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Statistical Models of Accidents on Interchange Ramps and Speed-Change Lanes

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FOREWORD

This report is a preliminary step toward the accomplishment of the Interactive Highway Safety Design Model (IHSDM), which is a Federal Highway Administration (FHWA) objective to develop a highway safety evaluation tool. In particular, this research is a preliminary effort to relate multivehicle accidents on interchange ramps and speed-change lanes to highway design elements. The results are of interest to highway planners and designers. Moreover, the results are useful to researchers who will eventually improve, validate, and complete these preliminary accident models.

All regression models were developed to predict total accidents, and fatal and injury accidents. The models based on the negative binomial distribution explained between 10 and 42 percent of the variability in the accident data. However, most of the variability was explained by ramp Annual Average Daily Traffic (AADT). Other variables found to be significant in some models include mainline freeway AADT, area type (rural/urban), ramp types (on/off), ramp configuration, length of ramp, and length of speed-change lane. The best models obtained for predicting accident frequencies were those obtained when modeling the combined accident frequency for an entire ramp with its adjacent speed-change lane.

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

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16. Abstract

The objective of this research was to develop statistical models for defining the relationship between traffic accidents and highway geometric design elements and traffic volumes for interchange ramps and speed-change lanes. The data base used to develop the models consisted of data for interchange ramps and speed-change lanes in the State of Washington and was obtained from the FHWA Highway Safety Information System. Additional geometric design features were obtained from the review of interchange diagrams. Data on other geometric design features, such as the ramp grades and horizontal curvature, were collected for a sample of ramps from aerial photographs and other existing highway agency files.

The statistical modeling approaches used in the research included Poisson and negative binomial regression. Regression models to determine relationships between accidents and the geometric design and traffic volume characteristics of ramps were difficult to develop because the observed accident frequencies for most ramps and speed-change lanes are very low. The regression models developed, based on the negative binomial distribution, explained between 10 and 42 percent of the variability in the accident data, with the negative binomial distribution providing a poor to moderate fit to the data. However, most of that variability was explained by ramp Annual Average Daily Traffic (AADT). Other variables found to be significant in some models included mainline freeway AADT, area type (rural/urban), ramp type (on/off), ramp configuration, and combined length of ramp and speed-change lane.

The best models obtained for predicting accident frequencies were those obtained when modeling the combined accident frequency for an entire ramp, together with its adjacent speed-change lanes. These models provided a better fit than separate models for ramps and speed-change lanes. Models developed to predict total accidents generally performed slightly better than did models to predict fatal and injury accidents.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

(Revised September 1993)

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1. INTRODUCTION

This technical report presents the results of statistical analyses of accident experience for interchange ramps and speed-change lanes. A background discussion to define the terminology used for interchange types and their components is presented below. The objectives and scope of this research and the organization of this report are then discussed.

Background

Highway interchanges are systems of minor roadways designed to connect two or more major roadways. The major roadways connected at an interchange may consist of two fully access-controlled freeways, one freeway and one arterial highway, or two arterials. This research has focused exclusively on freeway-freeway and freeway-arterial interchanges. Arterial-arterial interchanges were not considered.

Interchanges have many different possible configurations. The configuration chosen for the design of any particular interchange must be appropriate for the volumes of traffic making specific turning movements at the interchange, the alignments of the roadways being connected, the surrounding terrain, the adjacent development, and physical constraints such as existing rivers, railroads, and roadways. Figure 1 illustrates typical interchange configurations—from the simplest full-diamond interchange to complex, multi-level directional interchanges. Many variations of each of these basic interchange configurations are possible.

The minor roadways that are provided within an interchange to allow traffic to move from one major roadway to another are known as *ramps*. Ramps come in various configurations appropriate to the design of the interchange in which they are located. Many ramp types are named after the interchange types in which they are most commonly used. Thus, the ramps of a diamond interchange are typically known as diamond ramps, and the loop ramps within a partial cloverleaf (parclo) interchange are typically known as parclo loop ramps. Figure 2 illustrates a number of typical ramp configurations. Each of the ramps of the ramp configurations illustrated serves traffic exiting from a mainline freeway, but an analogous ramp configuration for traffic entering the mainline freeway also exists.

A ramp that leaves a mainline freeway facility is known as an *off-ramp* or *exit ramp*. A ramp that joins a mainline freeway facility is known as an *on-ramp* or *entrance ramp*. This distinction is important because vehicles typically travel along off-ramps at higher speeds than along on-ramps, so that accidents are more likely to occur on off-ramps. Ramps that join mainline freeways at both ends serve as both off-ramps and on-ramps.

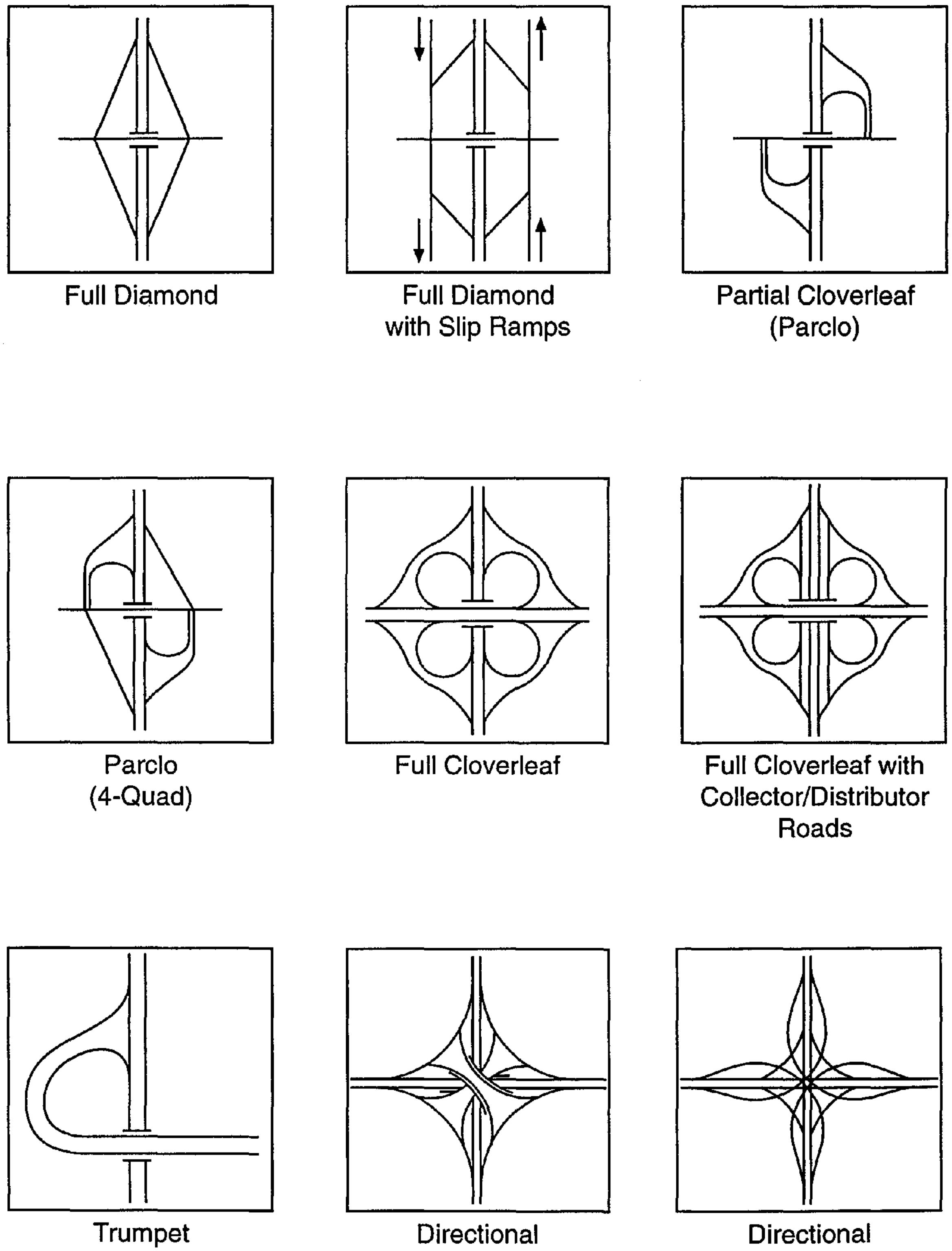
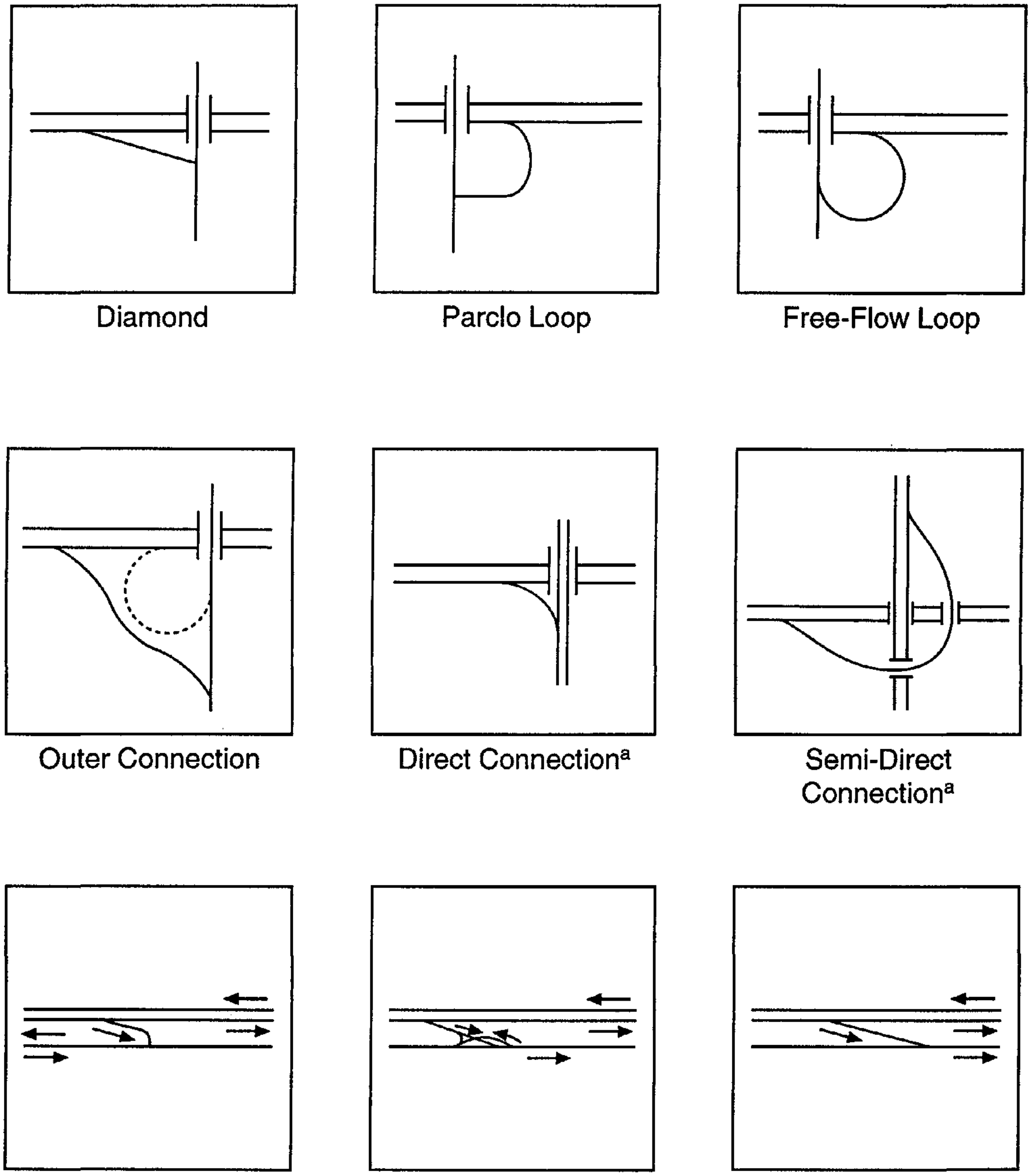


Figure 1. Typical Interchange Configurations



[a] When used in directional interchanges
[b] Scissors connection

Figure 2. Typical Ramp Configurations

Ramps are connected to mainline freeways and, in some cases, to arterials by *speed-change lanes* that allow entering and exiting vehicles to speed up or slow down without conflicting with through traffic. The speed-change lane for an off-ramp is known as a *deceleration lane*, while the speed-change lane for an on-ramp is known as an *acceleration lane*. Figure 3 illustrates the distinction between ramps and their adjacent speed-change lanes.

Most ramps connect directly to the adjacent mainline freeway by means of speed-change lanes. However, a few larger interchanges have intermediate roadways, known as *collector/distributor roads* or *C/D roads*, that connect the ramps and the speed-change lanes. Figure 1 illustrates a full cloverleaf interchange with C/D roads. Some basic descriptive statistics on the safety performance of C/D roads were assembled in this research, but no statistical modeling of accidents on C/D roads was performed.

Research Overview

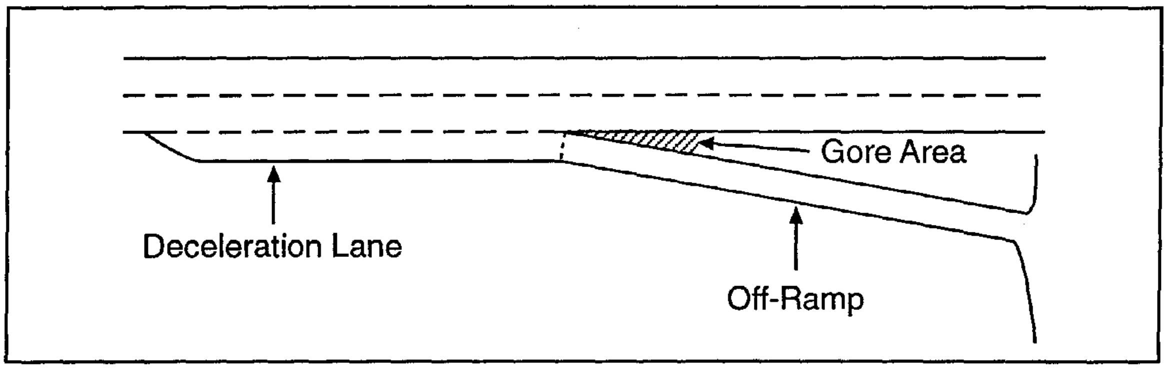
The objective of this research study was to develop statistical models for defining the relationships between traffic accidents and highway geometric elements, and traffic volumes for interchange ramps and speed-change lanes. It was hoped that these models could be used in predicting the effects on accidents of specific geometric design decisions at interchange ramps and speed-change lanes.

