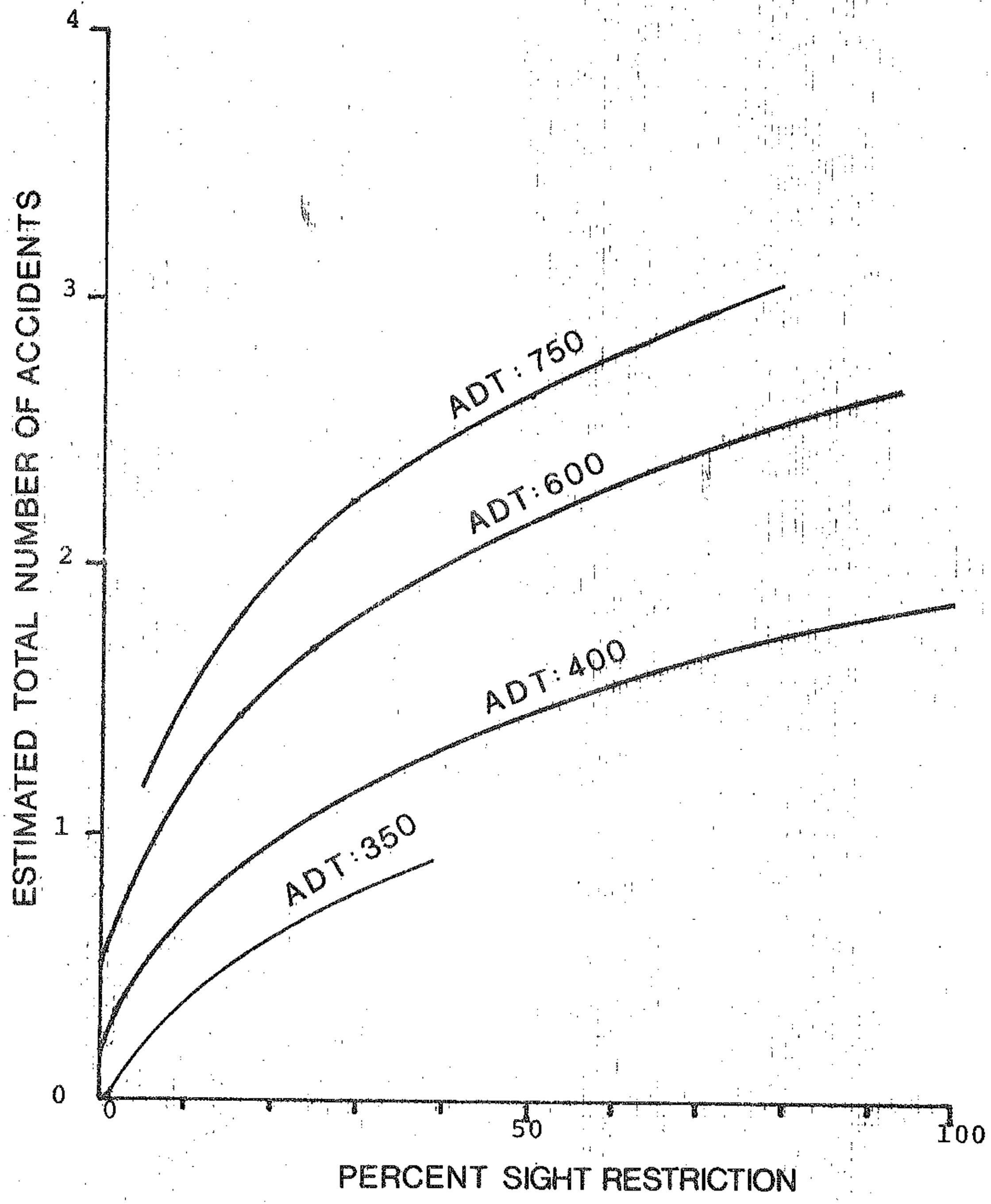


FIGURE 4-7 MULTIPLICATIVE TOTAL ACCIDENT PREDICTION MODEL: PSR AND ADT

Total Accident, Overall Model; In its final form the linear model explains 68% of the variation in the number of off-road accidents, and the multiplicative model 65%. In the linear model, the ratio of regression variance to the theoretical Poisson variance is approximately 2.

Linear Model; When applying a model of practical form to the entire sample it is not easy to represent an interaction affecting only some sub-groups, as has been determined by AID analysis. A usual method to add a multiplicative term of two or more variables is employed here to represent the interaction. The final form of the model is as follows: Note that the intercept is suppressed in the regression (also refer to Appendix Table A-4-5 for an ANOVA table).

$$\begin{aligned}\hat{y} &= 10^{-4}\sqrt{ADT}\left\{3.158\ IC \times OB20 + 20.71\ OB14 + 867.5\right\}\\ &+ 10^{-5}\ ADT\left\{1.357\ PSR + 42.09\ NC\right\},\\ R^2 &= .678\end{aligned}$$

where object exposure (OB14, OB20) and sight restriction (PSR) are in percent. It should be noticed from the above that all variables other than ADT are introduced in the multiplicative form, namely as interaction terms with ADT. Needless to say, those variables involved in the model show the important effect of roadway alignment as well as object exposure on accident frequency.

Increasing ADT has a diminishing effect on the number of accidents, expressed by the square root of ADT in this model. Bearing this basic relationship of ADT and number of accidents in mind, it can be seen that the number of accidents increases linearly with the exposure to objects within 14 feet. The fourth and fifth terms express the non-linear relationships of percent sight restriction and number of curves per mile to the number of accidents since their effects are further multiplied by $\sqrt{ADT}$ (this effect is shown later on Figure 4-8). This captures the importance of good roadway alignment on high ADT highways. A figure is directly obtained from the model showing that the existence of one curve per mile on a roadway with ADT of 2500 increases the number of accidents in four years by approximately 1.

This equation is plotted against ADT in Figure 4-8 using various combinations of values for the explanatory variables. The wide range of predicted values will be noticed. It can be found that "a roadway with bad curves and objects" (Curve ④) has a different shape from others, with a steeper gradient. This is the only case, among these five, where bad alignment is assumed, but the object exposure is identical to Curve ③. Thus, this example clearly shows the effect of bad alignment in relation with ADT which was described above. A comparison of Curve ② to Curve ① shows the effect of well-designed curves on accidents, when those curves do not cause any sight restriction. It is noticeable that the increase in predicted accidents is relatively small. Another comparison of Curve ⑤ to Curve ① gives the maximum effect of

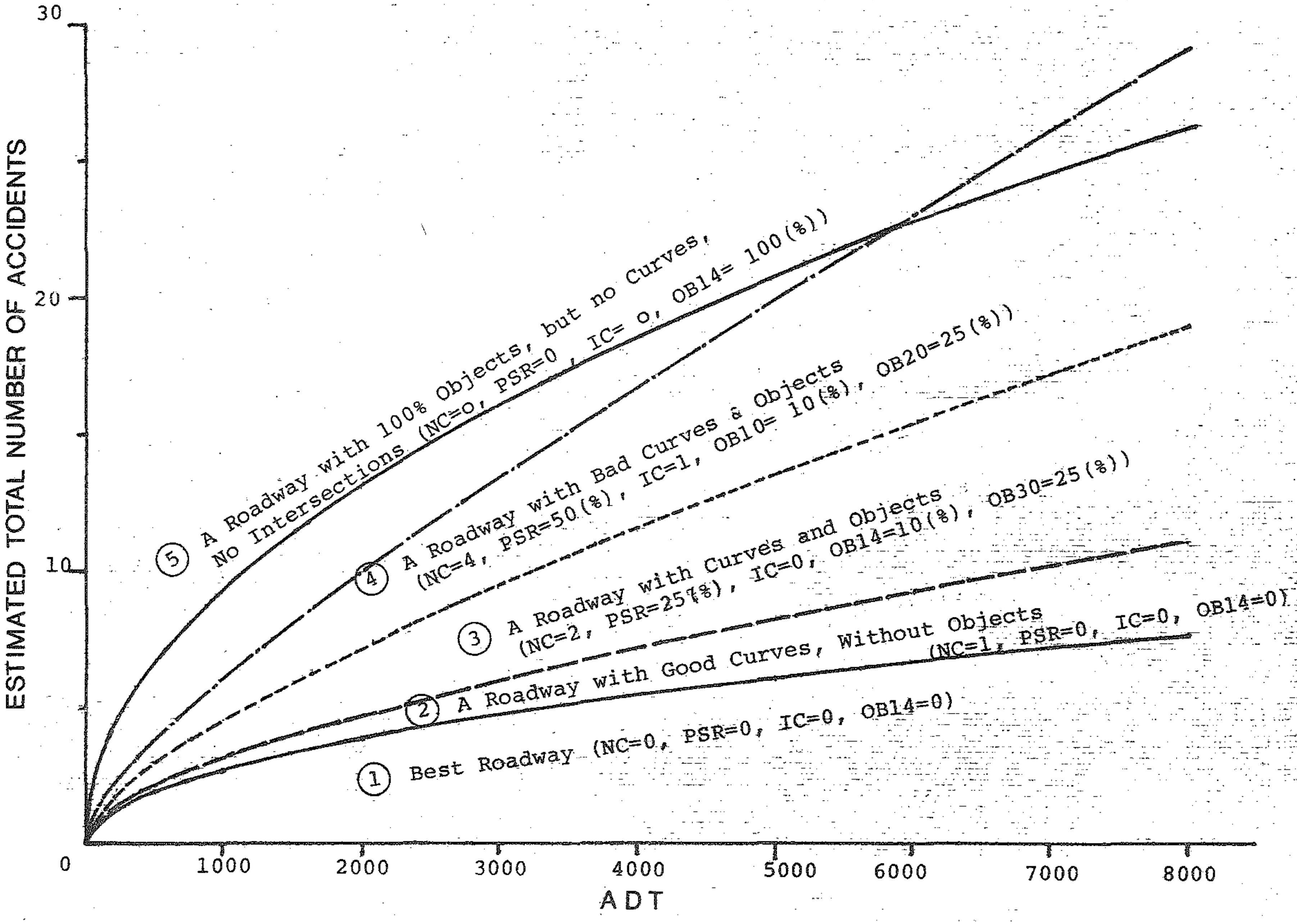


FIGURE 4-8 TOTAL ACCIDENT ESTIMATION MODEL: ADT AND ROAD CHARACTERISTICS

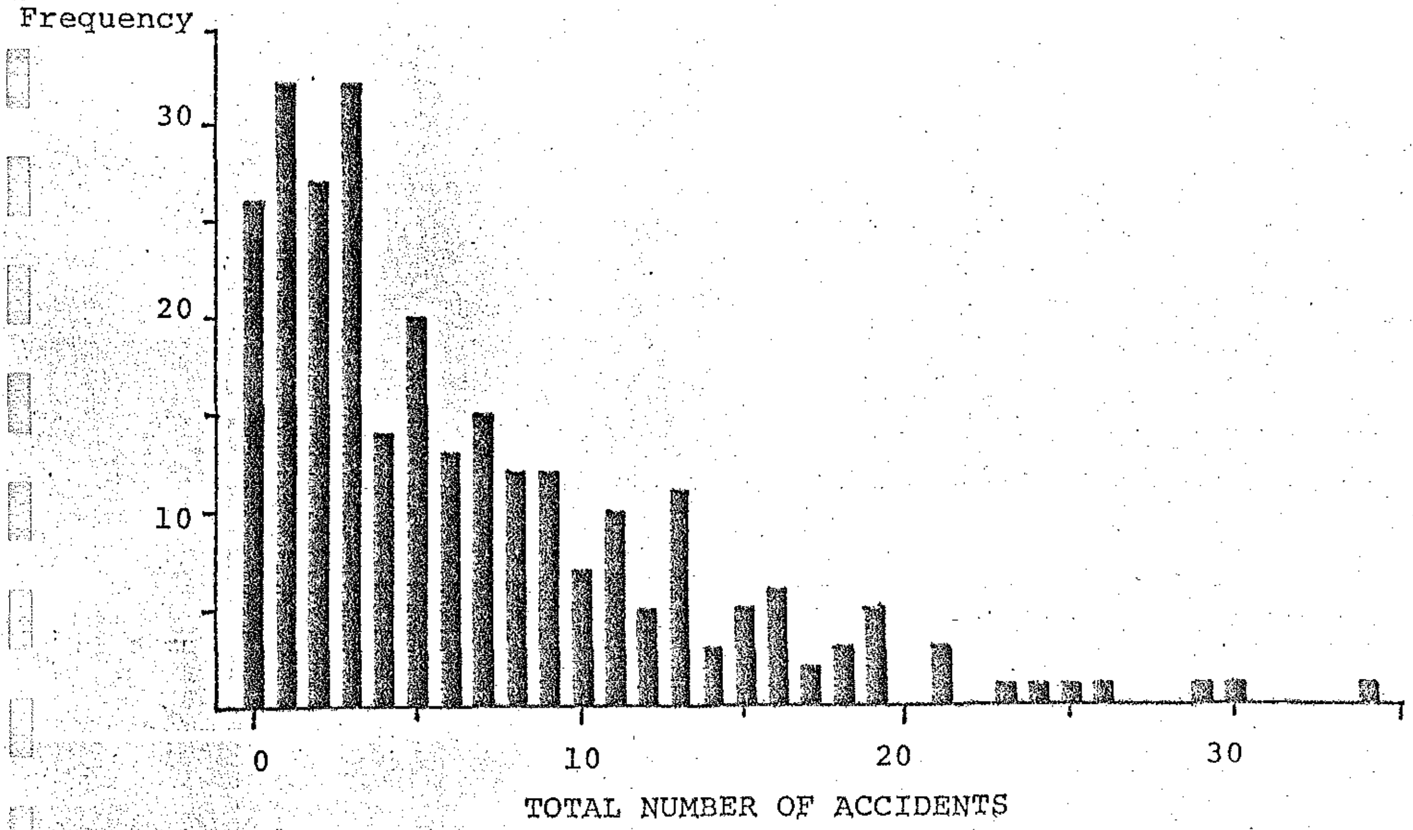
object when no curve exists in a roadway section, and object exposure length changes from 0% to 100% of the section.

Figure 4-9 compares the result of prediction by the linear model to the actual value in the form of a univariate distribution. The range of predicted values for this sample is $1.43 \leq y \leq 28.75$. It is clearly seen that the model overestimates the number of accidents on those low accident sections with less than two accidents. In a scatter plot diagram, (Figure 4-10) this tendency is also seen. It is also found that there exist a few cases with high accident exposure which are underestimated. Those values are probably "extreme values" in which independent investigation of the respective cases is more appropriate than trying to incorporate their effect in the overall model.

The reason for the overestimation of low accident cases is accounted for by the inability of the model to represent the partial interactions affecting only sub-groups of the entire sample. As the AID diagram (Figure 4-5) clarifies, the low ADT group which represents most of the low accident sections is not affected by variables such as IC. However, these factors that are ineffective in this sub-group actually inevitably affect the prediction to a certain extent resulting in the above overestimation. There is also sampling variation.