Several major technical tasks were performed during the research, including:

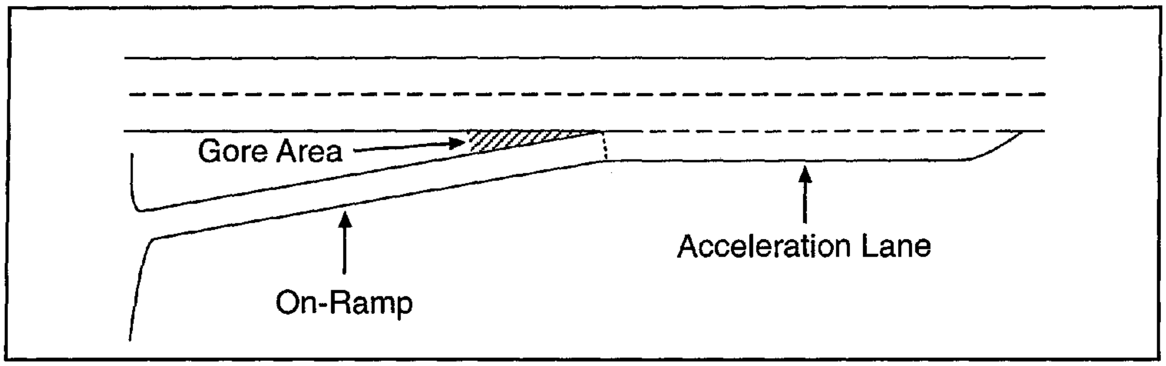
- A review of previously published and unpublished literature concerning the relationship between traffic accidents and interchange ramp and speed-change lane geometrics, as well as between traffic accidents and highway geometric design features in general.

- A review of existing policies, guidelines, standards, and practices for design of interchange ramps and speed-change lanes.

- A review of existing highway agency files containing geometric design, traffic volume, and accident data, including the data bases in the Federal Highway Administration (FHWA) Highway Safety Information System (HSIS). As a result of these efforts, the data base from the Washington State Department of Transportation (DOT) was found to be best suited for the investigation of relationships between interchange ramp and speed-change lane geometrics and accidents, and was used for developing statistical models and testing statistical approaches in this research.



Deceleration Lane and Off-Ramp



On-Ramp and Acceleration Lane

Figure 3. Illustration of Ramps and Adjacent Speed-Change Lanes

- The development of statistical models for relationships between traffic accidents and geometrics. Alternative modeling approaches were investigated based on various assumptions about the distribution of accidents, including the Poisson and the negative binomial distributions. The goodness of fit of these various alternative models and the role of geometric design variables in these models were assessed. Statistical models were developed for various combinations of interchange elements.

- The collection of additional data of geometric parameters for a sample of 200 ramps using aerial photographs and other existing files of the Washington State Department of Transportation. Additional statistical analyses incorporating these variables were conducted.

Scope and Organization of This Report

This report is organized into six main sections and four appendixes, including this introduction. Each section is briefly described below.

Section 2 provides a brief overview of the literature related to modeling traffic accidents. Advantages and disadvantages of the various statistical modeling approaches are discussed.

Section 3 provides a review of available accident and roadway files of State highway agencies, including the States in the HSIS. This section documents the reasons for selecting the Washington data base for this work.

Section 4 provides details on the geometric design, traffic volume, and accident variables for interchange ramps and speed-change lanes for the Washington data base.

Section 5 presents the results from various statistical models that were developed with Poisson and negative binomial regressions for various combinations of interchange elements. These results were derived from the Washington data base.

Section 6 presents the findings and conclusions of the study.

Appendix A presents definitions of geometric design and traffic volume variables from the Washington data base.

Appendix B presents accident severity distributions by ramp segment type for eight selected ramp types.

Appendix C presents accident type distributions by ramp segment type for eight selected ramp types.

Appendix D presents accident frequency distributions for selected interchange elements.

2. OVERVIEW OF LITERATURE AND STATISTICAL MODELING APPROACHES

This section of the report presents a brief overview of previous studies of interchange ramp and speed-change lane accidents. The discussion also reviews nontraditional statistical approaches to accident modeling used in recent research and describes how those nontraditional approaches can be applied to models for ramp and speed-change lane accidents.

Previous Evaluations of Ramp and Speed-Change Lane Accidents

There has been substantial earlier research on the safety effects of various interchange elements, but none of this research has resulted in relationships that appear directly useful in estimating the effectiveness of various interchange improvements. The most recent summary of research on interchange safety was prepared in the early 1990s by Twomey, Heckman, and Hayward.(1) Earlier sources include an annotated bibliography prepared in the early 1980s by Harwood et al. and a summary of research findings prepared by Oppenlander and Dawson in 1970.(2,3,4)

Statistical Modeling of Interchange Accidents

Several previous studies have undertaken statistical modeling of accidents in interchange areas. One of the best known efforts of this type was the Interstate System Accident Research (ISAR) study undertaken by FHWA in the late 1960s. A key summary of this work is presented by Cirillo, Deitz, and Beatty and includes 6 multiple regression models to predict accident frequencies for entire interchange areas and 13 models of specific interchange components, including ramps and speed-change lanes.(5) Accident severity distributions were also examined. Traffic volumes were found to be a key variable in predicting interchange accident experience. Geometric features of ramps considered in accident modeling included ramp type (on-ramp vs. off-ramp), ramp length, speed-change lane length, presence of curvature, maximum curvature on ramp, central angle of first curve on ramp, ramp grade, right and left shoulder widths, minimum stopping sight distance, and difference between ramp and speed-change lane design speeds. In their accident modeling work, Cirillo, Deitz, and Beatty developed separate models for ramps and their associated speed-change lanes, while most other studies combined these features.

Multiple regression modeling of ramp accidents was also conducted by Morganstein and Edmonds, using the ISAR data base, and by Kim, using a data base developed in Michigan.(6,7) Other studies of interchange safety focused on determining average accident rates for interchange features rather than developing statistical models.

Effect of Horizontal Alignment of Ramps

Research by Yates with the ISAR data base estimated the average accident rates as a function of curvature and traffic volume for loop and outer connection ramps in cloverleaf interchanges.(8) As shown in table 1, ramps without curvature were found to have smaller accident rates than those with curvature in both urban and rural areas for all traffic volume levels except for 0 to 499 veh/day in urban areas. Rural loop ramps with low curvature were found to have higher accident rates than those with high curvature, as shown in table 2, while the opposite was true in urban areas.

A California study by Lundy completed in 1965 determined accident rates for ramps grouped by ramp type and curvature.(9) Off-ramps were found to have consistently higher average accident rates than on-ramps, while the average accident rates of curved ramps were only sightly higher than straight ramps. No statistical analyses of these data were conducted.

A 1961 review of interchange accident experience in New Jersey by Fisher concluded that very few accidents could be attributed to loop ramps with radii over 31 m (100 ft).(10)

Effect of Vertical Alignment of Ramps

The general ramp grade can be determined by whether the crossroad at an interchange goes over or under the mainline freeway. Lundy found that upgrade off-ramps had lower accident rates than downgrade off-ramps.(9) However, the accident rates of on-ramps did not appear to depend on whether the on-ramp was on an upgrade or downgrade.

Effect of Ramp Configuration

Lundy determined the accident rates for ramps of different ramp types (on-ramp vs. off-ramp) and ramp configurations.(9) These findings are summarized in table 3. They generally indicate that diamond ramps have the lowest accident rates. Loop ramps, which involve higher curvature, were found to have higher accident rates. The highest accident rates were found for scissors connections, where ramps cross one another with stop-sign control, and for ramps that enter or leave the left side of the mainline freeway lanes. Although the Lundy data shown in the table were first developed in 1965, the California Department of Transportation (Caltrans) has continually updated these accident rate estimates by ramp type and configuration over the years as the basis for their accident surveillance program for freeway interchanges.

Table 1. Accident Rates on Outer Connection Ramps as a Function of Curvature and Average Daily Traffic Volume[(8)]

Average daily traffic volume (veh/day)	Accident rate (per 100 million vehicles)			
	Urban ramps		Rural ramps	
	Straight[a]	Curved[b]	Straight[a]	Curved[b]
0-499	0.74	0.64	0.00	0.67
500-1,000	0.34	0.72	0.13	0.49
1,001-1,500	0.64	0.84	0.00	0.61
1,501-2,000	0.15	0.93	0.00[c]	0.20
> 2,000	0.49	0.82	0.00[c]	0.72
COMBINED	0.44	0.81	0.05	0.56

[a] Less than 1 degree of curvature.
[b] Greater than 1 degree of curvature.
[c] Based on less than 10 ramps.

Table 2. Accident Rates for Loop Ramps as a Function of Curvature and Average Daily Traffic Volume[(8)]

Average daily traffic volume (veh/day)	Accident rate (per 100 million vehicles)			
	Urban ramps		Rural ramps	
	Low curvature[a]	High curvature[b]	Low curvature[a]	High curvature[b]
0-499	0.000[c]	0.841	1.000	0.260
500-1,000	0.000[c]	0.960	0.810	0.370
1,001-1,500	1.320[c]	0.690	0.000[c]	0.000
1,501-2,000	0.000[c]	0.720	0.000[c]	0.000
> 2,000	0.141	1.000	0.000[c]	0.000
COMBINED	0.200	0.940	0.631	0.250

[a] Less than 12 degrees of curvature.
[b] Greater than 36 degrees of curvature.
[c] Based on less than 10 ramps.

Table 3. Accident Rates by Ramp Type and Configuration[9]

Ramp configuration	Accident rate (per million vehicles) On-ramp	Off-ramp	Combined
Diamond	0.40	0.67	0.53
Cloverleaf outer connection with C/D roads[a]	0.45	0.62	0.61
Direct connection	0.50	0.91	0.67
Cloverleaf loop with C/D roads[a]	0.38	0.40	0.69
Buttonhook	0.64	0.96	0.80
Other loop with C/D roads	0.78	0.88	0.83
Cloverleaf outer connection without C/D roads	0.72	0.95	0.84
Trumpet ramps	0.84	0.85	0.85
Scissors ramps	0.88	1.48	1.28
Left-side ramps	0.93	2.19	1.91
AVERAGE	0.59	0.95	0.79

[a] Only the combined on- and off-ramp accident rates include accidents on collector/distributor (C/D) roads.

Accident Locations Along Ramps

The Fisher study in New Jersey found that most accidents were associated with speed-change lanes and ramp terminals and very few accidents were associated with the main portion of the ramp.[10]

Effect of Ramp Traffic Volumes

Virtually every study of ramp accidents has concluded that traffic volumes are the single strongest predictor of accident frequencies and accident rates. By contrast, geometric design features of ramps were found to have much less ability to predict ramp accidents.[5,6]

Speed-Change Lanes and Weaving Areas

The safety performance of speed-change lanes and weaving areas was documented with the ISAR data by Cirillo.[11,12,13] Table 4 summarizes the average accident rates of off-ramps, on-ramps, speed-change lanes (including both deceleration and acceleration lanes), and weaving areas from the ISAR data for both rural and urban areas. Statistical modeling by Cirillo concluded that accident rate decreases with increasing length of weaving areas and speed-change lanes. Separate multiple-regression relationships of the relationship between length of weaving and speed-change lanes were developed for various traffic volume levels. Statistical relationships for weaving areas were based on the weaving volumes, and for speed-change lanes, they were based on the percentage of merging or diverging traffic. Accident rates in weaving areas and speed-change lanes generally increased with increasing traffic volumes. The effect of acceleration lane length on accident rate was found to be substantial when the percentage of merging traffic exceeded 6 percent. The effect of speed-change lane length was not as great for deceleration lanes as for acceleration lanes.

Table 4. Accident Rates by Area Type and Interchange Unit

Rural			
Interchange unit	Vehicle-miles of travel (100 million)	Number of accidents	Accident rate (per 100 million vehicle-miles)
Deceleration lane	2.51	348	137
Off-ramp	0.57	199	346
On-ramp	0.59	95	161
Acceleration lane	3.68	280	76
Mainline weaving area	0.49	87	116
AVERAGE	-	-	109
Urban			
Interchange unit	Vehicle-miles of travel (100 million)	Number of accidents	Accident rate (per 100 million vehicle-miles)
Deceleration lane	5.83	1,089	186
Off-ramp	1.48	546	370
On-ramp	1.61	1,159	719
Acceleration lane	8.40	1,461	174
Mainline weaving area	2.45	555	227
AVERAGE	-	-	214

1 mi = 1.61 km

Innovative Approaches to Statistical Modeling

In past research, including several of the studies discussed above, accident predictive models have often been developed with accident rates (i.e., accident frequencies per unit of exposure) as the dependent variable using simple multiple-linear regression. In this traditional approach, the dependent variable (accident rate) was modeled as a linear combination of highway-related parameters, with or without interactions, under the assumption that the dependent variable follows a normal distribution. The results obtained from this approach have generally been disappointing, both in terms of the proportion of the variation in accident rates explained by the models and the generally weak role of geometric design variables as accident predictors. Part of the reason for the disappointing results of past research may be that multiple regression is an inappropriate approach for developing such relationships.

There are several reasons for this concern. First, accident rates often do not follow a normal distribution. Traffic accidents are random, discrete events that are sporadic in nature. Normalizing accident frequencies with exposure estimates, such as million vehicle-miles of travel or million vehicles traveling on interchange ramps and speed-change lanes, to make accident rates appear to be a continuous random variable does not change the fundamentally discrete nature of accident data.

Second, accident frequencies for particular ramps and speed-change lanes or relatively small roadway sections are typically very small integers, even if several years of accident data are obtained for those interchange elements or roadway sections. In fact, it is not uncommon for a substantial proportion of the sites in an accident study to have experienced no accidents at all during the study period. Small integer counts, often zero or close to zero, do not typically follow a normal distribution. In fact, the Poisson and negative binomial distributions are often more appropriate for discrete counts of events that are likely to be zero or a small integer during a given time period.

Finally, accident frequencies and accident rates are necessarily non-negative. However, there is nothing to constrain traditional multiple-regression models from predicting negative accident frequencies or accident rates, which confronts the accident analyst trying to use the predictive model with a meaningless result.

Research to develop accident predictive models published in recent literature has moved away from approaches based on multiple regression and has begun to use underlying distributional assumptions other than the normal distributional assumptions. As stated above, the Poisson distribution is appropriate for rare events such as traffic accident counts where the number of events in a given time period is likely to be zero or a small integer.

Several recent studies have implemented these nontraditional statistical approaches. For example, Miaou and Lum investigated four types of regression models to evaluate the relationship between truck accidents and highway geometric design elements.[14] The four models considered by the authors were two conventional linear regression models (one was normal or additive; the other was lognormal or multiplicative) and two multiplicative Poisson regression models (one using an exponential rate function; the other, a nonexponential rate function). Miaou and Lum concluded that of the four models tested, the Poisson model with the exponential rate function provided the best form of the relationship between truck accidents and highway geometric design elements in their study. The authors also identified the inherent limitations in using a Poisson model, which are discussed below.

One of the basic assumptions when choosing a Poisson model is that the mean and the variance of the error distribution are equal. However, in many applications, including the work that will be presented in this report, the data exhibit extra variation (i.e., the variance is greater than the mean of the estimated Poisson model). This situation is referred to as overdispersion. An alternative statistical model for addressing error structures with overdispersion like that often found in accident data is the negative binomial distribution. This approach has been used recently by several researchers, including Hauer et al., Knuiman et al., Miaou et al., Shankar et al., Hadi et al., and Bauer and Harwood.[15-20]

The performance of Poisson and negative binomial regression models was recently compared by Miaou.[21] The author applied these models to define a relationship between truck accidents and geometric design of road sections. The author concluded that with moderate to high overdispersion in the data, the negative binomial model provides a sensible approach to modeling accidents in that particular application. However, with certain modeling estimation procedures, the regression coefficients are quite consistent between the Poisson and the negative binomial approach. In any case, Miaou suggests the use of Poisson regression as an initial step in the modeling effort, with the negative binomial model then being applied where appropriate. A 1987 paper by Lawless also examined the efficiency and robustness properties of the negative binomial and mixed Poisson regression models when applied to count data that exhibit extra variation.[22]

None of these past studies have addressed ramp and speed-change lane accidents, but their results suggest that Poisson and negative binomial regression are likely to be appropriate approaches to statistical modeling. The results obtained from implementing these approaches are presented in the remainder of this report.

3. DATA BASE SELECTION

The first major activity in the research was to identify one or more existing data bases of geometric design, traffic volume, and accident data for interchange ramps and speed-change lanes that were suitable for testing the development of statistical models for accident prediction. In order to be useful in the planned statistical analyses, the various data files of geometric and accident data needed to be linked together by a common location identification system, such as the milepost systems used by many State highway agencies.

The candidate data bases that were considered included the data bases available in the FHWA Highway Safety Information System (HSIS) and data bases from non-HSIS States. The two existing State data bases that were found to be best suited to this effort were those maintained by the California Department of Transportation (Caltrans) and the Washington State Department of Transportation. A detailed review of these data bases was made and trips were made to each agency to discuss the collection and coding of their data. At the time of this review, FHWA had reached a decision to include both California and Washington as new States in the HSIS, so it was apparent that data from both States would be readily available in HSIS formats.

The Caltrans highway data base, as part of the Traffic Accident Surveillance and Analysis System (TASAS), was found to include a file containing data on each individual ramp on the California State highway system. This file identifies the configuration of each ramp (e.g., diamond, loop) and includes an estimate of the annual average daily traffic (AADT) volume for each ramp. Each ramp is identified by the county, route number, and milepost of the gore area at which the ramp entered or exited from the mainline freeway. The locations of accidents on each ramp are identified by a code indicating whether the accident occurred at the beginning of the ramp, in the middle of the ramp, at the end of the ramp, or on the arterial crossroad (when the arterial crossroad was not a State highway with its own mileposting system). However, no data on the geometrics of individual ramps were included in the data base. If geometric data were to be considered in statistical analyses, they would have to be obtained from aerial photographs, photologs, or field visits.

The Washington data base also included data on each ramp in the State highway system. While the Washington data base did not include data on the ramp configuration, it did include a number of key geometric variables that were not available in the Caltrans data base. In particular, the Washington data base defined the cross section of each ramp (e.g., number of lanes, surface width, shoulder width), including variations in the dimensions of these cross-section elements along the length of the ramp. Accident locations were defined by mileposts along each individual ramp, which made it possible to link the accident data to particular geometric features of the ramp. For example, it was found that with some manual data reduction from existing interchange diagrams maintained by the Washington State DOT, it would be possible to distinguish ramp accidents from speed-change lane accidents. Although ramp configuration data were not available in the existing data file, it was also found that this could be determined directly from the interchange diagrams. Several other barriers to using the data (discussed in section 4) were also identified, but it was determined that these barriers could also be overcome through some manual data reduction.

The only major concern with the Washington data files was that traffic volume data were not available for every ramp. A separate ramp traffic volume file was available, but it included AADT data for only about 67 percent of the ramps. Previous research has shown that traffic volumes are the strongest predictor of ramp accident experience.

Based on the factors discussed above, it was decided that the advantages of the Washington data base were so great that they outweighed the lack of traffic volume data. The Washington data base includes geometric data for ramps at a level of detail that is not available for any other State. Thus, a decision was reached to obtain and use the existing Washington data, but to limit the analyses conducted to those ramps for which AADT data were available.

4. DATA BASE DESCRIPTION

This section describes the geometric design, traffic volume, and accident history variables that were available in the existing Washington data base or that were derived from other State records. These data were available for the statistical analyses that are reported in section 5 of this report.

Variables Available in the Washington State Data Base

Existing data files of geometric design and traffic volume data for ramps and speed-change lanes in the State of Washington were obtained for this analysis from the FHWA Highway Safety Information System (HSIS). A file of traffic volumes on mainline freeways was also obtained. These files were originally assembled by the Washington State DOT for their own use and, after careful data review and conversion to Statistical Analysis System (SAS) data sets, were included in the HSIS. The geometric and traffic volume data included in this study were for the year 1993, and the accident data were for the years 1993 through 1995, inclusive.

Table 5 presents a list of all relevant variables, such as geometric design features, traffic volume data, and other related factors from the existing Washington data base that were considered in the statistical analyses. Some of these variables were available directly in the existing data base and others were derived or calculated from the available data. For example, the total length of a ramp and its adjacent speed-change lane was not directly available in the existing data base, but could be computed from available milepost data. The speed-change lane length used in the study was the length from the gore point to the end of the taper where the speed-change lane joins the mainline freeway as shown in figure 3. The American Association of State Highway and Transportation Officials (AASHTO) design policies for speed-change lanes involve distances designated as the *acceleration length* and *deceleration length*, which do not include the mainline taper, but may include a portion of the ramp proper. The acceleration and deceleration lengths for speed-change lanes could not be determined from the available data. The analyses in this study were based on the physical lengths of speed-change lanes from the end of taper (where taper meets edge of travel-lane) to painted gore point.

The structure of the existing Washington geometric design file was such that each data record in the file represented a segment of a ramp or speed-change lane with homogeneous geometrics. In other words, the geometrics of each ramp and speed-change lane were documented by a series of roadway segments, each of which represented a portion of the ramp or speed-change lane with homogeneous geometrics. Whenever the value of a key geometric variable changed, a new segment began in the data base. In addition, a new segment generally began at the gore area where a ramp and a speed-change lane joined one another, wherever one ramp merged with or diverged from another, and at administrative boundaries such as county lines or city limits.

Table 5. Variables Available in the Existing Washington Data Base for Ramps and Speed-Change Lanes

Geometric Design Features • Ramp type (on-ramp/off-ramp) • Number of lanes • Surface width (ft) • Right shoulder type • Right shoulder width (ft) • Left shoulder type • Left shoulder width (ft) • Ramp or speed-change lane segment length (mi) for segments with homogeneous cross sections • Ramp length (mi) • Speed-change lane length (mi)
Traffic Volume Data • Annual average daily traffic (veh/day) for ramp or speed-change lane • Annual average daily traffic (veh/day) for adjacent mainline freeway
Other Related Data • Area type (rural/urban)

A review of the existing geometric design and traffic volume files found that they could not be used directly for statistical modeling of the relationships between ramp geometrics and traffic accidents. The limitations that prevented such analyses are as follows:

- No data were available to identify which segment boundaries represented points at which ramps merged with or diverged from other ramps. Without such data, it was not possible to determine whether the available traffic volume data represented the ramp as a whole or only a portion of the ramp.

- No data were available to distinguish which segment boundaries represented gore area locations at which ramps and speed-change lanes joined one another.

- No available surface width data represented the total traveled way width for ramps and speed-change lanes without curbs. However, where a curb was provided outside the shoulder for drainage reasons, the surface width variable then represented the sum of the traveled way and shoulder widths. Thus, where curbed sections were present, it was not possible to determine the traveled way or shoulder widths explicitly.

- No data were available to identify the basic configuration of each ramp (e.g., diamond, parclo loop, free-flow loop).

It was found that these deficiencies could be remedied through a manual review of the data records in the existing files and through review of interchange diagrams that had been prepared by the Washington State DOT for use in coding accident locations on ramps. The variables from these data sources are described in the next section.

Table 6 identifies the accident descriptors that were available for each ramp or speed-change lane accident from the existing Washington ramp accident file. Each accident record included a milepost that allowed the location of the accident along the ramp or speed-change lane to be determined and allowed that accident to be linked to the geometric data for a particular ramp or speed-change lane segment.

Additional Variables Obtained From Review of Interchange Diagrams

The interchange diagrams used by the Washington State DOT in coding accident locations were reviewed to obtain additional data of interest to the safety analysis. Figure 4 illustrates a typical interchange diagram. The following data were obtained from manual review of the existing data base and from review of the interchange diagrams:

- Each ramp or speed-change lane segment was classified as one of the following segment types:
  - — conventional deceleration lane
  - — deceleration lane with mainline lane drop
  - — conventional acceleration lane
  - — acceleration lane with mainline lane addition
  - — ramp proper
  - — two-way ramp proper segment (i.e., opposite directions of travel divided only by double yellow centerline)
  - — merge area on ramp [i.e., merge between two ramps or between a ramp and a collector/distributor (C/D) road]
  - — diverge area on ramp
  - — weaving area on ramp (i.e., combined merge and diverge area)

  This process required identification of the locations of gore areas, merge points, and diverge points on the ramps.

- Based on comparisons of the interchange diagrams and a printout of the geometric data, adjacent segments with the same segment type and identical (or nearly identical) geometrics were identified so that they could later be combined into longer segments.

- Based on comparisons of the interchange diagrams and a printout of the geometric data, the traveled way and shoulder widths were determined for each segment identified as having a curbed cross section. Generally, it was possible to match the combined traveled way and shoulder width of the curbed section with the combined traveled way and shoulder widths of adjacent non-curbed sections, one or more of which were often identical. Once the traveled way width was available, the average lane width on each ramp segment could be computed as the traveled way width divided by the number of lanes.

Table 6. Accident History Variables Derived From Washington State Accident File

• Total accidents for all 3 years combined
• Total accidents in calendar year 1993 • Total accidents in calendar year 1994 • Total accidents in calendar year 1995
• Total accidents for each calendar year by severity level: — fatal accidents — injury accidents — property-damage-only accidents
• Total accidents for each calendar year by location with respect to interchange features: — within specific ramp segments — within the limits of specific ramps — within the limits of specific speed-change lanes
• Total accidents by calendar year and by accident type: Single-vehicle non-collision accidents: — ran-off-road — overturned in road — other single-vehicle non-collision accident Single-vehicle collision accidents: — collision with parked vehicle — collision with train — collision with pedestrian — collision with bicycle — collision with animal — collision with fixed object — other single-vehicle collision Multiple-vehicle collision accidents: — head-on collision — sideswipe collision — rear-end collision — angle collision — right-turn collision — left-turn collision (or U-turn) — other multiple-vehicle collision

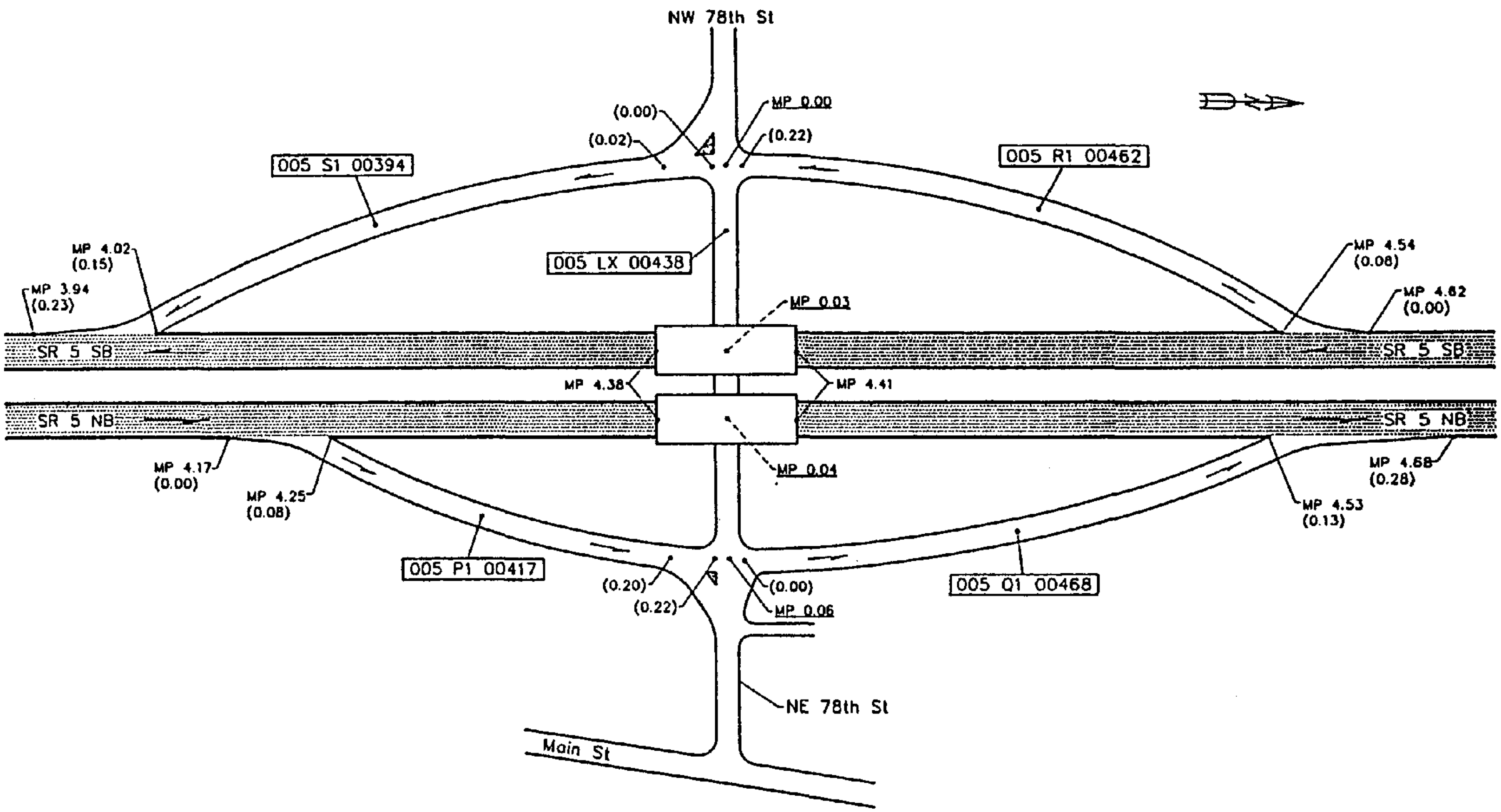


Figure 4. Typical Interchange Diagram Used to Determine Relationships Between Interchange Elements