For the linear model, it can be concluded that it captures the interactions to some extent and explains the

SAMPLE DISTRIBUTION



DISTRIBUTION OF ESTIMATES

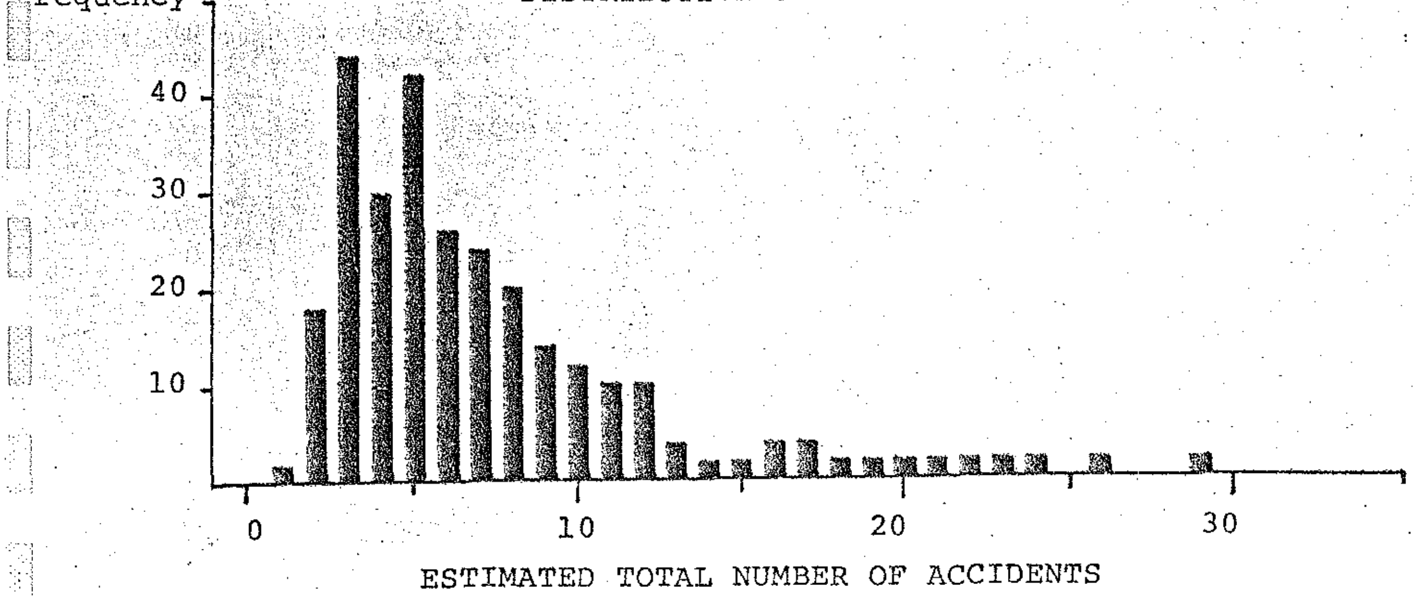
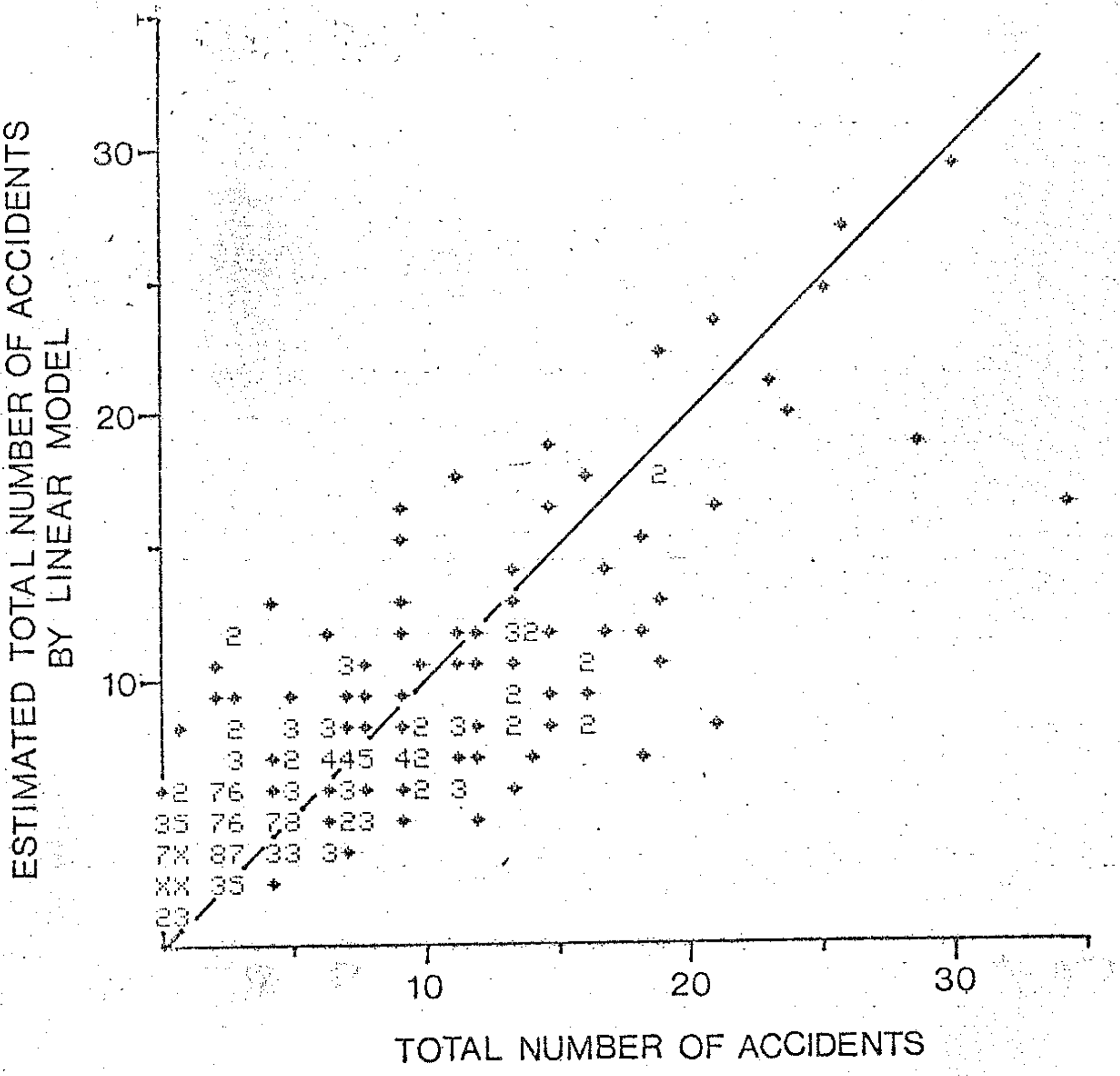


FIGURE 4-9 DISTRIBUTION OF SAMPLE AND ESTIMATED TOTAL NUMBER OF ACCIDENTS: LINEAR MODEL



* : one section

n ($2 \leq n \leq 9$): n sections

x: more than nine sections

FIGURE 4-10 ESTIMATED TOTAL ACCIDENTS AGAINST SAMPLE VALUES; LINEAR MODEL sample variation quite well. However since it does not completely capture the partial interactions it overestimates for those cases with very low number of accidents. Although its effect is relatively small and is even on the safe side, this systematic, rather than random, error of the model must be kept in mind in practical applications. As the scatter diagram shows, its performance in the middle to high accident range is quite adequate, and even the few extreme cases are in a reasonable range of error. Thus it can be concluded that the model can be applied for predictive purposes and will result in a satisfactory range of error.

Multiplicative Model; The multiplicative model solves the problem of overestimation in lower ranges of the linear model. The ADT exponent is .74 which shows the lessening effect of ADT on the number of accidents. The final form of the multiplicative model follows (an ANOVA table is shown in Appendix Table A-4-6):

$$\hat{Y} = .006969 \times (ADT)^{.7298} \times (PSR)^{.1233} \times (OB20)^{.2168} \times (IC)^{.1910} - 1,$$

$$R^2 = .646$$

Recall that PSR, OB20 and IC must have e (= 2.718) added.

In this model, percent sight restriction and object exposure within 20 feet represent roadway alignment and object exposure, respectively, and their effect is highly significant. Figure 4-11 compares the predicted and actual values in a univariate distribution form. It should be noticed that the fit at low accident density is improved in this model over the

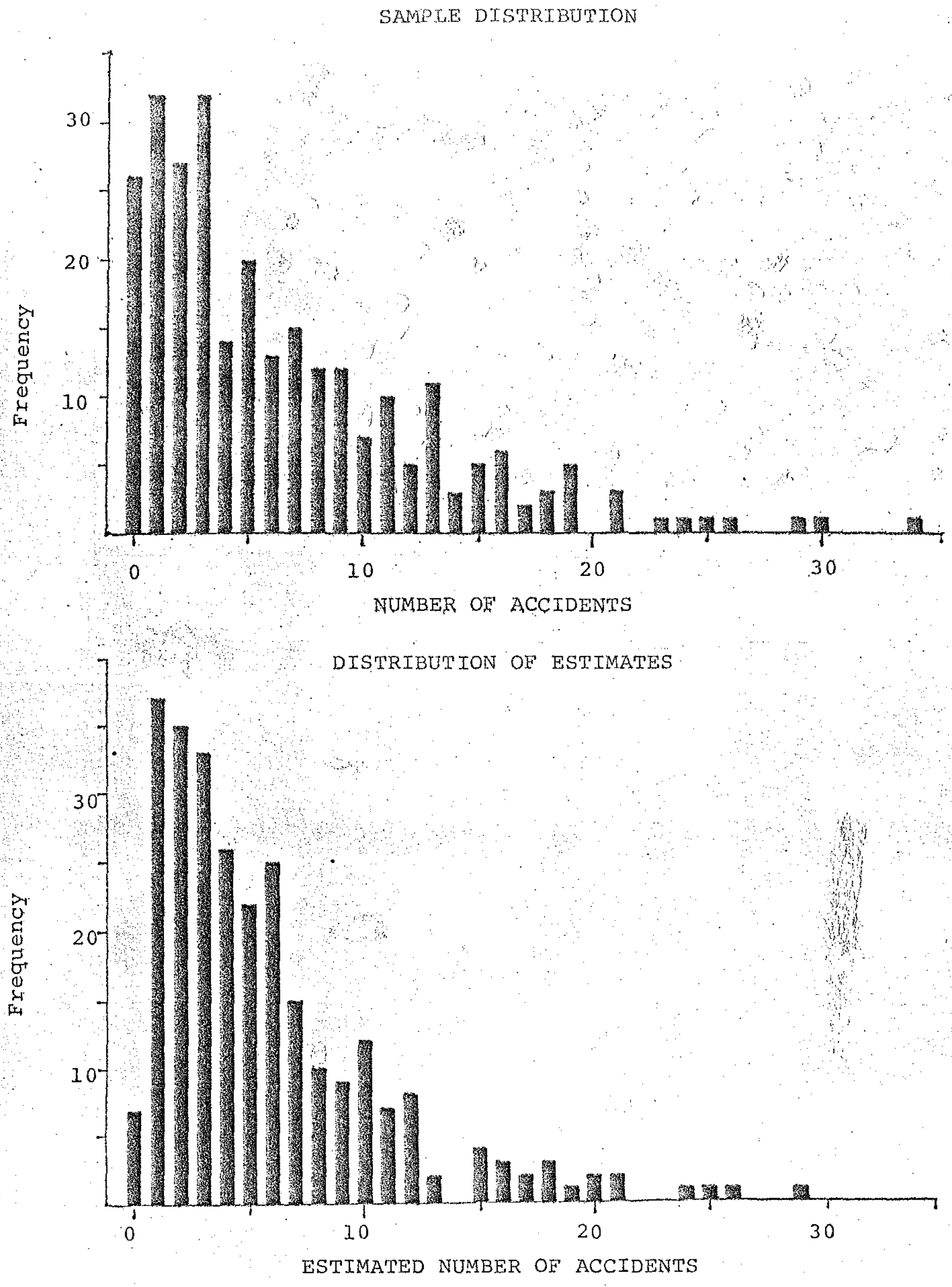


FIGURE 4-11 DISTRIBUTION OF SAMPLE AND ESTIMATED NUMBER OF TOTAL ACCIDENTS: MULTIPLICATIVE MODEL

linear model. However, further analysis of the residuals showed that the error in the high density region is increased in this model. This is quite natural because of the log-transformation in the regression.

Therefore it is suggested that the linear model be used for the prediction in middle to high range of accident prediction, and multiplicative model in the low to middle range. Since each single model itself has excellent characteristics and power of variation explanation this bimodal method of estimation will by far increase the predictive power in practice.

4.4.3 Injury Accident Estimation Model

AID; The effect of ADT is not so dominant in injury accidents as for total accidents. This indicates that the effect of other factors is more important in injury accidents.

After the first split by ADT shown in Figure 4-12, the curve length is next in importance in the lower ADT class, and object exposure within 30 feet in the higher class. It should be noticed that percent sight restriction, which played an important role in the splits of the low ADT class for total accidents (see Figure 4-5), does not appear at all in Figure 4-12. Instead the curve length and the number of curves appear in important splits. An interpretation is that the injury accident is more sensitive to the horizontal alignment of roadways than is the total accident and that the vertical

VARIATION EXPLANATION = 60.6%

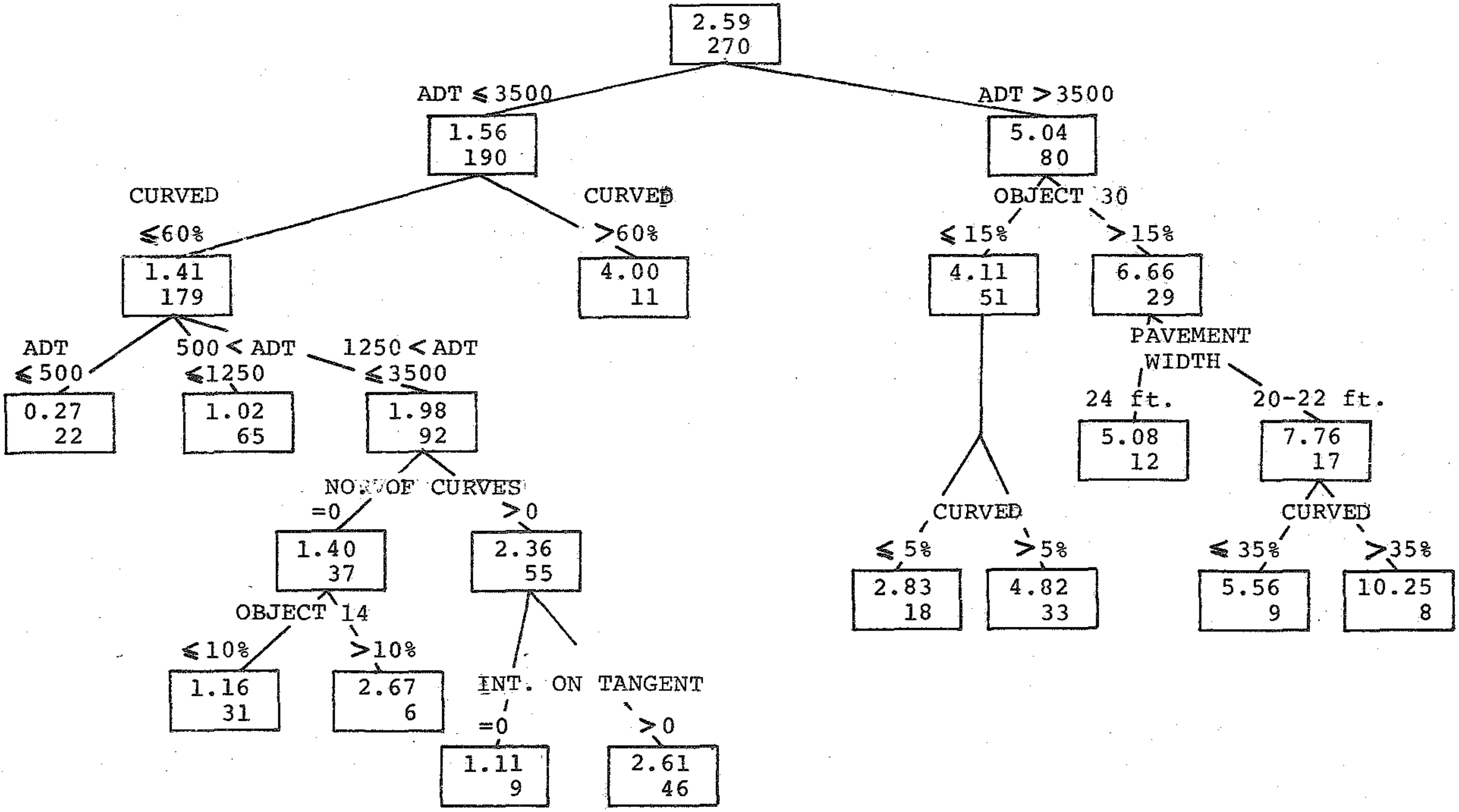


FIGURE 4-12 AID BRANCH DIAGRAM: 1971-74 INJURY ACCIDENTS

alignment, which is an important component of sight restriction, is less important in injury accidents. This is consistent with the result of Chapter III of this report.

One interaction of the pavement width should be noticed. The diagram shows that, on high ADT roadways, when object exposure is high (more than 15%) on more curved sections (more than 35%), the roadway with a 20- or 22-foot pavement has twice as many injury accidents as does a roadway with 24 foot pavement; but when the section does not involve this much curvature, the effect of wide pavement is not apparent (compare the four sub-groups in the lower right of Figure 4-12). Thus the diagram clearly shows that the effect of pavement width is not noticeable through the entire sample, but is restricted to limited situations.

Injury Accident Model; The final form of the linear model is as follows (see Appendix Table A-4-7 for an ANOVA table).

$$\hat{y} = 10^{-4} \times \text{ADT} \left\{ 0.6730\ \text{NC} + 0.2208\ \text{OB14} - 2.095\ \text{NCO} - 0.0005212\ \text{ADT} + 9.5292 \right\} + 0.04254,$$

$$R^2 = .549$$

It should be noticed that the regression coefficient is relatively low compared to the models for total accidents. However, using the total number of accidents as a measure of the inherent variation of the sample (a Poisson accident process), the ratio of the variance of the regression error by the linear model (shown in Appendix Table A-4-7) to the Poisson variation, is obtained as 880.2/699 = 1.26 which is very close to 1. Thus we can reasonably say that this model explains the sample variation to a very satisfactory extent.

The linear model accounts for 55% of variation, with the variables, object exposure within 14 feet (OB14), number of curves per mile (NC) and naturally ADT appearing.

The coefficient of the quadratic term of ADT is negative indicating the diminishing effect of ADT on injury accidents. For the average ADT of 2,800 (an approximate sample average) the estimated number of injury accidents varies by more than six when the object exposure varies from 0 to 100%. This variation is very large considering that the average of injury accidents is 2.59.

The multiplicative model is as follows (see Appendix Table A-4-8 for an ANOVA table).

$$\hat{y} = 0.02655 \times (ADT)^{.5213} \times (PCL)^{.1248} \times (STIFF) \times (OB10)^{.1167} - 1,$$

$$R^2 = .492$$

where, STIFF; a categorical variable takes values of 1.362 or 1.167 depending on the existence or non-existence of unyielding objects within 14 feet, respectively. PCL and OB10 must have e (= 2.718) added as before.

In the multiplicative model, a variable showing the existence of unyielding objects within 14 feet (STIFF) is introduced with high significance. The results show that injury accidents increase by 17% when there are unyielding objects close to the road. The appearance of object exposure within 10 feet (OB10), the nearby obstacle in this model suggests that the number of injury accidents is more affected by closer objects. Again, percent curve length (PCL) turns out to be one of the most significant variables of this model. This model can be considered as a macroscopic version of Glennon's model with one additional term representing alignment (PCL), which is highly significant.

In the models for ADT sub-groups (Table 4-4, ANOVA tables are in Appendix Tables A-4-9 through A-4-11) it can be seen that object exposure within 14 feet (OB14) is a quite effective variable throughout the range of ADT, which is different from the result for total accidents. Adding to ADT a dummy variable representing 100% sight restriction (PSR100) is significant in the low ADT group, and so is the curve density-ADT interaction, (NC) x (ADT), in the high ADT group. As is suggested by the AID diagram (Figure 4-12), the difference in interaction terms among ADT sub-groups is not so clear as in the total accident data. Thus various types of variables are involved in each model.

4.5 Predictive Variable Summary

Based on four AID analyses developed in this chapter, Table 4-5 is shown to summarize the importance of variables in off-road accident prediction. Since four types of accidents, 1971-74 total accidents, injury accidents, turnover accidents and

TABLE 4-4

INJURY ACCIDENT ESTIMATION MODELS BY ADT SUBGROUPS

$\mathrm{ADT} \leqslant 1250$	$\hat{y} = 0.004762\ \mathrm{ADT} - 0.2455 \times 10^{-5} \times \mathrm{ADT}^2 + 0.009004\ \mathrm{PSR} + 3.373\ \mathrm{PSR100} + 0.0002238\ \mathrm{NC} \times \mathrm{ADT} + 0.1675 \times 10^{-4} \times \mathrm{OB14} \times \mathrm{ADT} - 1.545, \quad R^2 = .367$
$1250 < \mathrm{ADT} \leqslant 3500$	$\hat{y} = 0.0002640\ \mathrm{ADT} + 0.008568\ \mathrm{PCL} + .2839\ \mathrm{NC} + 0.3319 \times 10^{-4} \times \mathrm{OB14} \times \mathrm{ADT} + 0.6552, \quad R^2 = .242$
$\mathrm{ADT} > 3500$	$\hat{y} = 10^{-4}\ \mathrm{ADT} \left\{1.659\ \mathrm{NC} - 1.002\ \mathrm{NCO} + .1552\ \mathrm{OB14} + 1.374\ \mathrm{STIFF}\right\} + 3.3728, \quad R^2 = .324$

For notation, refer to Table 4-2.

1971-73 fixed-object accidents, are involved, the table can be considered to have captured the general effect of each variable on the off-road accident.

The nineteen variables used in the analysis are arranged according to the number of their appearances and the highest ranks of split that they attained in AID diagrams.* Successive two (or more) splits on a single variable were considered as belonging to a same rank in the preparation of this table. Sixteen appearances are possible.

Obviously, ADT is the dominant predictor of the number of accidents of all types. It should be noticed that the next seven most important variables following ADT are all descriptors of either roadway alignment or roadside objects. In general, judging from its high rank in this table, percent exposure length to objects within 20 feet from the pavement edge can be practically used as a single measure of roadside object exposure.

As has been mentioned, the best descriptor of roadway alignment differs depending on ADT or the type of accident. For total accidents, passing sight distance restriction is a very good predictor for low ADT roadway sections, but not for high ADT roadways, nor for turnover accidents either. The most appropriate one for each case can be found in AID diagrams or prediction models presented in this chapter.

---

*The whole splits created under criteria described in a footnote in 4.4.3 (page 83), not the ones presented in figures of this chapter, are used for this table.

TABLE 4-5

VARIABLE FREQUENCY AND IMPORTANCE IN AID ANALYSES

	RANK OF AID SPLIT				
VARIABLE	1	2	3	3	TOTAL
ADT	7	1	4	4	16
OB20		3	2	1	6
CL		2	2	2	6
PSR		2	1	2	5
OB14		2		2	4
OB30		1	2	4	7
NC			2	3	5
STIF			2	3	5
NIC			2	1	3
PAVE. W.			1	1	2
AREA				5	5
SHOULD. W.				5	5
NIT				4	4
OB10				1	1
DITCH				1	1
OB 6					0
NITO					0
TREAT					0
ROLLING					0

For notation, see Table 4-2.

The importance of roadway cross-sectional features did not appear in this study, contrary to the Ohio study (14). The ranks of pavement width and shoulder width are low in this table (the split on pavement width in rank 3 is the one for injury accidents. Recall that its effect is limited to a specific sub-group of roadways as described in 4.4.3). Further, shoulder treatment never appeared in the AID diagrams. This completely conflicts with the view of the importance of a shoulder stabilization program recommended in the Ohio study. Since the Ohio study did not take such important factors as roadway alignment and object exposure into account, simultaneously, their analysis is confounded by the inter-correlation among variables and the analysis of the accident rate without paying attention to ADT and section length might have caused significant sampling error.

No object exists within 6 feet from the pavement edge in almost all sections, and this is the main reason for no entry of OB6 in the table. Similarly, the dominant object located less than 10 feet from the pavement is guardrail and it is far less important than other contributing factors.

Review of the Ohio Study:

One reason for the above conflict of the current results with those of the Ohio study can be found in the difference in the roadways between Michigan and Ohio. The Ohio study concluded that the effect of shoulder stabilization was maximum when the roadway (pavement) width was between 16 and 19.9 feet. Such narrow roadways are very rare (14 segments in the entire Sufficiency Rating segments; see Appendix B-4), and the current analyses do not consider them. Further possible reasons are discussed below.

In the second stage of the Ohio study (see 2.1 of this report), 210 highway sample sections were drawn, controlled by the roadway width and shoulder width. The effects of the roadway width, shoulder width, shoulder type and recovery area on the accident rate were examined using ANOVA. However, in this stage of the Ohio study, important factors such as the roadway alignment and traffic flow were not considered in deriving their final conclusion. Thus the conclusion was, very plausibly affected by those factors not included in their analysis. Judging from the current AID results involving many factors, the validity of the recommended program, shoulder stabilization, in Michigan is quite questionable.

Another comment on the Ohio study is concerned with the use of the accident rate. Discussions on the usage of rates can be found in Section 3.4 and Appendix A-2 of this report.

4.6 Reconsideration of Glennon's Model -- An Extension

The structure of Glennon's model discussed in detail in Chapter II of this report can be repeated in a generalized equation form as follows:

$$H = V \left[P(E)\right]\left[P(C|E)\right]\left[P(I|C)\right]$$

The models developed here for two-mile sections of roadway generally involve ADT as the measure of vehicle exposure, V, alignment as a factor related to probability of encroachment and severity (probability of an injury), object exposure length as a measure of collision probability, and the existence of closer unyielding objects as a macroscopic measure of the probability of an injury. Comparing these components with the above formula, the models can be regarded as a macroscopic extension of Glennon's model which is typically seen in the multiplicative injury accident model, except for the important difference of the inclusion of alignment as a predictive variable.

As described in an earlier part of this chapter, Glennon's model may be employed in the evaluation of object improvement strategies after a hazard section is identified applying the models developed here. In its application, Glennon's model required some modification to appropriately represent the effect of site-specific features: The severity index of objects must be modified by alignment. Table 3-9 of this report can be used for this purpose. The alignment has a tremendous effect on the accident rate as has been confirmed in this chapter. Concrete figures to be employed for the modification of Glennon's model are not directly available in this study.

The combined effect of alignment and object offsets is another aspect where Glennon's model should be improved and verified. Since this study is primarily oriented to the provision of practical macroscopic hazard evaluation model, this subject was not studied in depth. However, it can be seen in the data structure presented in Table 4-1 that this can be explored as an extension of this study.

4.7 Before and After Study

An attempt was made to verify the models which were developed in this study in a before-and-after study. A total of sixty-nine MDSHT control sections were identified as having 1972 improvements, the natures of which were investigated to examine their eligibility for a before-and-after study of accident experience. It turned out that there were 63 surfacing improvements (resurfacing or sealing), and they were not related to such important factors affecting the accident as alignment and roadside clearance. The rest of them involved construction of an additonal lane or were not completed within 1972. Thus the attempted study was not completed because of non-existence of sections with roadway and/or roadside improvements which might have affected the accident experience within the context of this study.

69 sections

4.8 Chapter Summary

Through successive analyses by AID and regression, practical models are specified for hazard evaluation. The practicability of these models can be seen in their high variance explanation with reasonably small numbers of variables, and with small range of prediction error. The complete spectrum of Michigan conditions serves as a basis for these models.

AID provided the basic information on the effectiveness of variables and interactions. ADT, object exposure and roadway alignment were confirmed to be principal variables in off-road accident prediction. Adding to its effect on severity, the effect of alignment on accident occurrence is confirmed. Further, AID revealed the effective variables are different among different ADT groups, which suggests the need for seperate estimation models by ADT sub-groups.

Two forms of models, linear and multiplicative, were developed through regression analysis. In their final forms, they explain more than 60% of the variation in total accidents with variables, ADT, object exposure, alignment (percent sight restriction or number of curves) and intersection density on curves used as explanatory variables. Injury accident models involving the same variables except for the intersection density were also developed.

In both models, it was found that the effect of ADT is not linear but decreases with increasing ADT, as the square root as a good approximation.

The multiplicative form of injury accident prediction model can be called a macroscopic version of Glennon's model with an additional term involving roadway alignment. This model can also be employed as a practical hazard evaluation model of highway sections. Further, this model shows the closer objects are effective predictors of injury accident estimation.

Regression analysis on respective ADT sub-groups showed that effective variables differ by groups, as shown by AID. Percent sight restriction is a good predictor on highways with low ADT.

CHAPTER V

RECOMMENDED UTILIZATION OF RESULTS

The use of the results of this study by the MDSHT could follow many paths. This is primarily because of the availability status of data needed. While none of the needed data is difficult to develop for any single section of highway the effort in developing it for the entire 6,000 mile system is administratively significant. It is estimated that approximately one-man year of photolog time would be required to develop all needed data and an additional engineer half-year needed for its application. Taking into account the necessary expected time lag and cost in developing the needed data the following procedure is suggested for immediate implementation into the safety program of the MDSHT so that the locations with the greatest reduction possibilities can be quickly identified.