- The configuration of each ramp was noted from the interchange diagrams in the following categories:

  — diamond
  — parclo loop
  — free-flow loop
  — outer connection
  — direct connection
  — semi-direct connection
  — buttonhook
  — slip ramp to parallel one-way frontage road
  — slip ramp to parallel two-way frontage road
  — collector/distributor (C/D) road
  — other ramp configuration

  Figures 1 and 2 illustrate these various ramp configurations and the interchange configurations in which they occur.

- The nature of the beginning and end points of each ramp was noted using the following categories:

  — begin/end taper on mainline freeway
  — painted gore on mainline freeway
  — physical gore on mainline freeway
  — other point on mainline freeway
  — begin/end taper on mainline freeway (with different route number than ramp)
  — painted gore on mainline freeway (with different route number than ramp)
  — physical gore on mainline freeway (with different route number than ramp)
  — other point on mainline freeway (with different route number than ramp)
  — begin/end taper on another ramp or C/D road
  — painted gore on another ramp or C/D road
  — physical gore on another ramp or C/D road
  — other point on another ramp or C/D road
  — crossroad intersection with stop sign or signal
  — crossroad intersection with free-flow connection
  — connection to parallel two-way frontage road
  — connection to parallel one-way frontage road

The data reduction from interchange diagrams was completed for all 1,405 ramps on the Interstate system, which includes approximately 69 percent of all ramps in Washington. The 641 ramps located on non-Interstate freeways and on arterial highways were not included in the analyses conducted.

Table 7 presents a list of the additional analysis variables that were obtained from manual review of the existing data base and from review of the interchange diagrams. These variables were added to the existing SAS files of ramp and speed-change lane data.

Table 7. Additional Variables Obtained From Review of Data and Interchange Diagrams

Geometric Design Features
• Ramp segment type • Ramp configuration • Traveled way width (ft) (corrected for curbed sections) • Average lane width (ft) • Right shoulder width (ft) (corrected for curbed sections) • Left shoulder width (ft) (corrected for curbed sections)

Additional Variables Obtained From Washington State DOT Records

At a later stage of the project, several additional analysis variables were obtained from existing records of the Washington State DOT. These additional variables, summarized in table 8, included:

- The radii of the horizontal curves on each ramp, determined from a review of aerial photographs of the highway system maintained by the Washington State DOT. These aerial photographs were taken at an approximate scale of 1″:400′. These data were obtained for a sample of approximately 200 urban diamond, parclo loop, free-flow loop, and outer connection off-ramps.
- The grades on each ramp were classified as either upgrades or downgrades from review of the interchange diagrams compiled by the Washington State DOT to determine whether the crossroad facility at the interchange went over or under the mainline freeway. These data were obtained for all ramps on the Interstate system in Washington.
- The annual average daily traffic (AADT) volume of the mainline freeway section adjacent to each speed-change lane was determined from an existing computer file of mainline freeway traffic volume by matching the ramp and mainline freeway mileposts. The mainline freeway AADT used in modeling was the one-way AADT in the direction of travel for the ramp in question, estimated as half of the two-way AADT for the mainline freeway.

Table 8. Additional Variables Obtained From Review of Other Highway Agency Records

Geometric Design Features
• Minimum radius of any horizontal curve on the ramp • Horizontal alignment index (curviness) for the ramp based on equation (1) • Horizontal alignment index (curviness) for the ramp based on equation (1), using an exponent of 1.0 rather than 1.5 for the D_i term • General grade of ramp (upgrade, downgrade)
Traffic Volume Variables
• Annual average daily traffic volume of the mainline freeway section adjacent to speed-change lane (veh/day)

For the sample of 200 ramps discussed above, data on the radius of each horizontal curve on the ramp were obtained from the aerial photograph of the interchange. The alternative measures of the horizontal curvature or curviness of each ramp were considered in statistical analyses. These were:

- Alternative 1—The smallest radius of all horizontal curves on the ramp.
- Alternative 2—The horizontal alignment index (curviness) of the ramp based on the following equation used in previous work by Bared and Vogt:[23]

$$H = (l/L_h)\ (\Sigma\ (D_i)^{1.5}\ lh_i) \tag{1}$$

where: H = horizontal alignment index
L_h = total length of ramp, including horizontal curves and tangents in hundreds of feet
D_i = degree of curvature for the i^{th} horizontal curve [change in angular heading per 31 m (100 ft)]
lh_i = length of i^{th} horizontal curve (in hundreds of feet)

- Alternative 3—The same equation for horizontal alignment index shown in equation (1), but with the coefficient of the D_i term set equal to 1.0, rather than 1.5.

Appendix A defines each of the variables in tables 5, 7, and 8 as continuous or categorical and defines the units of each continuous variable and the levels of each categorical variable.

5. STATISTICAL MODELING

This section describes the statistical modeling of interchange ramp and speed-change lane accidents that was conducted during the research, based on the Washington data base. The discussion includes both the data preparation steps prior to the analysis and the analyses that were conducted for the various combinations of interchange elements.

Data Preparation

The Washington data base, whose selection was described in section 3 of this report, contains information on geometric design features at more than 2,000 ramps located on the State highway system in Washington. Total accident frequencies on these ramps for the 3-year period from 1993 to 1995 were: 4,256 accidents in 1993; 4,548 accidents in 1994; and 4,902 accidents in 1995, for a total of 13,706 accidents over the 3-year period. Not all of these ramps and their associated accident experience could be used in statistical analyses because, as explained in section 3, traffic volume data are available for only a portion of the ramps. A preliminary assessment was made of the types of interchange elements that were in sufficient numbers and had sufficient data available for statistical modeling of accidents to be conducted. The selection of combinations of interchange elements, accident types, and geometric and traffic parameters is discussed in the following sections.

Types and Combinations of Interchange Elements

The Washington data base includes 2,046 ramps that are subdivided into 7,618 ramp segments. Of the 2,046 ramps, 1,405 ramps (68.7 percent) are located on Interstate freeways, and 641 ramps (31.3 percent) are located on non-Interstate freeways and arterials. The distribution of ramps by type of facility (Interstate/non-Interstate), ramp type (off-ramp/on-ramp, C/D road), and area type (rural/urban) is shown in table 9.

Table 9. Number of Ramps by Facility Type, Ramp Type, and Area Type

		Number of ramps		
Facility type	Ramp type	Rural	Urban	Total
Interstate freeway	Off-ramp	255	435	690
	On-ramp	258	429	687
	C/D road	0	28	28
	Total (%)	513 (37%)	892 (63%)	1,405
Non-Interstate freeway or arterial	Off-ramp	44	274	318
	On-ramp	45	273	318
	C/D road	0	5	5
	Total (%)	89 (14%)	552 (86%)	641
	Combined total	602 (29%)	1,444 (71%)	2,046

A decision was made during the assembly of the data base to limit the manual data reduction from interchange diagrams, described in section 4, to the 1,405 ramps on the Interstate system.

Table 10 shows the distribution of these 1,405 Interstate ramps by ramp configuration, area type, and ramp type. The first six categories of ramp configuration represent approximately 71 percent of the total number of ramps, and all analyses and statistical modeling focused on these six ramp configurations. Due to the small number of direct and semi-direct connection ramps, these two categories were pooled in all of the analyses presented in this report. When necessary in the statistical modeling because of limited sample sizes, the data for parclo loops and free-flow loops were pooled as well.

The availability of volume data was a major factor in the selection of ramps for analysis. The available ramp AADT data are all based on 1993 counts. A review of the traffic volume data showed that ramp AADT was only available for approximately 54 percent of rural ramps and 72 percent of urban ramps. In addition, since many urban ramps merge or diverge from other ramps, the available traffic volume data may not apply to all parts of all ramps. Only those ramps for which traffic volume data were available and for which that traffic volume data applied to the entire length of the ramp were included in the analysis.

The Washington freeway system includes a limited number of ramps that enter or exit from the left side of the mainline freeway lanes. Research has shown that left-side ramps often have higher accident experience than right-side ramps, and most interchanges are designed today with only right-side ramps. To prevent this design feature from becoming an uncontrolled factor in the analysis, a decision was made to exclude the few left-side ramps from all analyses.

The final selection of ramps for inclusion in statistical modeling was based on the following criteria. The ramp had to:

- Be located on the Interstate system.
- Have traffic volume data available.
- Have no merge or diverge points on the ramp at which traffic volume might change.
- Have all key cross-section geometric data available.
- Enter or exit from the right side of the mainline freeway lanes.

A total of 551 ramps met all of these criteria. The characteristics of these 551 ramps are summarized in table 11.

Table 10. Number of Interstate Ramps by Ramp Configuration, Area Type, and Ramp Type

Ramp configuration	Number of Interstate ramps								
	Rural				Urban				Total
	Off-ramps	On-ramps	C/D roads	Subtotal	Off-ramps	On-ramps	C/D roads	Subtotal	
Diamond	204	194	0	398	139	144	0	283	681
Parclo loop	14	13	0	27	7	15	0	22	49
Free-flow loop	1	3	0	4	37	44	0	81	85
Outer connection	18	14	0	32	45	31	0	76	108
Direct connection	3	5	0	8	24	27	0	51	59
Semi-direct connection	1	0	0	1	6	11	0	17	18
Buttonhook	2	2	0	4	4	5	0	9	13
Slip ramp (to/from parallel two-way frontage road)	2	2	0	4	15	15	0	30	34
Slip ramp (to/from parallel one-way frontage road)	0	0	0	0	0	2	0	2	2
C/D road	-	-	0	0	-	-	28	28	28
Other	10	25	-	35	158	135	-	293	328
Total	255	258	0	513	435	429	28	892	1,405

Table 11. **Number of Entire Ramps by Ramp Configuration, Area Type, and Ramp Type**

Ramp configuration	Number of ramps							Percentage
	Rural			Urban			All	
	Off-ramp	On-ramp	All	Off-ramp	On-ramp	All		
Diamond	119	64	183	118	94	212	395	71.7
Parclo loop	8	8	16	4	11	15	31	5.6
Free-flow loop	1	1	2	24	25	49	51	9.3
Outer connection	11	5	16	19	6	25	41	7.4
Direct or semi-direct connections	2	3	5	13	15	28	33	6.0
All ramp types	141	81	222	178	151	329	551	100
Percentage	25.6	14.7	40.3	32.3	27.4	59.7	100	

Statistical modeling was also performed for speed-change lanes. It was found that there was a total of 588 conventional deceleration lanes and 571 conventional acceleration lanes on the Interstate system in Washington. These counts do not include speed-change lanes at ramps where mainline freeway lanes are added or dropped and do not include speed-change lanes that are part of mainline freeway weaving areas connecting two ramps. As in the case of ramps, speed-change lanes were selected for analysis only if cross-section data for the speed-change lane were complete, traffic volume data were available for the adjacent ramp, and the speed-change lane was located on the right side of the freeway. A total of 277 deceleration lanes and 193 acceleration lanes met these criteria.

As explained in section 4, the Washington data base was originally structured as data records for relatively short homogeneous sections of ramps. During the data preparation, this data base was restructured to classify each segment type and to join those segments with identical (or nearly identical) cross-section geometrics. Only limited geometric data could be considered in analyses of the 551 ramps summarized above in table 11 because it is common for the cross-section geometrics of a ramp to change along its length. For example, it is not uncommon for lanes to be added or dropped on a ramp or for the lane and shoulder widths to change. In order to consider the effects on accidents of those cross-section geometric variables, it was necessary to analyze individual ramp segments rather than the ramp as a whole. The analyses focused on segments of the "ramp proper," which excluded from consideration speed-change lanes and merge, diverge, or weaving areas on the ramp. A total of 737 ramp proper segments met the criteria for inclusion in the analysis. This is larger than the number of ramps considered (551) because some ramps may have included more than one ramp proper segment that met the criteria for inclusion in the analyses. Table 12 summarizes the characteristics of the 737 ramp proper segments selected for analysis.