5.1 Recommended Immediate Procedure

For Routes with ADT > 1500

1. Develop a 1971-74 total of fixed-object plus turnover (all as well as injury-fatality accidents) accidents on each rural two-lane TVM in the state.
2. Convert this total to a rate per two miles of length.
3. Determine the mean and standard deviation of this distribution.
4. Select those high-accident sections for initial further study for which the rate exceeds the mean plus two standard deviations.
5. Obtain information on the variables in a selected model presented in this study for each of these sections by use of the photolog.
6. Calculate the expected number of accidents and injuries from the study model for each of these sections.
7. Identify those sections for which the observed total injury

or all-accident rate is greater than the predicted value plus twice the square root of the predicted value.

8. For as many sections on this list as possible conduct a field survey using forms similar to those developed in reference (41).

9. Calculate Glennon's hazard index using references (15) and (16) as well as the severity indices in Table 3-9.

10. Conduct the cost-benefit analysis suggested by Glennon.

For Routes with ADT < 1500

These routes are generally characterized by low rates per two miles and the model variables needed are readily available. Therefore, it is suggested that the percent sight restriction and average daily traffic be retrieved from existing computer files and the expected accident occurrence calculated. Considering the limited savings generally possible on this type of facility, sites should be selected for further detailed study as described above only when the actual frequency exceeds the expected value plus three times its square root or the expected value is in the range of those identified by the high ADT section analysis.

5.2 Later Uses

After all needed data have been developed, the long-term use of the models is visualized as taking two forms. First, the models should be applied to each section of road and the locations with the highest predicted accident expectation given close attention, particularly those in which the actual accident experience is statistically consistent with that predicted by the model.

Second, there is a reasonable expectation that the effects of a massive roadside improvement program can be crudely estimated by changing the countermeasure variables in the model and determining the effect on the expected accident frequency.

5.3 Outliers and Data

In any accident record based study there will be locations which have accident frequencies which are much higher than would occur by chance variation around the expected value. These locations provide an opportunity for creative study and analysis of additional causal factors which are undoubtedly at work. A classical imaginative engineering study of each of these situations is warranted. These locations will be quickly identified by the procedure described in Section 5.1.

For purposes of this study it was necessary to treat homogeneous sections of roadway two miles long using accident data over a four year period. For this amount of exposure the overall average number of off-road accidents is great enough to overcome much of the variability inherent in small exposure and good discrimination between low accident and high accident sites is possible, although a comparison of annual high accident sections shows more variation in the latter than desirable. The success of the models in capturing reasonable causal effects for those sections is clear.

The question arises as to how to handle sections which are not homogeneous and of different lengths. Data from other studies show that non-homogeneity is a factor that <u>increases</u> the accident experience above that found on homogeneous sections. We therefore conclude that the use of the homogeneous route models described in 5.1 identify the non-homogeneous sections with particularly bad potential until further results are available.

Differences in section length can be handled ~~in a straightforward manner~~ directly by obtaining the critical accident rate for a specific section length using standard Poisson techniques.

5.4 Highway Data

The MDSHT accident data computer files have proved to be immensely useful in this research program. Much of the time and effort spent on the project came from the need to use laborious techniques to extract the information on the highway system and its operations needed to accompany the accident data in our analysis.

Early steps toward placing these data in easily retrievable machine readable form will make studies of this type quick, easy and cheap to perform.

5.5 Use of Models on Rural County Roads

While no data on county roads in Michigan have been used in this study it is believed that the models developed here should be applicable to many miles on county primary routes and it is hoped that this application can be explored.

REFERENCES

REFERENCES

1. Agent, Kenneth R. and Robert C. Deen, "Relationships between Roadway Geometrics and Accidents", *Transportation Research Record No. 541*, 1975, pp. 1-11.

2. American Association of State Highway and Transportation Officials, *Highway Design and Operational Practices Related to Highway Safety*, Washington, 1974, 92 pp.

3. Baker, J. Stannard, *Single Vehicle Accidents: A Summary of Research Findings*, Automotive Safety Foundation, Washington, 1968, 37 pp.

4. Cantilli, Edmund J. and Bumjung Lee, "Treatment of Roadside Hazards - Decision and Design", *Highway Research Board Special Report 107*, pp. 101-108.

5. Cleveland, Donald E., *The Relation of Possible Vehicle Paths and Horizontal Curve Parameters*, Ann Arbor, Highway Safety Research Institute, University of Michigan, August, 1966, 6 pp.

6. Danyluk, Darrel John and Kathleen Dianne Gissing, *The Effect of Roadside Characteristics in Contributing to the Severity of Fixed Object Accidents*,Winnipeg, University of Manitoba, April 1972, 44 pp.

7. Dart, Olin K. and Lawrence Mann Jr., "Relationship of Rural Highway Geometry to Accident Rates in Louisiana", *Highway Research Record No. 312*, 1970, pp. 1-16.

8. Dawson, Robert F. and Joseph C. Oppenlander, "General Design", Chapter 11 in *Traffic Control and Roadway Elements-Their Relationship to Highway Safety*, Washington, Highway Users Federation for Safety and Mobility, 1971, 14 pp.

9. Deacon, John A., Charles V. Zeeger, and Roberts S. Deen, "Identification of Hazardous Rural Highway Locations", *Transportation Research Record No. 543*, 1975, pp. 16-33.

10. Dearinger, John A. and John W. Hutchinson, "Cross-section and Pavement Surface", Chapter 7 in *Traffic Control and Their Relationship to Highway Safety*, Highway Users Foundation for Safety and Mobility, 1970, 25 pp.

11. Deleuw Cather, Canada, Ltd., *The Relative Hazards of Roadside Obstacles and Design Elements,* Toronto, 1975, 4 vol.

12. Duke University National Driving Center, *A Study of Single and Multiple Vehicle Accidents*, July 1974, 11 pp.

13. Federal Highway Administration, U.S. Department of Transportation, "Identification and Surveillance of Accident Locations", *Highway Safety Program Manual: Vol. 9*, Washington, U.S. Government Printing Office, February 1974, 45 pp.

14. Foody, Thomas J. and Michael D. Long, *The Identification of Relationships Between Safety and Roadway Obstructions*, Columbus, Bureau of Traffic, Ohio Department of Transportation, January 1974, 83 pp.

15. Glennon, John C., *Roadside Safety Improvement Programs on Freeways: A Cost Effectiveness Priority Approach,* National Cooperative Highway Research Program Report 148, Washington, Transportation Research Board, National Research Council, 1974, 64 pp.

16. Glennon, John C. and Cathy J. Wilton, *Roadside Encroachment Parameters for Non-Freeway Facilities*, Kansas City, Midwest Research Institute, 1976, 41 pp.

17. Good, M.C. and P.N. Joubert, "A Review of Roadside Obstacles in Relation to Road Safety", In *Report of Expert Group on Road Safety*, Melbourne, Australia, Melbourne University, Department of Mechanical Engineering, 1973, 283 pp.

18. Gupta, R.C. and R.P. Jain, "Effect of Certain Roadway Characteristics on Accident Rates for Two-Lane, Two-Way Roads in Connecticut", *Transportation Research Record No. 541*, 1975, pp. 50-54.

19. Hall, J.W., C.J. Burton, D.G. Coppage and J.V. Dickinson, *Roadside Hazards on Non-Freeway Facilities*, College Park, Maryland University, Transportation Studies Center, 1976, 31 pp.

20. Hutchinson, John W. and Thomas W. Kennedy, *Medians of Divided Highways - Frequency and Nature of Vehicle Encroachments,* Engineering Experiment Station, Bulletin 487, Urbana, Illinois, University of Illinois, 1966, 35 pp.

21. Hutchinson, John W. and Thomas W. Kennedy, "Safety Considerations in Median Design", *Highway Research Record No. 162*, 1967, pp. 1-29.

22. Jehu, V.J., "The Influence of Roadside Obstacles on Road Safety and Traffic Accidents", *International Road Federation World Meeting*, Washington, International Road Federation, 1973, Paper C2.

23. Jorgensen, Roy and Associates & Westat Research Analysts, *Evaluation of Criteria for Safety Improvements on the Highway*, Gaithersburg, Maryland, 1966, 227 pp.

24. Kilhberg, Jaakko K., and K.J. Tharp, *Accident Rates As Related to Design Elements of Rural Highways*, National Cooperative Highway Research Program Report 47, Washington, Highway Research Board, National Research Council, 1968, 173 pp.

25. Lampela, Allen A. and Arthur H. Yang, *Analyses of Guardrail Accidents in Michigan*, Report TSD-243-74, Lansing, Traffic Research and Development Section, Traffic and Safety Division, Michigan Department of State Highways and Transportation, July 1974, 47 pp.

26. Laughland, John C., *et al.*, *Methods for Evaluating Highway Safety Improvements*, National Cooperative Highway Research Program Report 162, Washington, Transportation Research Board, National Research Council, 1975, 150 pp.

27. Leisch, Jack E. and Associates, "Alinement", Chapter 12 in *Traffic Control and Roadway Elements - Their Relationship to Highway Safety*, Washington, Highway Users Federation for Safety and Mobility, 1971, 19 pp.

28. Mercer, Donald J., *Freeway Curve Analyses*, Report TSD-G-102-69, Lansing, Standards Unit, Traffic Geometrics Section, Traffic and Safety Division, Michigan Department of State Highways, August 1969, 37 pp.

29. Michigan Department of Highways and Transportation, Traffic and Safety Division, *Design Guides for Roadside Safety Improvement Program, Task 1*, Lansing, January 1975, 17 pp.

30. Michigan State Office of Highway Safety Planning, *Status Report on the Fixed Object Problem in Relation to Traffic Crashes*, Lansing, 1974, 16 pp.

31. Michigan Department of State Police, *Michigan Traffic Accident Facts*, Lansing, 1974, 56 pp.

32. Ohio Department of Highways, *Methodology Employed in the Identification of Hazardous Locations and Sections on the Rural State Highway System*, Columbus, Bureau of Traffic, October 1972.

33. OECD Road Research Group, *Roadside Obstacles: Their Effects on the Frequency and Severity of Accidents; Development and Evaluation of Countermeasures*, Paris, Organization for Economic Cooperation and Development, August 1975, 124 pp.

34. Penn, Hugh S., "Causes and Characteristics of Single-Car Accidents: Part I", *Highway Research Record No. 79*, 1965, pp. 1-8.

35. Raff, Morton S., "Interstate Highway-Accident Study", *Highway Research Bulletin 74*, 1953, pp. 18-45.

36. Raff, Morton S., "Interstate Highway Accident Study", Highway Research Board Bulletin 158, 1957, pp. 4-26.

37. Rassam, Paul and Donald E. Cleveland, Probability of Collision with a Linear Obstacle Near the Roadway, Ann Arbor, Highway Safety Research Institute, University of Michigan, August 1966.

38. Schoppert, David W., "Predicting Traffic Accidents from Roadway Elements of Rural Two-Lane Highways with Gravel Shoulders", Highway Research Board Bulletin 158, 1957, pp. 4-26.

39. Stonex, K.A., "Roadside Design for Safety", Proceedings, Highway Research Board, Volume 39, 1960, pp. 120-157.

40. Weaver, Graeme D., et al., Selection of Safe Roadside Cross Sections, National Cooperative Highway Research Program Report 158, Washington, Transportation Research Board, National Research Council, 1975, 57 pp.

41. Weaver, Graeme D., Donald L. Woods and Edward R. Post, "Cost Effectiveness Analysis of Roadside Safety Improvements", Transportation Research Record No. 543, 1975, pp. 1-15.

42. Wright, Paul H. and Leon S. Robertson, Priorities for Roadside Hazard Modifications: A Study of 300 Fatal Roadside Object Crashes, Washington, Insurance Institute for Highway Safety, 1976, 19 pp.

APPENDICES

APPENDIX A : ANOVA Tables

Note on the Variables in Appendix A-4 ANOVA Tables

In all Chapter IV tables presenting coefficients of linear models, ADT is divided by 10, ADT^2 by 10,000 and PLC and all OB variables are in decimal fractions, except for Table A-4-11. In the equations following these tables, ADT is in vehicles/day and PLC and all OB variables are in percent, taking values from 0 to 100. In the multiplicative models, all variables except ADT, require addition of e (2.718) before being raised to the indicated power. Thus, PCL, for example, takes a value between 2.718 and 102.718 in the multiplicative models.

TABLE A-3-1

ANOVA:FIXED-OBJECT ACCIDENTS (LOG-TRANSFORM) (ALIGNMENT-SEVERITY-ADT)

SOURCE	SUM SQRS	DF	MEAN SQUARE	VARIANCE RATIO	(n_1,n_2)	$F_{.05}$
ALIGNMENT	11.763	1	11.763			
SEVERITY	2.130	1	2.130			
ADT	2.753	4	0.688			
ALIGNMENT x SEV.*	0.083	1	0.083	90.93	(1,4)	7.71
ALIGNMENT x ADT	0.223	4	0.056	61.00	(4,4)	6.39
SEVERITY x ADT	0.047	4	0.012	12.73	(4,4)	6.39
RESIDUAL	0.004	4	0.001			
TOTAL	17.003	19				

ESTIMATED COMPONENTS OF VARIANCE

ALIGNMENT x SEVERITY $\hat{\sigma}^2_{rc} = 0.016$

ALIGNMENT x ADT $\hat{\sigma}^2_{rg} = 0.027$

SEVERITY x ADT $\hat{\sigma}^2_{cg} = 0.005$

*SEV. = SEVERITY

TABLE A-3-2

ANOVA: FIXED-OBJECT ACCIDENT (LOG TRANSFORMED) (OBJECT-ALIGNMENT-SEVERITY)

SOURCE	SUM SQRS	DF	MEAN SQUARE	VARIANCE RATIO	(n_1, n_2)	$F_{.05}$
SEVERITY	3.819	1	3.819			
ALIGNMENT	16.174	1	16.174			
OBJECT HIT	9.079	6	1.513			
SEVERITY x ALIGNMENT	.191	1	0.191	14.72	(1,6)	5.99
SEVERITY x OBJECT	2.074	6	0.346	26.63	(6,6)	4.28
OBJECT x ALIGNMENT	.440	6	0.073	5.65	(6,6)	4.28
RESIDUAL	.078	6	0.013			
TOTAL	31.855	27				

ESTIMATED COMPONENTS OF VARIANCE

SEVERITY x ALIGNMENT $\hat{\sigma}^2_{rc} = .025$

SEVERITY x OBJECT $\hat{\sigma}^2_{rg} = .166$

OBJECT x ALIGNMENT $\hat{\sigma}^2_{cg} = 0.30$

TABLE A-3-3

ANOVA: FIXED-OBJECT ACCIDENTS (SEVERITY-IMPACT-OBJECT)

SOURCE	SUM SQRS	DF	MEAN SQUARE	VARIANCE RATIO	(n_1,n_2)	$F_{.05}$
SEVERITY	9.967	1	9.967			
IMPACT	26.656	2	13.328			
OBJECT	3.462	5	0.692			
SEVERITY x IMPACT	1.058	2	0.529	37.42	(2,10)	4.10
SEVERITY x OBJECT	3.386	5	0.677	47.91	(5,10)	3.33
IMPACT x OBJECT	0.496	10	0.050	3.51	(10,10)	2.98
RESIDUAL	0.141	10	0.014			
TOTAL	45.167	35				

ESTIMATED COMPONENTS OF VARIANCE

SEVERITY x IMPACT $\hat{\sigma}^2_{rc} = .086$

SEVERITY x OBJECT $\hat{\sigma}^2_{rg} = .221$

IMPACT x OBJECT $\hat{\sigma}^2_{cg} = .018$

TABLE A-3-3 (CONTINUED)

Impact Contribution to Severity

	No. of Accidents and Estimated Injury Accidents					
Object	Front	Side	Rear	Total	Estimated Severity	Actual Severity*
GUARDRAIL	1911	366	260	2537	.327	.257
	671	109	50	830		
HIGHWAY SIGN	1352	421	223	1996	.322	.189
	475	126	43	644		
POWER POLE	956	277	163	1396	.321	.397
	336	82	31	449		
CULVERT	283	35	28	346	.329	.552
	99	10	5	114		
DITCH	3023	471	419	3913	.328	.353
	1060	140	82	1282		
BRIDGE ABUTMENT OR PIER	100	13	16	129	.326	.511
	35	4	3	42		
BRIDGE RAILING	110	10	15	135	.333	.348
	39	3	3	45		
TREE	1555	394	232	2181	.325	.521
	546	117	45	708		
MAILBOX	1074	347	209	1630	.320	.182
	377	103	41	521		
FENCE	516	84	63	663	.329	.237
	181	25	12	218		
TOTAL	10880	2418	1628	14926	.325	.325
	3819	719	315	4853		

*Rollover impact is not included.