Table 12. Number of Ramp Proper Segments by Ramp Configuration, Area Type, and Ramp Type

Ramp configuration	Number of ramp proper segments							Percentage
	Rural			Urban			All	
	Off-ramp	On-ramp	All	Off-ramp	On-ramp	All		
Diamond	129	73	202	207	140	347	549	74.5
Parclo loop	8	9	17	5	12	17	34	4.6
Free-flow loop	1	1	2	27	29	56	58	7.9
Outer connection	11	5	16	29	11	40	56	7.6
Direct or semi-direct connection	2	3	5	15	20	35	40	5.4
All ramp types	151	91	242	283	212	495	737	100
Percentage	20.5	12.3	32.8	38.4	28.8	67.2	100	

A careful distinction in terminology is needed because both ramps as a whole and ramp segments with homogeneous cross sections have been analyzed. Throughout this report, the term "entire ramps" refers to the analysis of all or any subset of the 551 ramps for which the ramp as a whole was considered, and the term "ramp proper segment" refers to the analysis of all or any subset of the 737 ramp segments that have homogeneous cross sections.

Based on the selection criteria presented above and the availability of sufficient sample sizes in the Washington data base, statistical modeling of accidents was performed for the following combinations of interchange elements:

- Ramp proper segments (off- and on-ramps combined and off-ramps only).
- Entire ramps (off- and on-ramps combined and off-ramps only).
- Acceleration lanes.
- Deceleration lanes.
- Entire ramps plus adjacent speed-change lanes.
- Selected types of urban off-ramps: diamond, parclo loops, free-flow loops, and outer connection ramps.

Safety Measures of Effectiveness (Dependent Variables)

The available accident data base included all accidents that occurred on each ramp and speed-change lane. Accident mileposts along the ramp and speed-change lane allowed each accident to be assigned to a particular ramp segment with particular geometric features.

The analyses performed in this research focused on total accidents, including both single- and multiple-vehicle accidents. The conceptual plan developed for the FHWA Interactive Highway Safety Design Model (IHSDM) recommended that only multiple-vehicle accidents be addressed in statistical models and that the frequency of single-vehicle run-off-road accidents be predicted using an encroachment-based technique rather than a statistical model.[24] However, the statistical models in this report are based on accident frequencies including both single- and multiple-vehicle accidents.

The modeling efforts in the research addressed both total accidents (for all accident severity levels combined) and fatal and injury accidents. Property-damage-only (PDO) accidents were not analyzed separately because of concerns about incompleteness of accident reporting. It might have been desirable to evaluate PDO tow-away accidents (accidents in which one or more of the involved vehicles was towed from the scene) or fatal-plus-injury-plus-tow-away accidents, but, unfortunately, the available accident data for Washington do not explicitly identify tow-away accidents. In summary, the two dependent variables most extensively used in the modeling effort were:

- Total accidents of all severity levels that occurred during the 3-year study period.

- Fatal and injury accidents in the 3-year period.

In most cases, each analysis was performed for both dependent variables. However, in a few cases where the available sample size of fatal and injury accidents was limited, models were developed for total accidents only.

One preliminary analysis effort toward better understanding the nature of ramp and speed-change lane accidents was to develop an accident typology (i.e., to examine the distribution of accident types and circumstances). Appendixes B and C present the results of this effort. Appendix B presents accident severity distributions by ramp segment type; appendix C presents accident type distributions by ramp segment type. The results presented in these appendixes are discussed in greater detail in the next section on accident frequency distributions.

During the review of the interchange diagrams described in section 4, it was recognized that there was no explicit method to identify ramp-related accidents that occurred at crossroad ramp terminals. Ramp mileposting was then used to identify accidents that occurred at:

- Crossroad ramp terminals with stop signs or signals.
- Crossroad ramp terminals with free-flow connections.
- Ramp terminals located on parallel frontage roads.

The accidents so identified occurred within the curb-line limits of the ramp terminal. These classifications were used in the development of appendix C. However, no direct method could be found to identify accidents that occurred on the ramp proper, away from the crossroad ramp terminal, but that were related to the operation of the crossroad ramp terminal.

It was noted in the review of the data in appendix C that a substantial proportion of the accidents on off-ramps were rear-end accidents. It was postulated that many of the accidents might be related to collisions at the rear of a queue backed up from the crossroad ramp terminal. If so, it would be potentially misleading to attribute these accidents to the geometrics of the ramp or ramp proper segment on which they occurred, rather than to the ramp terminal itself.

To investigate this issue, a sample of 100 rear-end accidents on ramps was selected, and the hard-copy police accident reports for those accidents were obtained and reviewed. Only 5 of these 100 accidents involved rear-end collisions that were not related to the operation of the crossroad ramp terminal. Therefore, to avoid confounding analysis results for ramps with accidents related to the ramp terminal rather than to the ramp itself, it was decided to perform selected analyses, excluding all rear-end accidents from the dependent variable.

Selection of Geometric and Traffic Parameters of Interest (Independent Variables)

For each of the interchange elements mentioned above, a preliminary selection of geometric and traffic variables as candidate independent variables for the statistical modeling activities was made from among the variables included in the existing Washington data base (see table 5) and the additional variables obtained from the interchange diagrams (see table 7), based on engineering knowledge and statistical criteria. The new variables shown in table 8 were added at a later stage in the analysis when they became available. A few of the candidate independent variables were quantitative variables measured on a continuous scale (e.g., AADT, lane width, or shoulder width); however, most of the candidate independent variables were categorical (i.e., having a finite number of discrete levels). Appendix A identifies whether each candidate variable was continuous or categorical in nature and also identifies the levels for each categorical variable.

To determine which of the candidate independent variables were suitable for use in the statistical modeling activities, frequency tables were generated for each candidate variable. When the available sample size for any given level of any particular variable was too small, one of the following courses of action was taken: (1) the observations (i.e., ramps, ramp segments, or speed-change lanes) at that level were pooled with an adjacent level (where this made engineering sense) or (2) the observations at that level were deleted. After all levels of all categorical variables were reviewed, the process was repeated to ensure that all the sample sizes were now sufficient for data analysis. Any further minor changes found to be necessary were then made. If, for a particular categorical independent variable, all but a small number of the observations fell in a single category, then that variable had to be excluded from the modeling effort, because no effect can be determined unless a substantial number of observations fall in each level.

Ramp AADT data were included in all statistical models. For selected analyses, the AADT for the mainline freeway section adjacent to the ramp or speed-change lane was considered for inclusion in the models as well.

Accident Rates and Frequency Distributions

Of the 1,405 Interstate freeway ramps in the Washington data base, 690 were off-ramps and 687 were on-ramps (see table 9). After excluding all left-side ramps and those ramps without available traffic volume data, a total of 356 off-ramps and 287 on-ramps remained in the data base, for a total of 643 entire ramps.

Subsequent analyses focused only on ramp configurations that were present in sufficient numbers for a proper analysis to be conducted. There were five such ramp configurations:

- Diamond.
- Parclo loop.
- Free-flow loop.
- Outer connection.
- Direct or semi-direct connection.

Of the 643 ramps discussed above, 551 ramps (86 percent) had 1 of these 5 ramp configurations. For each ramp configuration, an average accident rate was computed based on the number of accidents in the 3-year period, the estimated AADT, and the length of each ramp. The 3-year accident frequencies and accident rates corresponding to these 643 ramps are shown in tables 13 and 14 for total and fatal and injury accidents, respectively. The tables identify, by means of a footnote, those accident rates that should be interpreted cautiously because they are based on fewer than 10 accidents.

Tables 13 and 14 show patterns in accident rates that are similar to those from the literature shown in table 3. The data show that off-ramps generally have higher accident rates than on-ramps, and diamond ramps (which are relatively straight) have lower accident rates than loop ramps (which are curved). There appears to be an exception for urban, free-flow loop ramps, generally found in cloverleaf interchanges, which had lower accident rates than diamond ramps for both off-ramps and on-ramps.

The 3-year accidents were further examined at each (homogeneous) ramp segment type for eight selected ramp configurations:

- Rural diamond off-ramps.
- Rural diamond on-ramps.
- Urban diamond off-ramps.
- Urban parclo loop off-ramps.

Table 13. Total Accident Frequencies and Rates for Entire Ramps by Ramp Configuration, Area Type, and Ramp Type (1993-1995)

Ramp configuration	Rural		Urban		Total
	Off-ramp	On-ramp	Off-ramp	On-ramp	
Number of ramps[a]					
Diamond	119	64	118	94	395
Parclo loop	8	8	4	11	31
Free-flow loop	1	1	24	25	51
Outer connection	11	5	19	6	41
Direct or semi-direct connection	2	3	13	15	33
All ramps	141	81	178	151	551
Number of total accidents (1993-1995)					
Diamond	92	34	423	284	833
Parclo loop	12	7	16	43	78
Free-flow loop	0	0	56	46	102
Outer connection	15	3	107	14	139
Direct or semi-direct connection	4	3	50	18	75
All ramps	123	47	652	405	1,227
Total accident rate (accidents per MVM)[b]					
Diamond	4.61	2.34	4.67	4.42	-
Parclo loop	9.77	4.09[c]	7.46	11.68	-
Free-flow loop	0.00[c]	0.00[c]	3.24	2.49	-
Outer connection	4.01	0.83[c]	6.19	1.98	-
Direct or semi-direct connection	4.71	5.11[c]	3.42	0.79	-

Conversion: 1 mi = 1.61 km.

[a] Includes all Interstate ramps with nonmissing AADT data for the five specific ramp configurations shown. Excludes all left-side ramps.

[b] Weighted average computed by dividing the sum of the accident frequencies for all ramps by the sum of the exposure in million vehicle-miles (MVM) of travel for all ramps.

[c] Based on fewer than 10 accidents.

Table 14. Fatal and Injury Accident Frequencies and Rates for Entire Ramps by Ramp Configuration, Area Type, and Ramp Type (1993-1995)

Ramp configuration	Rural		Urban		Total
	Off-ramp	On-ramp	Off-ramp	On-ramp	
Number of ramps[a]					
Diamond	119	64	118	94	395
Parclo loop	8	8	4	11	31
Free-flow loop	1	1	24	25	51
Outer connection	11	5	19	6	41
Direct or semi-direct connection	2	3	13	15	33
All ramps	141	81	178	151	551
Number of fatal and injury accidents (1993-1995)					
Diamond	36	16	190	116	358
Parclo loop	4	2	12	21	39
Free-flow loop	0	0	26	15	41
Outer connection	6	1	45	6	58
Direct or semi-direct connection	2	3	27	5	37
All ramps	48	22	300	163	533
Fatal and injury accident rates (accidents per MVM)[b]					
Diamond	1.81	1.10	2.10	1.81	-
Parclo loop	3.26[c]	1.17[c]	5.60	5.71	-
Free-flow loop	0.00[c]	0.00[c]	1.50	0.81	-
Outer connection	1.60[c]	0.28[c]	2.60	0.85[c]	-
Direct or semi-direct connection	2.35[c]	5.11[c]	1.85	0.22[c]	-

Conversion: 1 mi = 1.61 km.

[a] Includes all Interstate ramps with nonmissing AADT data for the five specific ramp configurations shown. Excludes all left-side ramps.

[b] Weighted average computed by dividing the sum of the accident frequencies for all ramps by the sum of the exposure in million vehicle-miles (MVM) of travel for all ramps.

[c] Based on fewer than 10 accidents.

- Urban free-flow loop off-ramps.
- Urban outer connection off-ramps.
- Urban direct or semi-direct connection ramps.
- Urban C/D roads.

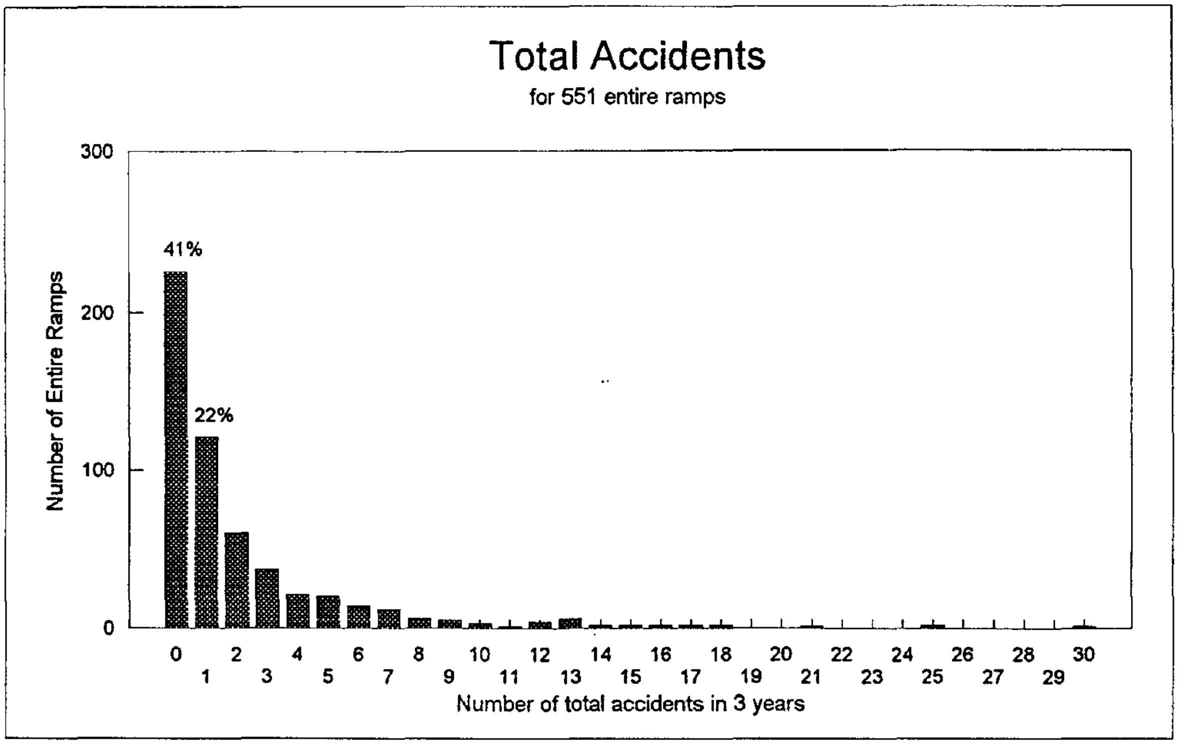
Appendix B presents accident severity distributions (fatal, injury, and property-damage-only accidents) by ramp segment type for these selected ramp configurations. Appendix C presents accident-type distributions (single-vehicle noncollision, single-vehicle collision, and multiple-vehicle accidents) by ramp segment type for these same ramp configurations.

Prior to beginning the statistical modeling activities, the general shape of each accident frequency distribution (total and fatal and injury) was assessed for entire ramps and for ramp proper segments. This was done visually by plotting the data for the 3-year totals and by calculating basic statistics.

Total and fatal and injury accident frequencies are plotted in figures 5 and 6 for entire ramps and for ramp proper segments, respectively. Figures 7 and 8 further juxtapose accident frequencies at ramp proper segments between off-ramps and on-ramps. The plots shown in figures 5 through 8 highlight the shapes of accident frequencies. With a large number of ramps or ramp proper segments with no or very low accident experience, these distributions tend to follow a Poisson distribution. Similar frequency distribution plots are shown in figures 9 through 15 in appendix D for the following interchange elements:

- Ramp proper segments, off-ramps only (rear-end accidents excluded from frequency distributions).
- Entire ramps, off-ramps only (rear-end accidents excluded from frequency distributions).
- Speed-change lanes (total and fatal and injury accidents).
- Entire ramps plus adjacent speed-change lane (total and fatal and injury accidents).
- Urban diamond off-ramps (total and fatal and injury accidents).
- Urban parclo and free-flow loop off-ramps (total and fatal and injury accidents).
- Urban outer connection off-ramps (total and fatal and injury accidents).

In addition, 1-year accident frequencies are presented in figures 16 and 17 in appendix D for the 551 entire ramps and the 737 ramp proper segments, respectively, studied in this report, comparing the 3 years of data for 1993 through 1995.



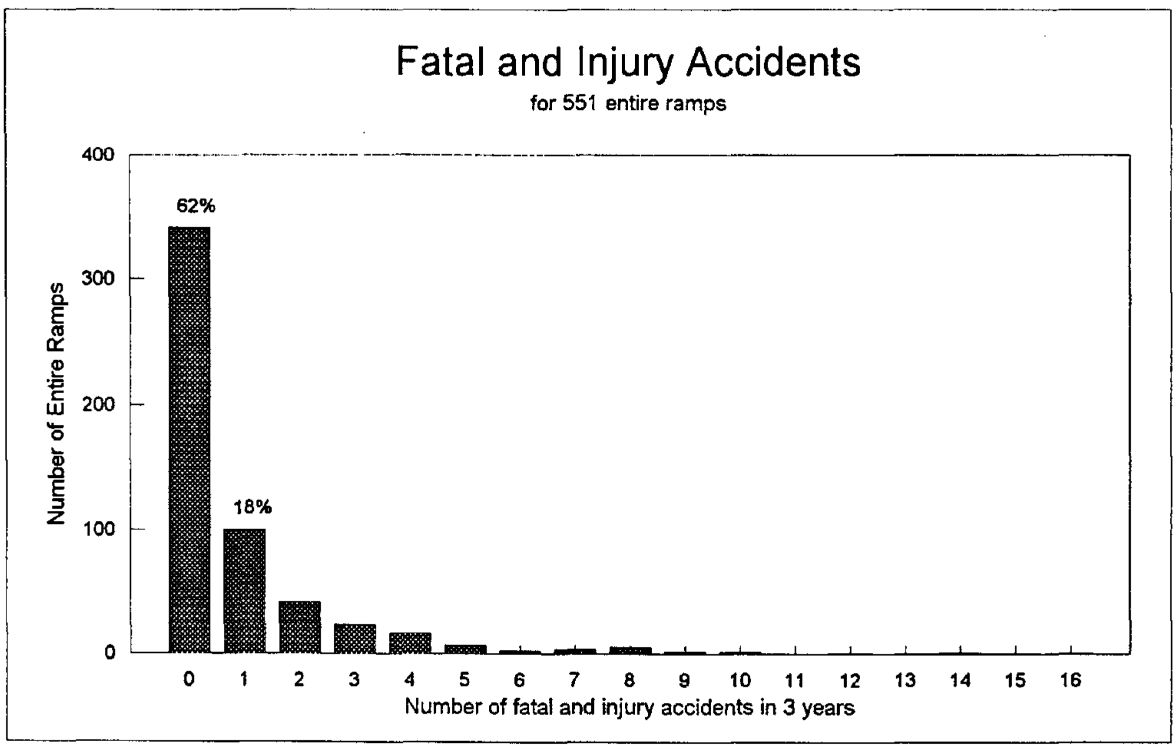
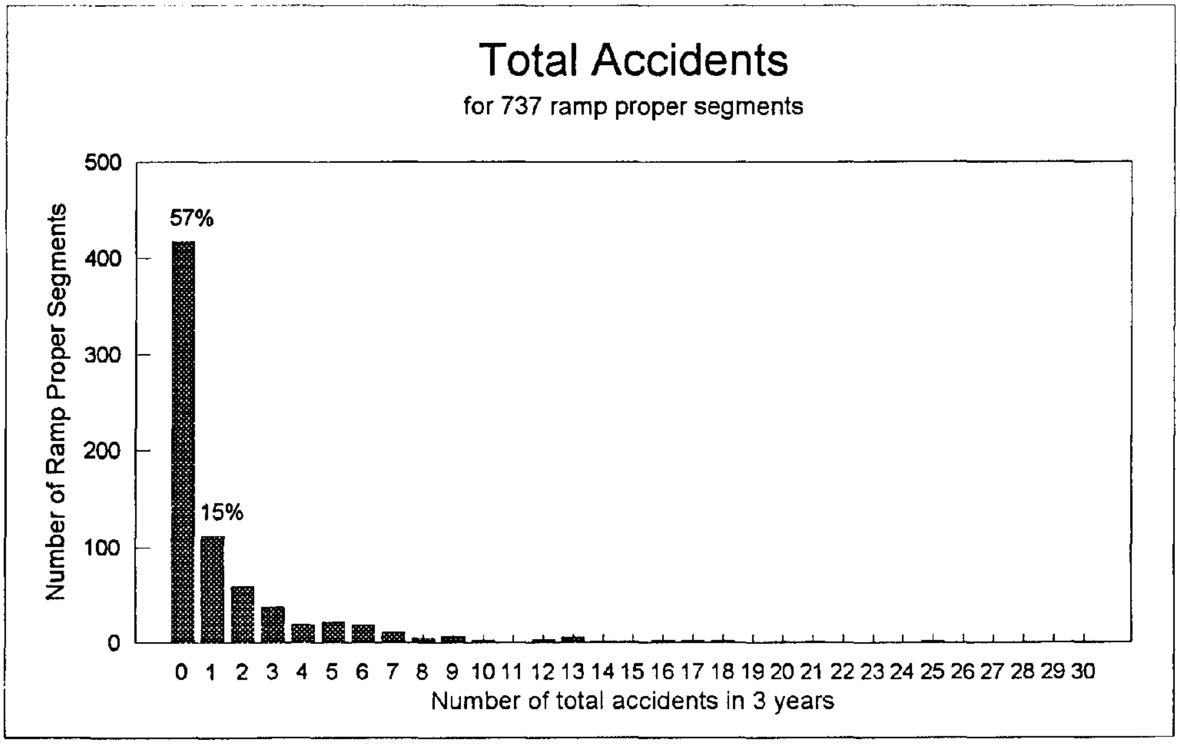


Figure 5. Accident Frequency Distributions for Entire Ramps



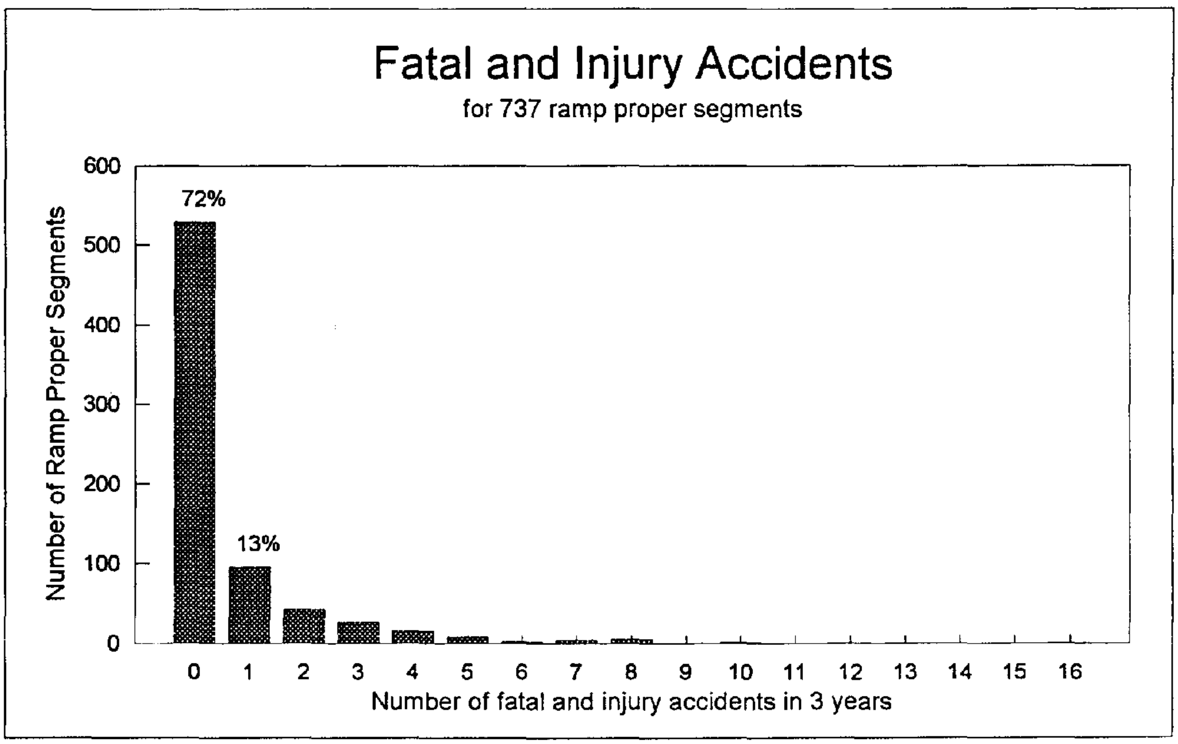
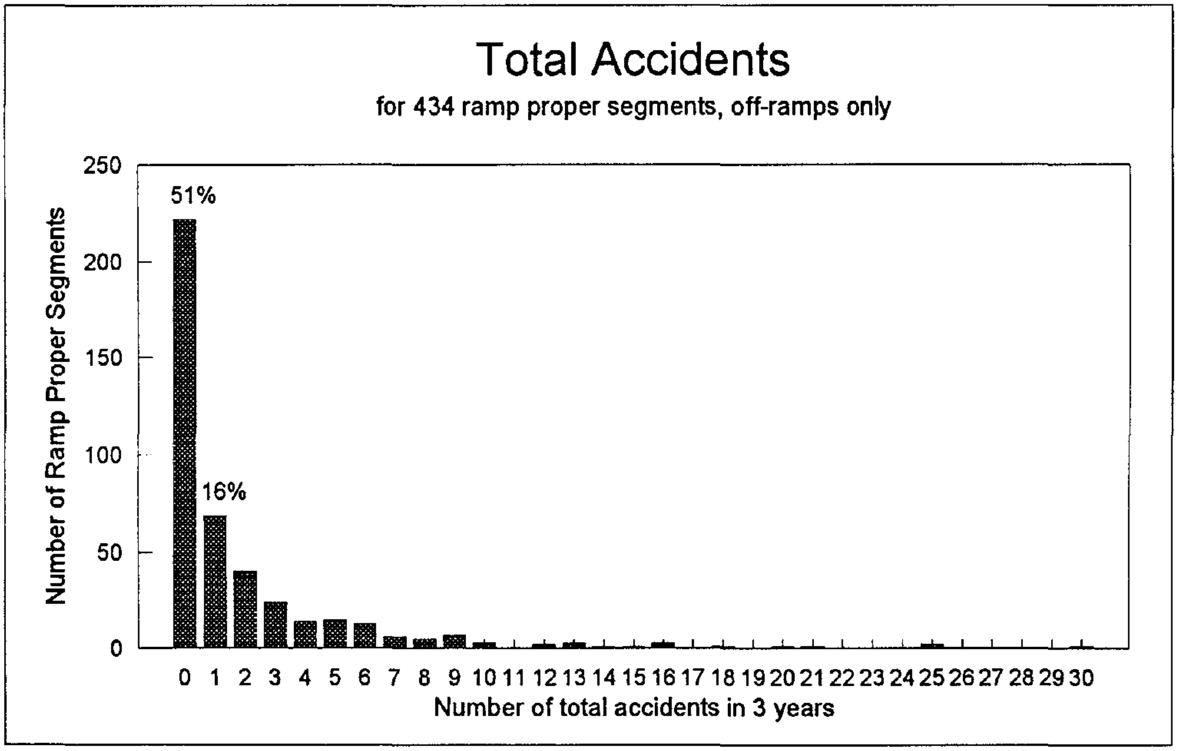