Variation of Actual Severity A = .0197

Variation of Estimated Severity B = .000017

B/A = 0.00086

TABLE A-3-4

ANOVA: FIXED-OBJECT ACCIDENTS (HIGHWAY AREA TYPE-ALIGNMENT-ADT)

SOURCE	SUM SQRS	DF	MEAN SQUARE	VARIANCE RATIO	(n_1,n_2)	$F_{.05}$
HIGHWAY AREA TYPE	4.547	1	4.547			
ALIGNMENT	12.085	1	12.085			
ADT	2.084	4	0.521			
HIGHWAY AREA TYPE x ALIGNMENT	0.002	1	0.002	0.55	(1,4)	7.71
HIGHWAY AREA TYPE x ADT	0.232	4	0.58	16.40	(4,4)	6.39
ALIGNMENT x ADT	0.289	4	0.072	20.38	(4,4)	6.39
RESIDUAL	0.014	4	0.004			
TOTAL	19.253	19				

TABLE A-3-5

ANOVA: ACCIDENTS (ALIGNMENT-ACCIDENT TYPE-ADT)

SOURCE	SUM SQRS	DF	MEAN SQUARE	VARIANCE RATIO	(n_1, n_2)	$F_{.95}$
ALIGNMENT	10.703	1	10.703			
ACCIDENT TYPE	5.228	1	5.228			
ADT	3.873	4	0.968			
ALIGNMENT-ACCIDENT x TYPE	0.062	1	0.062	16.87	(1,4)	7.71
ALIGNMENT x ADT	0.171	4	0.043	11.65	(4,4)	6.39
ACCIDENT TYPE x ADT	0.156	4	0.039	10.68	(4,4)	6.39
RESIDUAL	0.015	4	0.004			
TOTAL	20.208	19				

ESTIMATED COMPONENTS OF VARIANCE

ALIGNMENT x ACCIDENT TYPE $\hat{\sigma}^2_{rc} = .012$

ALIGNMENT x ADT $\hat{\sigma}^2_{rg} = .020$

ACCIDENT TYPE x ADT $\hat{\sigma}^2_{cg} = .018$

TABLE A-3-6

ANOVA: TURNOVER ACCIDENTS
(ALIGNMENT-SEVERITY-ADT)

SOURCE	SUM SQRS	DF	MEAN SQUARE	VARIANCE RATIO	(n_1,n_2)	$F_{.05}$
ALIGNMENT	9.726	1	9.726			
SEVERITY	1.116	1	1.116			
ADT	5.620	4	1.405			
ALIGNMENT x SEVERITY	0.174	1	0.174	∞	(1,4)	7.71
ALIGNMENT x ADT	0.134	4	0.033	∞	(4,4)	6.39
SEVERITY x ADT	0.038	4	0.010	∞	(4,4)	6.39
RESIDUAL	0.000	4	0.000			
TOTAL	16.809	19				

ESTIMATED COMPONENTS OF VARIANCE

ALIGNMENT x SEVERITY $\hat{\sigma}^2_{rc} = .035$

ALIGNMENT x ADT $\hat{\sigma}^2_{rg} = .017$

SEVERITY x ADT $\hat{\sigma}^2_{cg} = .005$

TABLE A-4-1

ANOVA-TOTAL ACCIDENTS-LINEAR & MULTIPLICATIVE MODELS ADT $\leqslant$ 750

LINEAR

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF
REGRESSION	2	99.94	49.97	26.41	.0000
ERROR	47	88.94	1.89		
TOTAL	49	188.88			

MULT R = .727 R^2 = .529 SE = 1.38

VARIABLE	PARTIAL	COEFF.	STD ERROR	T-STAT	SIGNIF
CONSTANT		.648	.294	2.20	.0328
PSR	.498	.312 -1	.792 -2	3.94	.0003
PSR 100	.518	6.235	1.503	4.15	.0001

$$\hat{y} = 0.03117 \text{ PSR} + 6.235 \text{ PSR } 100 + 0.6476$$

MULTIPLICATIVE

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	2	7.125	3.562	13.50	.0000
ERROR	47	12.400	.264		
TOTAL	49	19.525			

MULT R = .604 R^2 = .365 SE = .514

VARIABLE	PARTIAL	COEFF.	STD ERROR	T-STAT	SIGNIF.
CONSTANT		-3.974	1.321	-3.01	.0042
ADT-LOG	.396	.647	.219	2.96	.0049
PSR-LOG	.448	.247	.719 -1	3.44	.0012

$$\hat{y} = 0.01880 \times (\text{ADT})^{.6475} \times (\text{PSR})^{.2472} - 1$$

Any number at the far right of the columns is the exponent of base 10, 10^n. For example .312 -1 implies .0312.

TABLE A-4-2

ANOVA-TOTAL ACCIDENTS-LINEAR & MULTIPLICATIVE MODELS
$750 < ADT \leq 1500$

LINEAR

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	2	147.40	73.70	10.00	.0002
ERROR	55	405.22	7.37		
TOTAL	57	552.62			

MULT R = .516 R^2 = .267 SE = 2.71

VARIABLE	PARTIAL	COEFF.		STD ERROR		T-STAT	SIGNIF.
CONSTANT		2.874		.656		4.38	.0001
PSR	.322	.514	-1	.204	-1	2.52	.0147
PSR O	-.229	-1.596		.917		-1.74	.0872

$\hat{y}$ = 0.05137 PSR - 1.596 PSR 0 + 2.8741

PSR 0 ; 0-PERCENT SIGHT RESTRICTION DUMMY

MULTIPLICATIVE

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	1	7.465	7.465	18.26	.0001
ERROR	56	22.895	.409		
TOTAL	57	30.360			

MULTI R = .496 R^2 = .246 SE = .639

CONSTANT	PARTIAL	COEFF.	STD ERROR		T-STAT	SIGNIF.
CONSTANT		.459	.191		2.40	.0199
PSR-LOG	.496	.312	.729	-1	4.27	.0001

$\hat{y} = 1.5821 \times (PSR)^{.3115} - 1$

Any number at the far right of the columns is the exponent of base 10, 10^n.

TABLE A-4-3

ANOVA-TOTAL ACCIDENTS-LINEAR & MULTIPLICATIVE MODELS
$1500 < ADT \leqslant 3500$

LINEAR

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF
REGRESSION	2	358.97	179.49	17.77	.0000
ERROR	79	797.81	10.10		
TOTAL	81	1156.78			

MULT R = .557 $R^2 = .310$ SE = 3.178

VARIABLE	PARTIAL	COEFF.	STD ERROR	T-STAT	SIGNIF
CONSTANT		4.526	.425	10.64	.0000
OB14	.452	19.102	4.244	4.50	.0000
OB14 x IC	.313	3.646	1.243	2.93	.0044

$$\hat{y} = 0.1910 \times OB14 + 0.03646\ OB14 \times IC + 4.526$$

MULTIPLICATIVE

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	3	10.30	3.43	12.40	.0000
ERROR	78	21.59	.28		
TOTAL	81	31.89			

MULT R = .568 $R^2 = .323$ SE = .526

VARIABLE	PARTIAL	COEFF.		STD ERROR		T-STAT	SIGNIF.
CONSTANT		-5.096		2.039		-2.50	.0145
ADT-LOG	.312	.744		.257		2.90	.0049
OB20-LOG	.510	.409		.782	-1	5.24	.0000
PCL-LOG	.202	.842	-1	.463	-1	1.82	.0727

$$\hat{y} = 0.006121 \times (ADT)^{.7437} \times (OB20)^{.4094} \times (PCL)^{.08420} - 1$$

Any number at the far right of the columns is the exponent of base 10, 10^n.

TABLE A-4-4

ANOVA-TOTAL ACCIDENTS-LINEAR & MULTIPLICATIVE MODELS
ADT $\geq$ 3500

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	1	1333.9	1333.9	43.39	.0000
ERROR	78	2397.9	30.7		
TOTAL	79	3731.8			

MULT R = .598 R^2 = .357 SE = 5.545

VARIABLE	PARTIAL	COEFF.	STD ERROR	T-STAT	SIGNIF.
CONSTANT		8.700	.852	10.21	.0000
ADT x NC	.598	.633 -2	.960 -3	6.59	.0000

$$\hat{y} = 0.6326 \times 10^{-3} \times ADT \times NC + 8.700$$

MULTIPLICATIVE

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	3	11.845	3.948	23.42	.0000
ERROR	76	12.811	.169		
TOTAL	79	24.656			

MULT R = .693 R^2 = .480 SE = .411

VARIABLE	PARTIAL	COEFF.	STD ERROR	T-STAT	SIGNIF.
CONSTANT		-3.304	1.200	-2.75	.0074
ADT-LOG	.364	.465	.136	3.41	.0010
NC-LOG	.447	.870	.200	4.36	.0000
OB20-LOG	.464	.287	.630 -1	4.56	.0000

$$\hat{y} = 0.03672 \times (ADT)^{.4646} \times (NC)^{.8696} \times (OB20)^{.2874} - 1$$

Any number at the far right of the columns is the exponent of the base 10, 10^n.

TABLE A-4-5

ANOVA-TOTAL ACCIDENTS-LINEAR MODEL
ADT, SQUARE ROOT

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	5	18359	3671.9	281.7	.0000
ERROR	265	3455	13.0		
TOTAL	270	21814			

MULT R = .823 $R^2 = .678$ SE = 3.611

VARIABLE	PARTIAL	COEFF.		STD ERROR		T-STAT	SIGNIF.
$\sqrt{ADT}$	.651	.274		.197	-1	13.95	.0000
PSR x ADT	.194	.136	-3	.422	-4	3.21	.0015
NC x ADT	.356	.420	-2	.680	-3	6.19	.0000
IC x OB20 x$\sqrt{ADT}$	.176	.999	-1	.344	-1	2.90	.0040
OB14 x$\sqrt{ADT}$	.258	.655		.151		4.34	.0000

$$\hat{y} = 10^{-4}\sqrt{ADT}\left\{3.158\ IC \times OB20 + 20.71\ OB14 + 867.5\right\}$$
$$+ 10^{-5}\ ADT\left\{1.357\ PSR + 42.09\ NC\right\}$$

Any number at the far right of the columns is the exponent of the base 10, 10^n.

TABLE A-4-6

ANOVA-TOTAL ACCIDENTS-MULTIPLICATIVE MODEL

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	4	136.10	34.025	120.80	.0000
ERROR	265	74.64	.282		
TOTAL	269	210.74			

MULT R = .804 R^2 = .646 SE = .531

VARIABLE	PARTIAL	COEFF.	STD ERROR		T-STAT	SIGNIF.
CONSTANT		-4.966	.306		-16.25	.0000
ADT-LOG	.790	.740	.353	-1	20.97	.0000
PSR-LOG	.229	.123	.321	-1	3.84	.0002
OB20-LOG	.313	.217	.404	-1	5.36	.0000
IC-LOG	.160	.191	.726	-1	2.63	.0090

$$\hat{y} = 0.006969 \times (ADT)^{.7398} \times (PSR)^{.1233} \times (OB20)^{.2168} \times (IC)^{.1910} - 1$$

PSR; PERCENT SIGHT RESTRICTION

OB20; OBJECT 20

IC; INTERSECTIONS ON CURVES PER MILE OF CURVE

Any number at the far right of the columns is the exponent of the base 10, 10^n.

TABLE A-4-7

ANOVA-INJURY ACCIDENTS-LINEAR MODEL

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	5	1071.0	214.20	64.2	.0000
ERROR	264	880.2	3.33		
TOTAL	269	1951.2			

MULT R = .741 R^2 =.549 SE = 1.826

VARIABLE	PARTIAL	COEFF.		STD ERROR		T-STAT	SIGNIF.
CONSTANT		.4254	-1	.229		.19	.8525
ADT	.393	.9592	-2	.138	-2	6.94	.0000
ADT^2	-.260	-.5212	-3	.119	-3	-4.37	.0000
NCO x ADT	-.145	-.2095	-2	.880	-3	-2.38	.0180
NC x ADT	.206	.6730	-3	.196	-3	3.42	.0007
OB14 x ADT	.306	.2208	-1	.423	-2	5.22	.0000

NCO; NO CURVES, DUMMY
OB14; OBJECT 14
NC; NUMBER OF CURVES PER MILE

$$\hat{y} = 10^{-4} \times ADT \times \{0.6730 \times NC + 0.2208 \times OB14 - 2.095\ NCO$$
$$-0.0005212 \times ADT + 9.5292\} + 0.04254$$

Any number at the far right of the columns is the exponent of the base 10, 10^n.

TABLE A-4-8

ANOVA-INJURY ACCIDENTS-MULTIPLICATIVE MODEL

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	4	70.49	17.623	64.08	.0000
ERROR	265	72.88	.275		
TOTAL	269	143.37			

MULT R = .701 R^2 = .492 SE = .524

VARIABLE	PARTIAL	COEFF.	STD ERROR		T-STAT	SIGNIF.
CONSTANT		-3.629	.296		-12.26	.0000
ADT-LOG	.679	.521	.346	-1	15.07	.0000
PCL-LOG	.270	.125	.274	-1	4.56	.0000
STIFF	.130	.154	.724	-1	2.14	.0337
OB10-LOG	.166	.117	.427	-1	2.73	.0067

$$\hat{y} = 0.02655\ (ADT)^{.5213} \times (PCL)^{.1248} \times (STIFF) \times (OB10)^{.1167} - 1$$

PCL; PERCENT CURVED

OB10; OBJECT 10

STIFF TAKES VALUE 1.362 OR 1.167 DEPENDING ON THE EXISTENCE OR NON-EXISTENCE OF STIFF OBJECTS WITHIN 14 FT., RESPECITIVELY.

Any number at the far right of the columns is the exponent of the base 10, 10^n.