Figure 6. Accident Frequency Distributions for Ramp Proper Segments



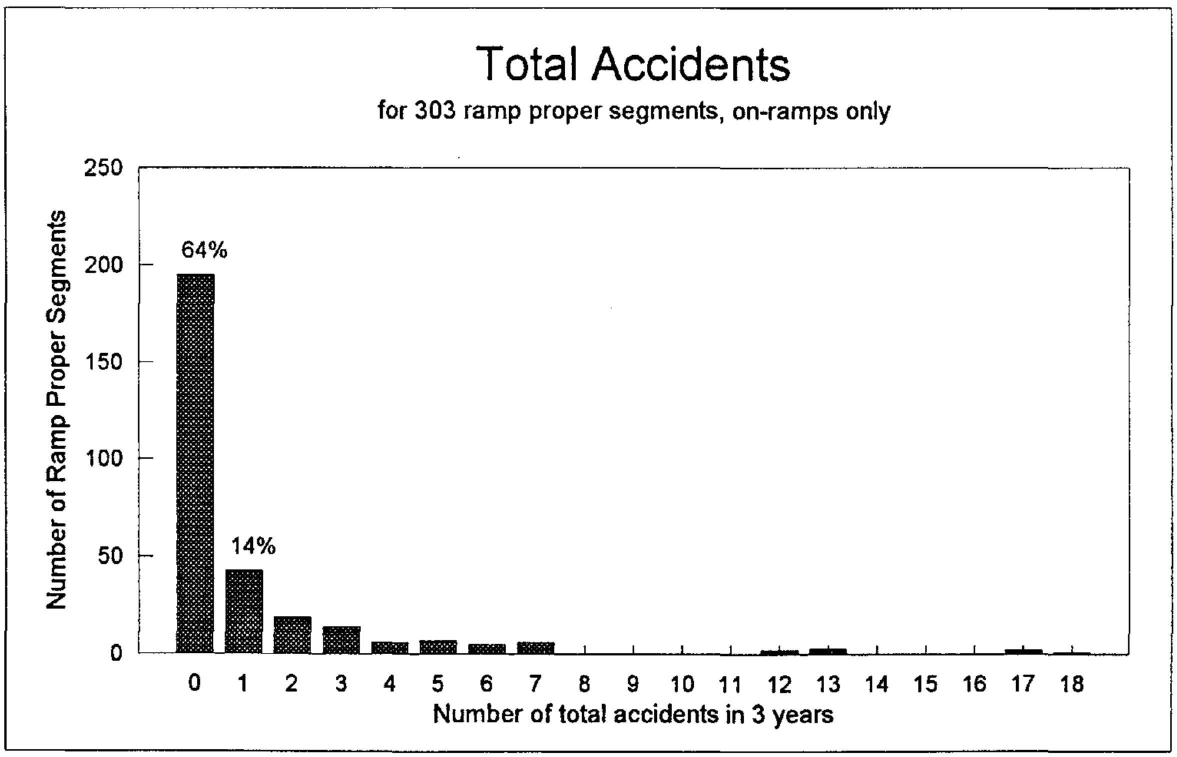
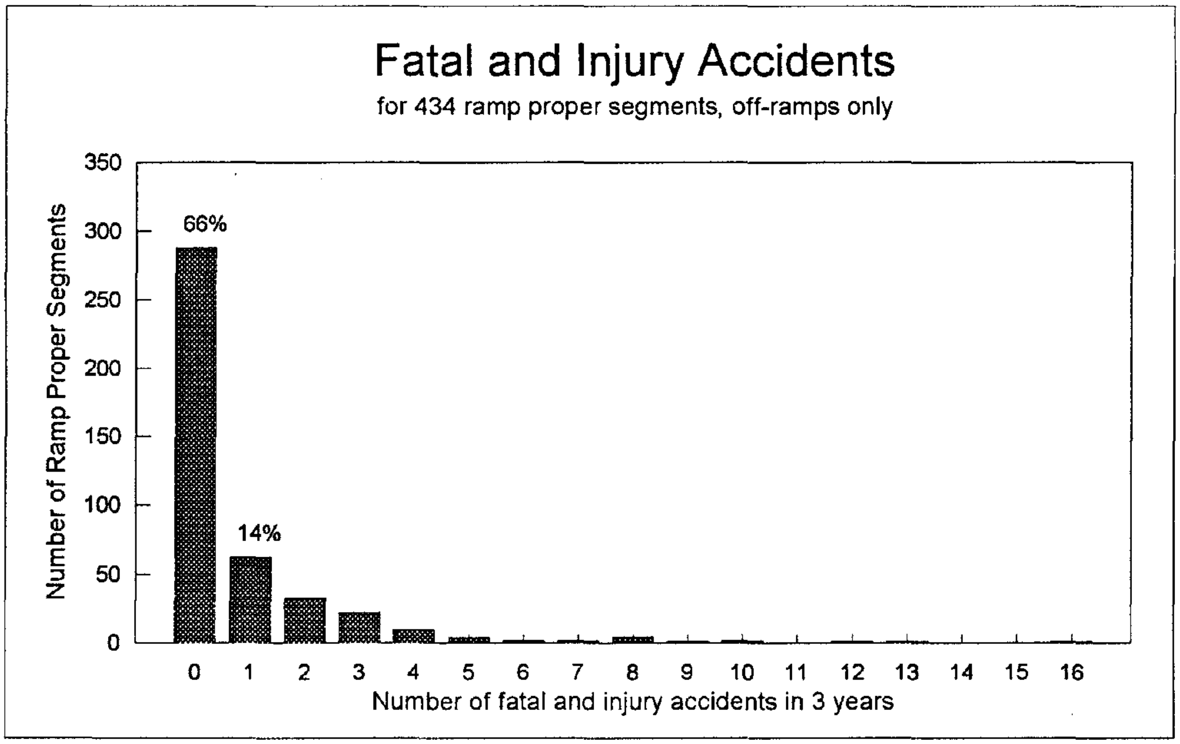


Figure 7. Total Accident Frequency Distributions for Ramp Proper Segments: Off-Ramps vs. On-Ramps



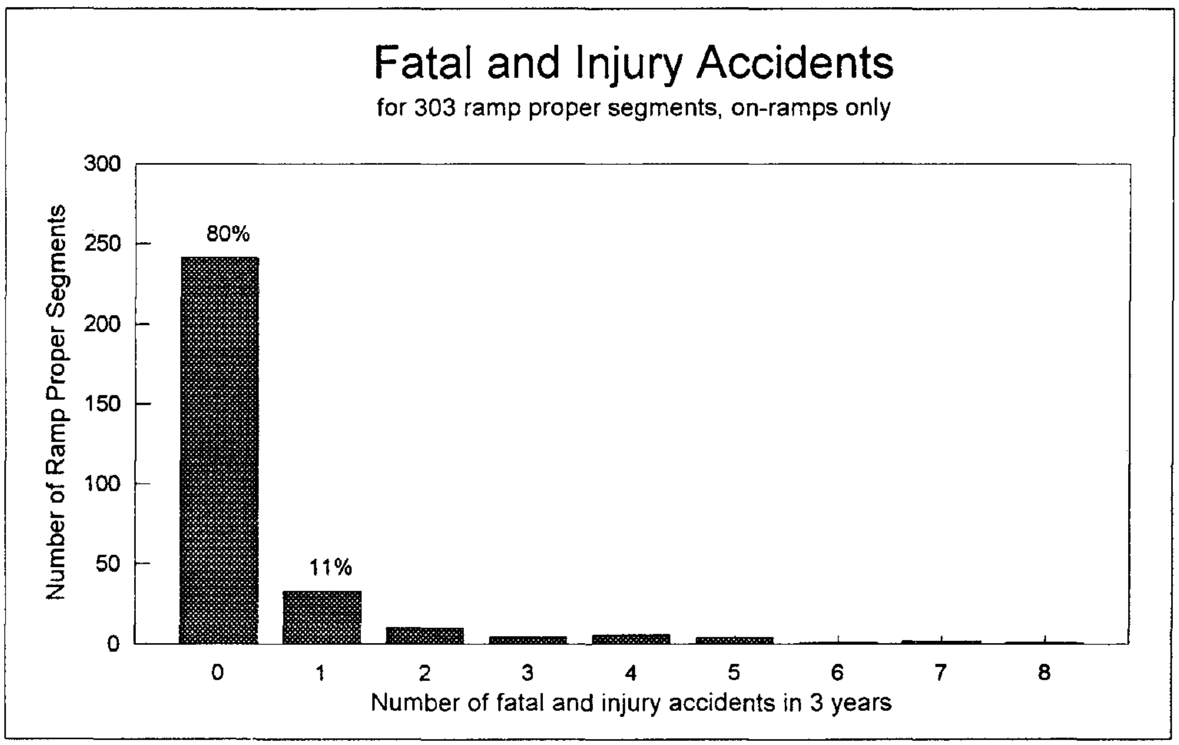


Figure 8. Fatal and Injury Accident Frequency Distributions for Ramp Proper Segments: Off-Ramps vs. On-Ramps

Loglinear Regression Models

Several candidate analysis methods were investigated for application to the accident frequencies in the various combinations of interchange elements considered in this study. The analysis approach was driven by both the actual distribution of the accident frequencies and by recommendations and evolving practices in the field of accident data analysis (see section 2). The frequency distributions of total and fatal and injury accidents in the 3-year study period are shown in figures 5 through 8 above and in appendix D.

A recurrent challenge in accident analysis of highway elements is that most sites experience very few accidents. The percentages of interchange elements with zero or one accident in the 3-year period are:

Interchange element combination (sample size)	Percentage of interchange elements with 0 or 1 accident in 3-year period	
	Total	Fatal and injury
Ramp proper segments (737)	72	85
Ramp proper segments–off-ramps (434)	67	81
Ramp proper segments–on-ramps (303)	79	90
Entire ramps (551)	63	80
Acceleration lanes (193)	75	84
Deceleration lanes (277)	90	95
Entire ramps, including adjacent speed-change lanes (467)	53	73
Urban diamond off-ramps (118)	42	64
Urban parclo loops (off-ramps) (4)	75	75
Urban free-flow loops (off-ramps) (24)	46	63
Urban outer connection off-ramps (19)	11	53

For most types of interchange elements, most sites experienced no more than one accident over the 3-year period. This is true especially for fatal and injury accidents. The large number of sites with zero or one accident over the 3-year study period, combined with the highly skewed distributions of accident frequencies (see figures 5 through 8 and appendix D), made it difficult to fit a statistical distribution model to the data. Modeling accidents to the small data sets for urban parclo and free-flow loop off-ramps and to urban outer connection off-ramps was particularly difficult given the erratic shape of their distributions as shown in appendix D.

Loglinear regression models were applied to the accident data in this study. They included Poisson and negative binomial regression models. Although Poisson regression models were applied in preliminary analyses of the data, it was found that all models were improved by applying the negative binomial models, and only their results are shown in this report. Statistical background on both the Poisson and negative binomial models is provided next.

Consider a set of n interchange elements from a given category (e.g., ramp proper segments, entire ramps). Associated with each element i is a set of q parameters (X_{i1}, X_{i2}, ..., X_{iq}) describing the geometric design, traffic volume, and other related characteristics of that element. Let the number of accidents occurring at the ith element during a 3-year period be denoted by Y_i, where i=1, ..., n. Next, denote by y_i the actual observation of Y_i during the 3-year period, i.e., $y_i = 0, 1, 2, \ldots$ and i=1, ..., n.

The objective of a statistical model is to provide a relationship between a function of the expected number of accidents, $E(Y_i)=\mu_i$, at the ith element and the q parameters, X_{i1}, X_{i2}, ..., X_{iq}. This relationship can be formulated through a general linear model of the form:

$$\text{Function}(\mu_i) = \beta_0 + \beta_1 X_{i1} + \ldots + \beta_q X_{iq} \tag{2}$$

where the regression coefficients, β_0, β_1, β_2, ... β_q, are to be estimated from the data. The estimation procedure used to obtain the regression coefficients is dependent on the assumption made about the distribution of the Y_i.

Note: Throughout this report, all logarithms are natural logarithms and are denoted by *log* in all equations.

In the present study, two loglinear models were considered for application to the accident frequencies at interchange elements—the Poisson and the negative binomial models. Their general forms are described below.

Poisson Regression Model

When the average number of accidents at a ramp is small, the assumption of a lognormal distribution [i.e., the assumption that $\log(Y_i)$ follows a normal distribution] is not valid. The Poisson model then becomes a natural choice as it models the occurrence of rare discrete events well. The relationship between the expected number of accidents occurring at the ith ramp and the q ramp parameters, X_{i1}, X_{i2}, ..., X_{iq}, is assumed to be of the form:

$$\log(\mu_i) = \beta_0 + \sum_{j=1}^{q} \beta_j X_{ij} \tag{3}$$

The assumption is made that the number of accidents, Y_i, follows a Poisson distribution with mean μ_i. That is, the probability that a ramp defined by a known set of predictor variables, $X_{i1}, X_{i2}, ..., X_{iq}$, experiences y_i accidents can be expressed as:

$$P(Y_i = y_i; \mu_i) = \mu_i^{y_i} e^{-\mu_i} / y_i! \quad (4)$$

where $y_i!$ denotes the factorial of y_i.

Note that the Poisson distribution has only one parameter, namely its mean, μ_i, with the limitation that the variance, σ^2, equals the mean of the distribution. Under the assumption of a Poisson distribution, the regression coefficients, β_0, β_1, β_2, ... β_q, are estimated by the maximum likelihood method. The asymptotic normality of maximum likelihood estimates is used to obtain tests of significance of the parameters and goodness-of-fit measures for the models.

In the case of a Poisson distribution, the model coefficients are estimated by the maximum likelihood method. The likelihood function is the product of the terms in equation (3) over all n interchange elements in the category of elements of interest. This function is viewed as a function of the parameters μ_i and, through them, the parameters β_i. The parameters are estimated by maximizing the likelihood, or more usually, by maximizing the logarithm of the likelihood (denoted by log likelihood). Equivalently, the estimation can be done by minimizing the negative of the log likelihood. The log likelihood is given by the equation:

$$\log(L) = \sum_{i=1}^{n} [y_i \log(\mu_i) - \mu_i - \log(y_i!)] \quad (5)$$

The maximum value possible for the likelihood for a given data set occurs if the model fits the data exactly. This occurs if μ_i is replaced by y_i in equation (2). The difference between the log-likelihood functions for two models is a measure of how much one model improves the fit over the other. A special case of this was defined by Nelder and Wedderburn as the **deviance**.[25] Specifically, they defined the deviance as minus twice the log of the ratio of the likelihood for a model to the maximum likelihood. For the Poisson distribution, the deviance takes the form given in equation (6):

$$D = 2[\sum_{i=1}^{n} y_i \ln(y_i/\mu_i) - \sum_{i=1}^{n} (y_i - \mu_i)] \quad (6)$$

where the second term is identically zero in the usual case that the model includes a constant or intercept term. The deviance so defined is measured from that of the saturated model and so terms involving constants, the data alone, or a scale factor alone are omitted. For a sample of n independent observations, the deviance for a model with p degrees of freedom (that is, p parameters estimated, including the mean or constant) has residual (n − p) degrees of freedom. When the residual degrees of freedom of the current model are approximately equal to the deviance, it is unlikely that further fitting of systematic components is worthwhile.

Since the deviance is effectively −2 times the log of the likelihood ratio, it has an asymptotic distribution that is chi-squared with degrees of freedom equal to n − p, where n is the number of interchange elements and p is the number of parameters estimated. This result can be used to construct a goodness-of-fit test for the model. In addition, by forming the ratio of the deviance to its residual degrees of freedom, an estimate of the scale constant can be found. For the Poisson distribution, this should theoretically be equal to one. Values substantially in excess of one reflect overdispersion of the data.