TABLE A-4-9

ANOVA-INJURY ACCIDENTS-LINEAR MODEL
ADT; 0-1250

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	6	64.96	10.82	8.21	.0000
ERROR	85	112.03	1.32		
TOTAL	91	176.99			

MULT R = .606 R^2 = .367 SE = 1.148

VARIABLE	PARTIAL	COEFF.		STD ERROR		T-STAT	SIGNIF.
CONSTANT		-1.545		.796		-1.94	.0556
ADT	.212	.476	-1	.238	-1	2.00	.0482
ADT^2	-.160	-.245	-1	.164	-1	-1.50	.1385
PSR	.136	.900	-2	.714	-2	1.26	.2105
PSR 100	.277	3.373		1.269		2.66	.0094
NC x ADT	.142	.224	-2	.170	-2	1.32	.1910
OB14 x ADT	.184	.168	-1	.973	-2	1.72	.0887

PSR; PERCENT SIGHT RESTRICTION
PSR 100; 100% SIGHT RESTRICTION DUMMY
NC; NUMBER OF CURVES PER MILE
OB14; OBJECT 14

$$\hat{y} = 0.004762 \text{ ADT} - 0.2455 \times 10^{-5} \text{ ADT}^2 + 0.009004 \text{ PSR} + 3.373 \text{ PSR100} + 0.0002238 \text{ NC} \times \text{ADT} + 0.1675 \times 10^{-4} \times \text{OB14} \times \text{ADT} - 1.545$$

Any number at the far right of the columns is the exponent of the base 10, 10^n.

TABLE A-4-10

ANOVA-INJURY ACCIDENTS-LINEAR MODEL
ADT; 1250-3500

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	4	75.79	18.95	7.42	.0000
ERROR	93	237.19	2.55		
TOTAL	97	312.98			

MULT R = .492 R^2 = .242 SE = 1.597

VARIABLE	PARTIAL	COEFF.		STD ERROR		T-STAT	SIGNIF.
CONSTANT		.655		.645		1.02	.3123
ADT	.105	.264	-2	.260	-2	1.02	.3126
PCL	.074	.857		1.198		.72	.4762
NC	.105	.284		.279		1.02	.3110
OB14 x ADT	.385	.332	-1	.826	-2	4.02	.0001

PCL; PERCENT CURVED

NC; CURVES PER MILE

OB14; OBJECT 14

$$\hat{y} = 0.0002640\ \mathrm{ADT} + 0.008568\ \mathrm{PCL} + 0.2839\ \mathrm{NC} + 0.3319 \times 10^{-4} \times \mathrm{OB14} \times \mathrm{ADT} + 0.6552$$

Any number at the far right of the columns is the exponent of the base 10, 10^n.

TABLE A-4-11

ANOVA-INJURY ACCIDENTS-LINEAR MODEL
ADT > 3500

SOURCE	DF	SUM SQRS	MEAN SQR	F-STAT	SIGNIF.
REGRESSION	4	233.92	58.48	8.97	.0000
ERROR	75	488.97	6.52		
TOTAL	79	722.89			

MULT R = .569 R^2 = .324 SE = 2.553

VARIABLE	PARTIAL	COEFF.		STD ERROR		T-STAT	SIGNIF.
CONSTANT		3.373		.534		6.32	.0000
NC x ADT	.335	.166	-3	.538	-4	3.08	.0029
NCO x ADT	-.091	-.100	-3	.127	-3	-.79	.4314
OB14 x ADT	.262	.155	-4	.659	-5	2.35	.0212
STIF x ADT	.171	.137	-3	.914	-4	1.50	.1371

$$\hat{y} = 10^{-4}\ \mathrm{ADT}\left\{1.659\ \mathrm{NC} - 1.002\ \mathrm{NCO} + .1552\ \mathrm{OB14} + 1.374\ \mathrm{STIFF}\right\} + 3.3728$$

Any number at the far right of the columns is the exponent of the base 10, 10^n.

TABLE A-4-12

SAMPLE MEAN AND VARIANCE OF TOTAL ACCIDENT AID SUB-GROUPS

SUB-GROUP NO.*	NO. OF SAMPLES	MEAN ($\bar{\bar{y}}$)	VARIANCE ($\hat{\sigma}_y^2$)	POISSON INDEX $\hat{\sigma}_y^2/\bar{y}$
1	37	1.08	1.52	1.41
2	36	1.89	2.84	1.50
3	13	3.38	6.92	2.05
4	21	3.38	6.65	1.97
5	14	4.57	10.26	2.25
6	8	4.63	4.84	1.05
7	45	5.62	8.83	1.57
8	8	7.00	16.57	2.37
9	5	7.80	13.70	1.76
10	7	8.71	26.90	3.09
11	25	9.40	16.17	1.72
12	6	9.67	14.67	1.52
13	9	10.78	8.44	.78
14	11	13.55	17.47	1.29
15	5	13.80	10.70	.78
16	8	18.63	8.27	.44
17	7	19.71	46.90	2.38
18	5	26.00	33.50	1.29
TOTAL	270	6.51	9.21	1.41

*For group number see Figure 4-5.

Appendix A-2: Dependent Variables in Chapter III ANOVA Tables

In the Chapter III ANOVA tables, the severity index (the ratio of injury plus fatality accidents to the reported total) is not used as a dependent variable. Rather, the number of accidents by severity is employed, resulting in a three-way ANOVA when accident severity is examined with respect to two other factors.

The first reason for the use of the number of accidents is simply that the study is more concerned with the number of accidents than the rate. Thus, the ANOVA model is constructed for the description of the number of accidents for each specific combination of contributing factors. The model is not valid when the exposure to each factor varies. However it should be noted that the exposures are exactly identical for property-damage-only accidents and for injury accidents, and this is the reason why we are able to examine the effect of each factor on accident severity through the interaction terms involving severity as one factor. To clearly show the structure of the analysis, let us illustrate by an example.

For simplicity let us assume that there exist only two factors, Alignment and ADT, that affect accident severity. Then an ANOVA model may be

$$X_{ijk} = a_i b_j c_k u_{ij} v_{ik} w_{ki} U_{ijk} \dots\dots\dots\dots\dots\dots \quad (1)$$

where, a_i: the main effect of Severity,

b_j: the main effect of Alignment,

c_k: the main ef-ect of ADT, and

u_{ij}, v_{jk}, w_{ki}: interaction terms of Severity-Alignment, Alignment-ADT, and ADT-Severity, respectively, and

U_{ijk}: a random disturbance.

Now, if Alignment does not have any effect on severity, the ratio of expected number of injury accidents to property damage only accidents should not vary over classes of Alignment (say, ℓ and m). Namely,

$$E\left(\frac{X_{1\ell k}}{X_{2\ell k}}\right) = E\left(\frac{X_{1mk}}{X_{2mk}}\right) \quad \dots\dots\dots\dots\dots\dots \quad (2)$$

where the first subscript assumes 1 for injury accidents and 2 for property damage only accidents. But since

$$\frac{X_{1\ell k}}{X_{2\ell k}} = \frac{a_1 b_\ell c_k u_{1\ell} v_{\ell k} w_{k1}}{a_2 b_\ell c_k u_{2\ell} v_{\ell k} w_{k2}} = \frac{a_{1\ell}}{a_{2\ell}} \; \frac{u_{1\ell} w_{k1}}{u_{2\ell} w_{k2}} ,$$

the above equation (2) implies

$$\frac{a_1 \; u_{1\ell} w_{k1}}{a_2 \; u_{2\ell} w_{k2}} = \frac{a_1 \; u_{1m} w_{k1}}{a_2 \; u_{2m} w_{k2}} .$$

Thus,

$$u_{1\ell}/u_{2\ell} = u_{1m}/u_{2m}.$$

But from constraints in ANOVA (note log transformation is applied to obtain a linear model),

$$\ell n(u_{1\ell}) + \ell n(u_{1m}) = 0, \text{ and}$$
$$\ell n(u_{2\ell}) + \ell n(u_{2m}) = 0.$$

Namely: $u_{1\ell}\, u_{1m} = 1$, and

$u_{2\ell}\, u_{2m} = 1$.

Then,

$$\frac{u_{1\ell}}{u_{2\ell}} = \frac{1/u_{1m}}{1/u_{2m}} = \frac{u_{2m}}{u_{1m}} \neq \frac{u_{1m}}{u_{2m}}, \quad \text{in general.}$$

Thus for the equation (2) to hold, $u_{1\ell}$, $u_{2\ell}$, u_{1m} and u_{2m} all have to be unity. This simply means that the Severity-Alignment interaction term has to be zero. Otherwise the expected ratio of injury accidents to the Property Damage Only accidents varies over the factors. Naturally the severity index varies according to this interaction term although the index itself is not intended to test. It should be noticed that all main effects terms are cancelled out when examining the ratio of injury accidents to property-damage-only accidents.

The second reason for the employment of the number of accidents is that a rate generally has undesirable features as a dependent variable compared to an absolute number, and no well accepted theory exists as to the treatment of the variance of ratio.

As an example, we consider Glennon's severity index. Let us assume that the total number of accidents is non-stochastic for the illustrative purpose. Then the number of injury accidents is well assumed as binominally distributed with parameters N and p, where N is the total number of accidents and p is the probability of an injury accident given an accident occurred. Note that p is the population value of Glennon's severity index. Then the variance of the number of injury accidents is $p(1-p)$, and the variance of the severity index is

$$\text{Var} = \frac{p(1-p)}{N}.$$

It should be noticed that the variance is affected not only by the population severity index, but also by the number of accidents. Thus, when we use the ratio in the analysis, we lose the means to control the heteroskedasticity since the number of accidents does not appear in the analysis. Contrary to this, when we use the number of accidents the heteroskedasticity is easier to control. As a reasonable assumption we assume that the distribution of the number of accidents is Poisson. Then the population variance equals the mean, whose unbiased estimate is the observed number of accidents. Thus we see that the variance of the number of accidents equals the number of accidents itself. Theoretical treatments of this type of heteroskedasticity have been developed. In this study, the log transformation is used as a means to reduce the heteroskedasticity.

APPENDIX B-1: MDSHT ACCIDENT DATA REQUEST

All the item numbers appearing below are identical to those in the 1975 Coding Manual for Michigan Accidents, Traffic and Safety Division, Michigan Department of State Highways and Transportation.

1. Definition of accidents of concern.

   We are concerned with:

   a) Off-roadway, fixed object accidents and off-roadway, single-vehicle turnover accidents.

      The former, fixed-object accidents, refer to accidents in which fixed objects were struck by the accident vehicles, regardless of the cause of the collision or the chronological sequence of incidences, for fixed objects located on the roadside (not within the traffic way). These accidents can be identified from Item 36, 'Object Hit': The accidents whose entry code 16 (other on-traffic-way object), 18 (overhead fixed object), or 19 (not known) appears, should be excluded (since the off-roadway condition might not be satisfied), or preferably the accident should further be examined on its location using appropriate information[1] and be included if off roadway.

      The latter, turnover accidents, can be identified by examining:

      i) Item 23, 'Number of Vehicles': should be one

      ii) Item 19, 'SP Accident Type': should be Code 01, 'Motor Vehicle overturned'.

---

[1] We would appreciate it if we could discuss this information in detail with your colleagues.

Adding to these, the accident location has to be identified to be off roadway on the appropriate information .

b) Two-lane, undivided, and

c) Rural (not within city limit, identified by Item 25, 'Population') highways.

The accident vehicle type should be confined to the usual motor vehicles excluding farm equipment, snowmobiles, etc. Therefore, Codes 06, 07 and 08 of Item 26, 'Vehicle Subscript' should be excluded.

2. Categories of control variables.

The control variables to be employed in the tabulation are shown below with their category specification.

ADT; (1) x 1,000, (2) 1,000 x 2,000, (3) 2,000 x 4,000, (4) 4,000 x 16,000, (5) x 16,000

Alignment; (1) Straight, (2) Curve, (3) Transition, (4) Unknown (same as Item 16)

Severity; (1) Property damage only, (2) Injury, (3) Fatal, (4) Not Known

Object Hit; 19 categories as appear in Item 36, 'Object Hit' in the manual. (Code 01, NONE, should be included hereafter).

Impact Code; All 10 categories as in Item 39, 'Impact Code'.

Situation; All 7 categories as in Item 37, 'Situation'.

Highway Area Type; 4 categories as in Item 4, 'Highway area type', namely, (1) Interchange area, (2) Intersection area, (3) Non-intersectional and non-interchange area, (4) Non-traffic motor vehicle accident.

The following two variables will appear only in overall tables to be requested in 3-A below.

Population (1) Rural (Code 1, 'Rural' of Item 25, 'Population')
(2) Urban (Codes 2 and 3 of Item 25)

Highway Type (1) 2-lane
(2) 3-lane
(3) 4-lane, undivided
(4) 4-lane, divided
(5) others

3. List of Tabulation.

All data should be tabulated for respective years of 1971, 1972, 1973, and 1974.

3-A Overall Tables

The following tabulations are requested as to the number of fixed-object accidents and turnover accidents, defined by 1 (a) above, to be the overall figures of fixed-object accidents on the state highways.

1. Population x Highway type.
2. ADT x Highway Type, and
3. Severity x Highway type.

3-B Tabulation for two-lane, undivided rural highways.

Tabulations of the number of fixed-object accidents (as defined by a), b) and c) of 1) are requested for the respective categories (as specified in 2) of;

1. ADT
2. Alignment
3. Severity

4. Object Hit
5. Impact Code
6. Situation, and
7. Highway Area Type

Two or three-dimensional tabulations are requested for the combinations of;

8. ADT x Alignment
9. ADT x Severity
10. ADT x Situation
11. Alignment x Severity
12. Alignment x Situation
13. Alignment x Object Hit
14. Alignment x Impact Code
15. Severity x Object Hit
16. Severity x Impact Code
17. Severity x Situation
18. Object Hit x Impact Code
19. ADT x Alignment x Severity
20. ADT x Severity x Object Hit
21. Severity x Object Hit x Alignment
22. Severity x Object Hit x Impact Code
23. ADT x Alignment x Situation

4. Complementary Information Requested

The below information is requested for the normalization of accident numbers on traffic exposure. These both are for two-lane, undivided, rural highways.

i. The roadway mileage for each ADT class
ii. The roadway mileage and the vehicle-mile travelled for each categories in Alignment, if available.

5. Additional Tabulations

The fixed object and turnover accidents as defined in 1 above include possible types of:

Fixed Object Accident (Item 36-Code 01) (Item 19-Code 01)	Single Vehicle	Fixed Object i
		Fixed Object, Vehicle Overturned after the collision. . .ii
	Multi-Vehicle	Initial Collision with other vehicles, Secondary Collision with fixed objects . . .iii
		Other types. iv
and		
Turnover Accident (Item 19-Code 01)	Single	Vehicle Overturned . . .v
		Vehicle Overturned, then Collision with Fixed Objects ...vi

Following tabulations are requested to examine each of the subdivided accident types shown above.

(A) <u>For Turnover Accidents</u> (which should have Code 01 for Item 19, 'SP Accident Type', and should be single vehicle accident). Tabulation of the number of accidents for each category in

(Object Hit)

'Object Hit' should have the same categories as defined in 2 above, including Code 01, 'No Object hit'.

(B) <u>For Single Vehicle Fixed Object Accidents</u> (whose code of Item 19 should <u>not</u> be 01, 'Vehicle overturned' and Item 23 should be 1). Tabulation of the number of accident controlled by

(Object Hit) x (Impact Code)[2]

where

Object Hit: Same categories as defined in 2 above

Impact Code (Item 39): (1) Code 0, Rollover

(2) Others

(C) <u>For Multi-Vehicle, Fixed Object Accidents.</u>

Tabulation controlled by

(Object Hit) x (Situation) x (Impact Code)

where

Situation (Item 37) (1) Code 05, Hit object after initial collision.

(2) Others

Other variables are same as defined in (A) and (B) above.

---

[2] Our special interest is concerned with accidents of type (ii). It is our understanding that Item 39, 'Impact Code' can be utilized to identify the accidents of this type.

APPENDIX B-2: PHOTOLOG ROADSIDE OBJECT SURVEY

The MDSHT maintains a trunkline "photolog" system, which was sucessfully utilized in this study in the preparation of a roadside-object inventory on a sample of 540 miles of two-lane rural highways. The photolog contains one hundred pictures every mile taken from a van-mounted movie camera directed slightly down and away from the centerline angle. These pictures generally retain enough quality for the purpose of a roadside-object study, and the 53 feet interval between two successive pictures provided practically adequate accuracy for the estimation of longitudinal object length. Each section of the trunkline is filmed in both directions. This roadside survey was generally for the right side of the roadway in one direction and then for the opposite side in the same way.

The type of an object, its dimensions (depth, width and height, if necessary), offset from the pavement edge, roadway alignment and highway area type associated with the object were recorded for each object. Objects farther than 30 feet from the pavement edge were generally not recorded. Special care was exercised for those objects that were within 20 feet from the pavement edge, or appeared in intersectional areas.

Adding to the object record, roadway alignments were recorded as points of curvature, points of tangency and directions, with supplemental remarks of "very slight" or "very sharp". Another important record was the number of intersections, which was recorded with classifications of three-leg, four-leg and others, and channelized or un-channelized. In the survey, an intersection was defined as a public roadway junction with yield, stop-sign or higher type control. Work-sheets used are shown in Figs. B-2-1 and B-2-2 with examples of records.

The eligibility of each sampled section was confirmed on the photolog to determine if it was strictly a rural, two-way, two-lane, undivided highway. One of the greatest advantages in using the photolog was that it showed the roadside development and speed limit, which clearly indicated the urban characteristics of many sections (in the Sufficiency Rating and TVM files, a significantly urbanized area was sometimes classified as "rural"). The speed limit was carefully checked in urbanized areas and whenever a section had a speed limit less than 45 mph, the section was regarded as inappropriate. Also changes in the number of lanes, pavement width and shoulder width were carefully checked. A sampled section that appeared not appropriate was replaced with an equivalent other section whenever it was possible, otherwise discarded. Thus the homogeneity of highway characteristics within each sampled section was maintained.

The items that were counted as "objects" involved; the objects that appear in the accident file, e.g., trees, power poles, guardrails and bridge rails (see, for example, Table 3-8); roadway cross-sectional features such as steep cuts, embankments and deep ditches; and drainage structures such as culverts (and associated fills) and headwalls. Objects in the third group were carefully examined since they were considered to be potential hazards that had not been paid proper attention in previous studies. Among the objects in the first group, traffic signs and mailboxes were excluded from our object list. In spite of their relatively high

Fixed Object Inventory
Supplemental Worksheet

Observer: DEC Recorder: RK Date: 7/2

Section Information

Route No. M-37 Recording Direction: Mileage Increasing ☒
Mileage Decreasing ☑

Control Section No.: 08032

Point of Beginning: 10.230

Curves:	Length	POB-POE	Remarks
1)	0.48	(11.50-11.98)	∠
2)	.	(-)	
3)	.	(-)	
4)	.	(-)	
5)	.	(-)	
6)	.	(-)	
7)	.	(-)	
8)	.	(-)	
9)	.	(-)	
10)	.	(-)	

Intersections:	Curve	Tangent	Total
3 LEG			0
4 LEG		NG, NP, NP	3
OTHER			
TOTAL	0	3	3

General Observations (ditch, shoulder, etc.):

Ditch Bottom Offset-	+ 15-20+ ft	Hazard	Fair	[✓ Good]	Excel.
	- 15-20+ ft	Hazard	Fair	[✓ Good]	Excel.
Shoulder Type-	+ GRAVEL				
	- GRAVEL.				

ADT (SR-72) 4200

ADT (TVM) 71 4500

72 4800

73 5000 ____

Pavement Width (SR-72) 24 ft, Shoulder Width (SR-72) 8 ft

% Sight Restriction (SR-72) 0 %, Rolling (SR-72) 1 or [✓ 2]

No. of Fixed-Obj. Acc.	Total	71___	72___	73___	___		
	Inj.	71___	72___	73___	___	Total	___
No of Turnover Acc.	Total	71___	72___	73___	___		
	Inj.	71___	72___	73___	___	Total	___

No. of Intersections (Photolog) 4-leg ____ 3-leg ____ Total ____

No. of Curves (Photolog) ____ Total length of curves ____.____ mile

Figure B-2-1 WORKSHEET FOR PHOTOLOG ROADSIDE OBJECT SURVEY: ROADWAY INFORMATION

Fixed Object Inventory

Observer: DEC Recorder: RK Date: 7/2

Section Information

Route No. M-37 Recording Direction: Mileage Increasing ☑
Mileage Decreasing ☑

Control Section No.: 08032 Section Length: 2.0 miles

Point of Beginning: 10.230

Accident Rate: . accidents/mvm .

Pavement Width: 20☐ 22☐ 24☒ ADT: 4200

Shoulder Width: ☐ 0-1 ☐ 2-3 ☐ 4-5 ☐ 6-7 ☒ 6 ☐ 9-10 % Sight Restriction: 0

Fixed Object Information

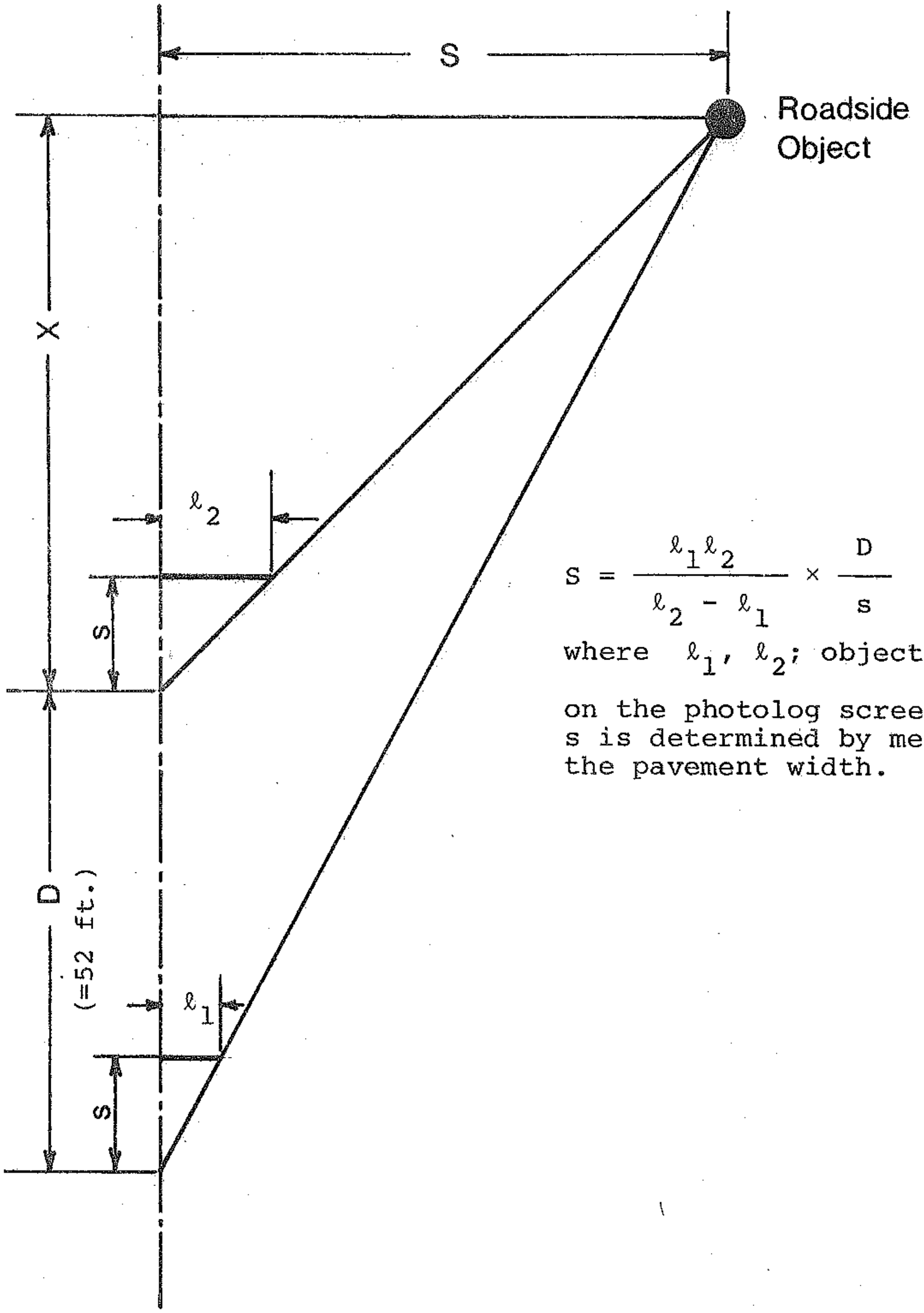
Tang	Curve	Inter	Category	Category Subcode	Object Offset	Object Length	(Optional) Width	Height	Remarks
<+> ☑	☐	☑	GR	CA-	7	250			F.S.
☑	☐	☐	GR	CA-	7	275			
☑	☐	☐	DP	DR-	18				
☑	☐	☐	GR	CA-	7	250			A BRIDGE COMPLEX.
☑	☐	☐	BR	SO-DI	10	100			
☑	☐	☐	CB	MO-	8	100			
☑	☐	☐	GR	CA-	8	200			
☑	☐	☑	DP	IN-	18				NS + FS
☑	☐	☐	CU	DR-	18				
☑	☐	☐	GR	CA-	8	100			
☑	☐	☐	GR	CA-	8	900			
☐	☑	☐	GR	CA-	8	750			
☑	☐	☐	CU	DR-	20		10		
<-> ☑	☐	☐	FL	DR-	20		10		
☑	☐	☐	GR	CA-	8	200			
☐	☑	☐	GR	CA-	8	800			
☑	☐	☑	GR	CA-	8	1300			
☑	☐	☐	DP	-	18				
☑	☐	☑	CU	IN-	20				NS + FS.
☑	☐	☐	GR	CA-	8	350			SAME BRIDGE COMPLEX.
☑	☐	☐	BR	SO-Di	10	100			
☑	☐	☐	CB	MO-	8	100			
☑	☐	☐	GR	CA-	7	200			
☑	☐	☐	2× DP	DR-	18				
☑	☐	☐	FL	DR-	15		∞		
☑	☐	☑	GR	CA-	7	100			N.S.
☐	☐	☐		-					
☐	☐	☐		-					

Figure B-2-2 WORKSHEET FOR PHOTOLOG ROADSIDE OBJECT SURVEY: ROADSIDE OBJECT INVENTORY frequency of being hit, their severity indices are the lowest, (see Chapter III) thus they are less significant with respect to the accident cost. Almost all traffic signs appearing along two-lane rural highways were standard regulatory or warning types which were very fragile; other types were recorded, particularly the substantial signs used for state and national parks and forests.

The longitudinal length of linear objects, e.g. continous groves of trees and long guardrails, was measured by counting the number of frames showing these objects. Standard roadside structures, such as bridge rails and guardrails, were able to be accurately measured by counting the number of spans then multiplying by the standard length. In other cases a transparency was utilized in measuring both longitudinal and lateral dimensions of objects.

The offset of objects is one of the most important factors acting on the accident occurrence and severity. Naturally the determination of object offsets was most cautiously carried out. Unfortunately since a picture is just a projection of a three-dimensional space on a two-dimensional plane, the photolog did not provide the best means for this purpose. However, consistent and reasonably accurate measurements were made employing the following method: A transparency prepared by the Photolog Department, MDSHT, was usually used in measuring longitudinal and lateral dimensions of objects as well as their offsets. It appeared to give very accurate measurements for objects within 10 feet from the pavement edge; it also gave good results on typical roadways - level and straight with standard cross-sections - where measurements within 20 feet had high accuracy. When a cross-section was different from the typical one for which the transparency was prepared, the measurements were not completely reliable; then the observer's subjective judgement seemed to give better results. Using simple geometrical relations provided a more accurate measurement for this case as is shown in Figure B-2-3. Since we knew that the distance between two points, (D), where two successive pictures had been taken, was 52.8 feet, we could obtain an offset by measuring two lateral distances to an object from reference points in respective pictures, then applying the formula presented in the figure. The centerline was adopted as a reference point. The distance was measured along a horizontal line on the screen to a fixed point on the object at the same level of the pavement (the selection of the point on the object could have been a source of an error; thus this method did not always ensure a highly accurate result). This method was employed by observers in doubtful cases, and, what was important, helped them to improve their intuitive feel of the offset. Another rather primitive method used was to scan the pictures at a relatively high speed and, in the perspective movement thus created, compare the offset with, say, the pavement width whose dimensions were already known. These three methods were repeatedly used until the observers' judgement was developed to a point not to always require all of them.

The most serious problem about the offset determination occurred when an object appeared outside a sharp curve, especially on an embankment. Only the continuous characteristics of the



$$S = \frac{\ell_1 \ell_2}{\ell_2 - \ell_1} \times \frac{D}{s}$$

where ℓ_1, ℓ_2; object offsset on the photolog screen, and s is determined by measuring the pavement width.

Figure B-2-3. Object Offset Determination on Photolog roadway, such as shoulder width, and the appearance of an object were the basis of judgements. Fortunately, the worst cases were not frequent, and the offset could roughly be estimated by scanning pictures to obtain perspective, or intuitively, by judging from the appearance of ground cover or tree trunks. In any case, the intuitive but comprehensive judgements of observers seemed to be highly reliable after some experience.

Since the determination of offset sometimes greatly depended on observers' subjective judgements, some sections that were observed on early dates of the survey were re-observed after all observations had been finished. The results were satisfactory in every respect and the consistency of observations was assured.

Another problem appeared in the investigation of drainage structures; sometimes dense grass or embankments completely hid these roadside structures from our view, and the hazard of ditches was generally hard to be determined exactly from the pictures. The existence of driveway culverts was rather easily suspected from adjacent similar structures that were completely visible. Headwalls were usually indicated by posts along the shoulder. However the configuration of ditches was hard to tell, even if they were visible, except for very shallow or very narrow and deep ditches, and their hazard was difficult to be estimated, especially the effect on turnover accidents. Thus some drainage structures and cross-sectional configurations were not completely revealed in our survey. In spite of this, it is our general evaluation that good approximations with reasonable range of errors have been obtained for these purposes.

The features of the survey on roadside objects employing the photolog will be summarized as follow:

It is an extremely inexpensive, less time-consuming and convenient method. The coverage of 540 miles from throughout the state would otherwise have never been attained under limited time and fund availability.

Almost all roadside objects can be clearly captured on the screen. In this respect, a photolog survey does not seem to be less accurate than a field survey except for hidden drainage structures;

The offset of objects is generally determined with adequate accuracy for the specific purposes here;

It gives information on traffic controls and roadside development as well as roadway alignments and intersections; however,

It has disadvantages in measuring offsets of objects on curves, and in completely revealing cross-sectional configurations and drainage structures along highways.

APPENDIX B-3: COMPUTER DATA FILE PREPARATION

Preparation of Original File

The computer data file prepared for the modelling study has four different MDSHT sources:

Trunkline Vehicle Mileage (TVM),
Sufficiency Rating (SR),
Accident Master File, and
Photolog survey of the current study.

The first three were provided by the MDSHT and the study personnel conducted the photolog survey (see Appendix B-2).

The first two files were already used to obtain data for the determination of the two-mile sections sampled. TVM also provides precise ADT information for each control section segment for 1971, 1972 and 1973, an average of which is used in the data file. Among the various data in the SR file, the following are used in the study file; Pavement Width, Shoulder Width, Percent Sight Restriction (PSR), and Rolling.

The control-section number, point of beginning and route number are recorded for each sample for reference and identification. The district is coded into three groups; upper penninsula (MDSHT Districts 1 and 2), middle penninsular (Districts 3 and 4) and lower penninsular (Districts 5, 6, 7, 8 and Metropolitan District).

The number of accidents in each sample segment was manually counted from a listing from the Accident Master File. The number is recorded in eight groups stratified by; accident type, fixed-object or turnover; year, (1971-73 total or 1974); and accident severity, (property damage only or injury and/or fatality).

Variables concerning the off roadway features are provided by the results of the photolog survey, which provides; the number of curves, total length of curves, number and location of intersections (on curve or tangent), shoulder treatment, ditch condition and dominant ditch offset. The number of intersections are recorded by alignment and channelization resulting in four categories. The shoulder treatment is recorded as treated or gravel. The dominant ditch bottom offset and ditch condition is determined by the general description found in the worksheet of photolog survey (Fig. B-2-1). When a steep cut or an unprotected embankment is found in the object list provided by the photolog survey, the sample segment is classified as having bad ditch conditions. However, the limitation in the accuracy of those variables in describing the actual ditch condition is fully recognized by the researchers, and they are always used with special care.

Each object in the object list of the photolog survey is converted into an equivalent length employing the basic relationship found in Glennon's study (15).

Assuming a constant encroachment angle of 11°, an object can be represented by an exposure length at the edge of pavement;

$$\begin{aligned} L &= l + d \csc \Theta + w \cot \Theta \\ &= l + 5.24 + 5.14\, w \end{aligned}$$

where; l = longitudinal length of an object, and

w = lateral width of an object.

Further assuming an average width of vehicles to be 6.7 ft. (1973 average), we have

$$L = 1 + 5w + 35 \quad \text{(ft)}.$$

The last equation was used in converting the object dimension into an equivalent exposure length.

The offset of objects is categorized into five groups; $x \leqslant 6$ (ft), $6 < x \leqslant 10$ (ft), $10 < x \leqslant 14$ (ft), $14 < x \leqslant 20$ (ft) and $20 < x \leqslant 30$ (ft). The above equivalent exposure length was accumulated for each of these offset categories, and the total exposure length is recorded in the data file for each offset group. The following two sketches describe the method employed to record the exposure length of a very wide object, and a complex of objects with various offsets (Fig. B-3-1).

Though the original object list from the photolog survey is very rich in its description of the type of object, the amount of information that is transferred into the data file of obstacles in this study is naturally limited by the general treatment.

A very simplified summary variable describing the existence of unyielding objects is introduced as showing the type of objects. When unyielding objects exist within 14 ft. of the pavement edge, the variable (called STIFF) is given a value of 1, otherwise it takes a value of 0.

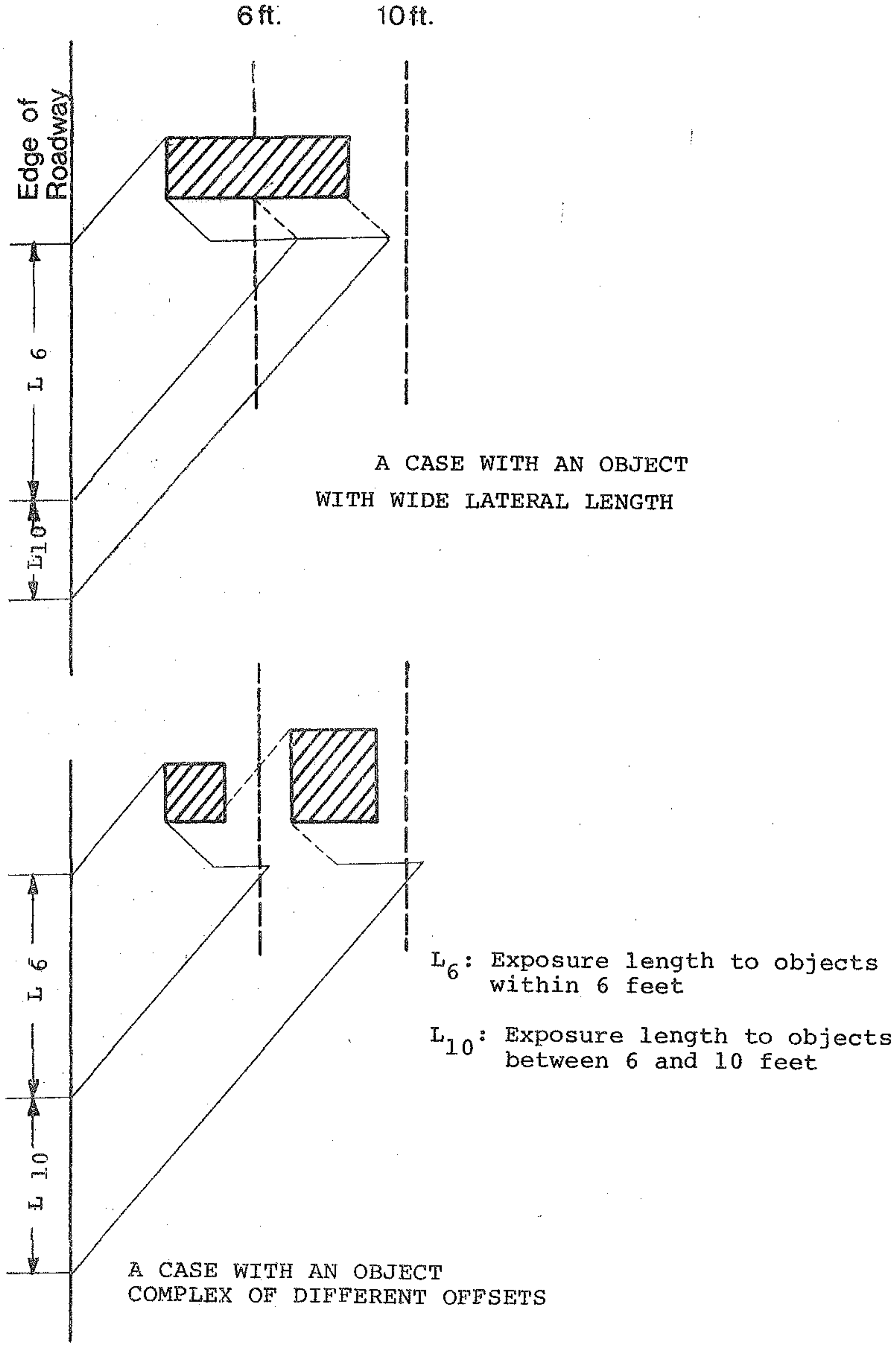


Figure B-3-1 COMPUTATION OF OBJECT EXPOSURE LENGTH

File Preparation For Aid And Regression Analysis

All variables in the file must be grouped into categories to be used by the University of Michigan AID3 program package. The grouping of variables such as ADT or object exposure was done following a principle of providing closer intervals in the range where many sample values are concentrated. A value of special importance, e.g., 0% or 100% sight restriction, is given one category by itself.

For regression analysis, many variables are transformed into general forms to make the interpretation of the coefficient and application of the model easy. For example, the number of curves in a two-mile sample segment is converted into a number of curves per mile, the curve length into percentage of total length, etc. Also various dummy (binary) variables which were expected to be useful are provided in this stage.

In both files, the object exposure is converted into a cumulative form by accumulating the exposure length according to increasing offset. Thus each value of an offset category represents the exposure to objects that lie within the distance which the category has as its upper bound. Though the independence among those exposure variables of various offsets is lost to some extent by this conversion, this transformation provides a practical measure of roadside obstacle density.

A Note on the Object Exposure Length

In this study, a procedure developed by Glennon (15) is employed to obtain the object exposure length at the edge of a traffic way. The most significant difference of the current method from Glennon's model is that this study develops the exposure length by object offset, and therefore the distribution of lateral displacement is not used as a measure associated with collision probability. Two assumptions in Glennon's procedure in developing the exposure length are discussed here; a tangent trajectory, and a constant encroachment angle at 11° (the mean of median encroachment angles). Although these assumptions greatly reduce the complication involved in the computation of the exposure length, they are very strong assumptions, and not satisfactory to represent the real conditions since the dynamics of the vehicle-drive system conditioned on site-specific environmental elements is not reflected.

The object exposure length in this study is associated with the two-mile sample sections, not with each object. Since many objects exist in these sections, which have have to be summarized in a reasonably small number of variables with a limited amount of time and effort, the above two assumptions are considered to be appropriate for the objectives of this study. In a later stage at the highway improvement program where potential roadside hazards are identified, more detailed study for individual hazards involving dynamic effects of traffic and roadway features, such as the alignment and roadside slope on collision probability may be appropriate.

APPENDIX B-4 SAMPLING PROCEDURE

There are several possible approaches to sampling data from the highway system for purposes of this study. Sampling was necessary because of limited resources and time available as well as because a complete or large sample should not be necessary for purposes of model development and validation.

A stratified random sampling plan was used. This, rather than a simple random sample of the entire network, was used because it was believed of crucial importance to obtain data on all combinations of possible contributing causal elements rather than take the chance that important combinations would be missed. This guaranteed that sections were selected from the full range encountered for each possible causal condition and for the less frequent but possibly critically important combinations of these variables. The need for extrapolation in the use of the model would then be minimized. The initial problem was to identify the population of two-lane rural sections in the state. To do this a review of all sufficiency rating sections in the 1974 summary report for those which were rural and had pavement widths less than 26 feet long was made.

At later stages of the process (including the photolog study) additional sections were eliminated, primarily because of the discovery of urbanized villages, near approaches to urbanized areas and reconstruction to three or four-lane standards.

The length of the sample section was fixed to be two miles in all cases. Previous data show that a section of less than one mile causes exaggerated variation in the number of accidents experienced, thus preventing the analysis from capturing the true accident process from the natural variation. By selecting a two-mile section and aggregating accident data for three or four years the average number of accident per section would exceed 5 (actually the sample averaged 6.5) and the chance of a hazardous section recording a small number of accidents would be satisfactorily low. Another advantageous aspect is associated with the fixed length of sections. This provides the most relevant comparison of accident experience among sections of different characteristics.

Following this reduction a total of 1392 rural two-lane segments with a surface width less than 26 feet were identified. Of these 292 were in the upper peninsula. These segments were classified into 10 ADT groups with class marks at multiplies of 1000 (the highest ADT group was $>$ 9000). The most popular value was 1000 - 1999 but more than 100 sections had values in each class up to 5000 vpd. Following analysis of the pavement width distribution it was found that only 14 segments had surface widths less than 20 feet and these were eliminated from further consideration. Approximately equal numbers of segments had widths of 20, 22 and 24 feet.

The shoulder width distribution was also determined. More than 70 percent of the segments had 8 foot wide shoulders although 7 percent were wider than that. About 5 percent had shoulders of 4 feet or less. The joint distribution of shoulder width groups are shown in Table B-4-1.

In addition the percent sight restriction for each segment was recorded. Also, the sufficiency classification of the terrain as rolling or level was utilized as a stratifying element.

The final strata used for the sampling procedure consisted of the following mutually exclusive groupings:

1. Area
    - a. Upper peninsula
    - b. Districts 3 and 4
    - c. Districts 5 - 8, Metropolitan
2. ADT
    - a. 0-1000
    - b. 1000-3000
    - c. 3000-5000
    - d. > 5000
3. Shoulder width
    - a. 0-3 ft.
    - b. 4-7 ft.
    - c. 8 ft.
    - d. > 8 ft.
4. Surface width
    - a. 20 ft.
    - b. 22 ft.
    - c. 24 ft.

TABLE B-4-1

PAVEMENT AND SHOULDER WIDTH GROUPS

SHOULDER WIDTH	PAVEMENT WIDTH 20 FT.	22 FT.	24 FT.
0-3 FT.	1%	---	0
4-7 FT.	10%	4%	1%
8 FT.	16%	34%	28%
> 8 FT.	---	1%	5%

--- < 0.5%

5. Percent sight restriction
    a. 0%
    b. 1-50%
    c. 51-99%
    d. 100%

If all combinations above existed there would be about 1400 possibilities.

Individual segements were then reviewed to determine if their length was two miles or greater. This was done at this point to obtain an estimate of the extent to which short segement length was correlated with the variables described above. It was found that short segments frequently had high ADT values, indicating their nearness to urbanized areas.

The size of the sample to be drawn was determined from time and fund availability to be limited to between 500 and 600 miles of photolog analysis (250-300 segments). This meant that an approximately 20 percent sampling rate on sections could be used (resulting in a 9 percent sampling of mileage). Particular concern was felt for the extreme values for each variable and the combinations of extreme values from more than one variable. In all cases where a combination had one or two segments only, all segments were included in the sample. For all other cells at least two segments were included in the sample. Approximately equal samples were drawn from the three state areas.

As a result of this process all extremes of the population and extreme combinations were heavily represented, yet there was duplication in at least every cell. This rigorous sample protects the results from extrapolation errors in the use of the resulting model at the cost of greater error in the mid-range of all variables.

For each of the segments a random point of beginning (to 0.01 mile) was selected from the possible beginning points of two mile sections and these sections were used in the photolog study (Appendix B-2). After determining the point of beginning, each sections was checked against a corresponding TVM section so that the two-mile section was in the same sufficiency-rating and TVM sections, which are sometimes differently defined. When the two-mile length could not be obtained because of this problem a replacement sample was drawn with the same combination of characteristics.

At the conclusion of the sampling (and of the photolog study described in Appendix B-2) a total of 270 sections had been analyzed. These data are the source of the Chapter IV analyses.