Negative Binomial Regression Model

As mentioned above, a limitation of the Poisson distribution is that the mean equals the variance of the distribution. Previous work in the field of accident research has shown that this is not always the case. Suppose a Poisson model is used for modeling accidents and the variance (or dispersion) of the data exceeds the estimated mean of the accident data distribution. The data are then said to be overdispersed, and the underlying assumption of the variance being equal to the mean for the Poisson distribution is violated. The negative binomial, which is a discrete distribution, provides an alternative model to deal with overdispersion in count data such as accident frequencies.

Unlike the Poisson distribution, the negative binomial distribution has two parameters. As for the Poisson model above, the relationship between the expected number of accidents occurring at the ith element and the q parameters, $X_{i1}, X_{i2}, ..., X_{iq}$, is still taken to be:

$$\text{Function}(\mu_i) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_q X_{iq} \tag{7}$$

However, the assumption is now made that the number of accidents, Y_i, follows a negative binomial distribution with parameters α and k (with $0 \le \alpha \le 1$ and $k \ge 0$). That is, the probability that a ramp defined by a known set of predictor variables, $X_{i1}, X_{i2}, ..., X_{iq}$, experiences $Y_i = y_i$ accidents can be expressed as:

$$\Pr\left(Y_i = y_i;\ \alpha, k\right) = \frac{\left(y_i + k - 1\right)!}{y_i!\ (k - 1)!}\ \frac{\alpha^{y_i}}{(1 + \alpha)^{y_i + k}}\ ;\quad y_i = 0, 1, 2 \ldots \tag{8}$$

where $y_i!$ denotes the factorial of y_i.

The mean and variance of the negative binomial distribution of accident counts can then be expressed in terms of the parameters α and k as follows:

$$\text{mean} = E(Y) = \mu_i = k\alpha, \text{ and} \tag{9}$$

$$\text{variance} = Var(Y) = k\alpha + k\alpha^2 = \mu_i + \mu_i^2/k \tag{10}$$

The term μ_i can be referred to as the Poisson variance function and μ_i^2/k as the extra component arising from combining the Poisson distribution with a gamma distribution for the mean to obtain the negative binomial distribution. The parameter k is not known a priori, but can be estimated so that the mean deviance becomes unity or the Pearson chi-square statistic equals its expectation (i.e., equals its degrees of freedom).[26]

As for the Poisson model, the model regression coefficients, β_0, β_1, β_2, ... β_q, are estimated by the method of maximum likelihood. The asymptotic normality of maximum likelihood estimates is used to obtain tests of significance of the parameters and goodness-of-fit measures for the models. The estimation of the model parameters can be done by minimizing the negative of the log likelihood. For the negative binomial distribution, the log likelihood is given by the equation:

$$\log(L) = \sum_{i=1}^{n} y_i \log[\alpha/(1+\alpha)] - nk\log(1+\alpha) + \left(\text{function of } y_i, k\right) \tag{11}$$

Substituting $\alpha = \mu_i/k$ into the term $\log[\alpha/(1+\alpha)]$ of equation (11), gives the function

$$\log\left(\frac{\mu_i}{\mu_i + k}\right) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_q X_{iq} \tag{12}$$

The parameters α and k of the negative binomial distribution can thus be indirectly estimated using a generalized linear model and, by means of equations (7) and (12), the model regression coefficients, β_0, β_1, β_2, ... β_q, are obtained. SAS provides a procedure—PROC GENMOD (a generalized linear model procedure)—that can be used to estimate the regression coefficients by implementing equations (8) and (12).[27]

Treatment of Traffic Volume Variables in Loglinear Regression Models

In all models in this study, the natural logarithm of the AADT was used. The AADT applies to the interchange elements (e.g., ramp proper segment, entire ramp) considered in the models. In the special case of modeling accidents at the combination of a ramp and its adjacent speed-change lane, the mainline freeway AADT was also included in the models, again in the logarithmic form. This parallels the approach taken by other researchers where accident counts rather than accident rates are modeled. On the log-scale, the ratio of accident counts over AADT becomes the difference between log(accident counts) and log(AADT). The difference here is that it is assumed that the coefficient of log(AADT) is not equal to one, but rather is a coefficient to be estimated through analysis. Thus, in the Poisson and negative binomial models described above, X_1 generally represents log($AADT_{ramp}$). The multiplicative model relating the expected accident counts and independent variables can thus be rewritten as:

$$\text{function}(\mu_i) = \exp(\beta_0)\left(AADT_{ramp}\right)^{\beta 1} \exp(\beta_2 X_{i2}) \bullet \ldots \bullet \exp(\beta_q X_{iq}) \qquad (13)$$

Accident Modeling Results

The following sections present the modeling results separately for each of the seven selected interchange elements or combinations of elements:

- Ramp proper segments (including all accidents).
- Ramp proper segments, off-ramps only (excluding rear-end accidents).
- Entire ramps (including all accidents).
- Entire ramps, off-ramps only (excluding rear-end accidents).
- Acceleration and deceleration lanes, separately.
- Entire ramps plus adjacent speed-change lane.
- Selected urban off-ramp:
    - — diamond ramps
    - — parclo loops
    - — free-flow loops
    - — outer connection ramps

All of the models presented below are based on data for only the five ramp configurations shown in tables 13 and 14. Some analyses were limited to only one or more of these five ramp configurations. Other ramp configurations, such as buttonhook ramps and slip ramps to parallel frontage roads, were not considered in the modeling because the available sample sizes of ramps and accidents were too limited.

Ramp Proper Segments (Including All Accidents)

An analysis of ramp proper segments was conducted first, because only a segment-based analysis can include many of the key cross-section geometric variables of interest. These variables cannot be included in the analysis of entire ramps, which is presented later, because the cross-section geometrics often vary over the length of the ramp.

The first step in the analysis of ramp proper segments was to select candidate independent variables for that particular group of interchange elements. Both engineering judgment and sample size requirements for the levels of each candidate variable were involved in the decision of whether a particular variable was included in the modeling effort. In addition to a number of variables chosen for consideration as main effects, the interaction between ramp type (off/on) and ramp configuration was considered in the modeling. For two categorical variables, the levels were pooled across those categories with only small numbers of ramp segments. These were:

- Ramp configuration. Parclo loops (4.7 percent of the available data) and free-flow loops (7.9 percent) were grouped into a single loop/ramp category, due to mathematical difficulties in estimating the interaction term of the model.
- Number of lanes. The number of lanes was grouped into two categories: ramp segments with one lane (83.6 percent) or ramp segments with two or more lanes (16.4 percent). Ramp segments with two lanes (14.7 percent) and those with three lanes (1.8 percent) were pooled because the limited data for ramp segments with three lanes could not be evaluated by itself.

Table 15 identifies the independent variables and the interaction selected for modeling accident frequencies at the 737 ramp proper segments. The independent variables considered were:

- Ramp AADT.
- Average lane width.
- Number of lanes.
- Right shoulder width.
- Left shoulder width.
- Segment length.
- Area type (rural/urban).
- Ramp type (off/on).
- Ramp configuration.
- Ramp type by ramp configuration interaction.

The dependent variables are 3-year accident frequencies by severity level for accidents of all types. This table also provides descriptive statistics for three types of variables: (1) total and fatal and injury accident frequencies in the 3-year study period (i.e., the dependent variables for the modeling effort); (2) all continuous independent variables considered; and (3) all categorical independent variables considered. Minimum, mean, median, and maximum values are given for the first two types of variables. Three-year totals are given for all accident frequencies, and the total length of ramp proper segments included in the models is given as well. For all categorical variables and for the interaction term, the percent of ramp proper segments within each level is given.

Next, using all the continuous and categorical variables and interaction term shown in table 15, a negative binomial (NB) regression model was fit separately to the data for total and fatal and injury accidents. These models are called full models because all of the candidate independent variables are included.

Table 15. Descriptive Statistics for Ramp Proper Segments

Parameter	Level	Percent of ramp segments	Minimum	Mean	Median	Maximum	Total
Number of ramp segments: 737							
Total accidents: 1993 through 1995 combined			0	1.70	0	30	1,253
Fatal and injury accidents: 1993 through 1995 combined			0	0.72	0	16	530
Ramp AADT (veh/day)			27	5,158	4,376	24,365	
Average lane width (ft)			10	15.40	14	39	
Right shoulder width (ft)			0	7.75	8	16	
Left shoulder width (ft)			0	4.10	4	16	
Segment length (mi)			0.01	0.12	0.12	0.69	90.68
Area type	Rural	32.8					
	Urban	67.2					
Ramp configuration: off-ramps	Diamond	45.6					
	Loop	5.6					
	Outer connection	5.4					
	Direct or semi-direct connection	2.3					
	All off-ramps	58.9					
Ramp configuration: on-ramps	Diamond	28.9					
	Loop	6.9					
	Outer connection	2.2					
	Direct or semi-direct connection	3.1					
	All on-ramps	41.1					
Number of lanes	1	83.6					
	2 or more	16.4					

Conversion: 1 ft = 0.305 m, 1 mi = 1.61 km.

The NB regression analyses were performed using the GENMOD procedure with the NB distribution and the appropriate deviance functions and variance adjustment factor, k, of the SAS statistical software package.[26,27] This procedure fits generalized linear models as defined by Nelder and Wedderburn and uses the maximum likelihood procedure to estimate the values of the regression coefficients. The GENMOD procedure can be customized for many distributions, including the NB distribution used here.

The significance of each regression coefficient was examined. Generally, the analysis results for the full model found some independent variables to be statistically significant at the 10-percent significance level and other variables not to be statistically significant. To obtain the best estimates of the regression coefficients for the independent variables that are statistically significant and the best estimate of the goodness of fit of the model as a whole, the NB regression model was fit again, including only those independent variables that were found to be statistically significant in the full model (i.e., the independent variables and/or interaction that were found not to be statistically significant were dropped). This model is called the reduced model.

The choice of a 10-percent significance level (or a 90-percent confidence level) reflects a moderately restrictive approach in the selection of independent variables that might significantly contribute to the variability in accidents. Many previous accident research efforts have used the more restrictive 5-percent significance level, which would generally include fewer independent variables in the predictive models. Thus, the choice of a 10-percent significance level retained some variables that would not have been statistically significant at the 5-percent level. Since this step in the effort to identify statistically significant variables serves primarily as a screening step, this approach was considered appropriate. The text of the report identifies those independent variables that were found to have significance levels between 10 percent and 20 percent. This significance level, α, is shown for each such variable. In selected cases in which it was considered appropriate, such variables were included in models presented in this report; however, the contractors generally tried to avoid including independent variables with significance levels above 10 percent.

Throughout the report, the following format was adopted in presenting the modeling results. The list of all the independent variables, including interactions, considered in the full models is shown in the descriptive statistics table in each section of the report. The subsequent model diagnostics table in each section of the report presents model diagnostics for both the full and reduced models. In particular, the model diagnostic table identifies the number of parameters (i.e., independent variables) retained in the reduced models as well as identifying any interaction effects included in the reduced models. The specific variables and interactions remaining in the reduced model are shown in the regression results tables for total and fatal and injury accidents, respectively.

Table 16 shows various model diagnostics for the full and reduced NB regression models. The model diagnostics, which are shown separately in table 16 for each type of accident considered, include both basic statistics and goodness-of-fit criteria.

Table 16. **Model Diagnostics for Total and Fatal and Injury Accidents on Ramp Proper Segments**

Negative Binomial Regression Models	Full model[a]	Reduced model[a]
Total accidents (3-year period)		
Number of ramp segments (n)	737	737
Number of parameters in model[b]	9	4
Parameters degrees of freedom[c] (p)	15	11
k factor	1.47	1.47
Deviance/(n-p)	1.00	1.01
Pearson chi-square/(n-p)	1.15	1.14
R^2 (%)	16	14
R^2_{FT} (%)[d]	16	13
Fatal and injury accidents (3-year period)		
Number of ramp proper segments (n)	737	737
Number of parameters in model[b]	9	6
Parameters degrees of freedom[c] (p)	15	12
k factor	0.70	0.70
Deviance/(n-p)	1.01	1.01
Pearson chi-square/(n-p)	1.62	1.62
R^2 (%)	15	14
R^2_{FT} (%)	15	15

[a] Includes the ramp type by ramp configuration interaction.
[b] Does not include interaction term.
[c] Includes 1 degree of freedom for the intercept and 4 degrees of freedom for interaction.
[d] A goodness-of-fit parameter based on the Freeman-Tukey variance stabilizing transformation of variables.

The following model statistics are shown:

Model statistic	Explanation
Basic Statistics	
Number of interchange elements, n	Total sample size in that category of interchange elements.
Number of parameters in model	Total number of independent variables, both categorical and continuous. This number does not include the interaction term.

Model statistic	Explanation
Parameters degrees of freedom, p	Each continuous independent variable has 1 degree of freedom; the number of degrees of freedom associated with each categorical variable equals the number of levels minus 1. The interaction has (a-1)x(b-1) degrees of freedom, where a and b are the number of levels of the two terms in the interaction. The intercept has 1 degree of freedom. The sum of these degrees of freedom is denoted as p.
k factor	The use of this factor results in a ratio of the deviance to its degrees of freedom of approximately 1.

Criteria for Assessing Goodness of Fit

Deviance/(n - p)	The deviance of the model containing all the parameters (including the intercept) divided by its degrees of freedom, n - p. This statistic (mean deviance) provides a test for over- or underdispersion and a measure of fit of the model. Asymptotically, this value tends toward 1.
Pearson chi-square/(n - p)	The Pearson chi-square statistic divided by its degrees of freedom, n - p. This statistic provides another measure of fit of the model. Asymptotically, this value tends toward 1. This statistic is called the Pearson chi-square ratio in subsequent sections.
R^2	A goodness-of-fit parameter based on the ordinary multiple-correlation coefficient.
R^2_{FT}	A goodness-of-fit parameter based on the Freeman-Tukey variance stabilizing transformation of variables discussed in Fridstrøm et al.[28]

Two goodness-of-fit measures, the mean deviance and the Pearson chi-square ratio (the Pearson chi-square value divided by its degrees of freedom), were used jointly to assess the fit of each model. The use of these criteria to evaluate the goodness-of-fit of these models is also discussed in Miaou.[29] In all NB regression models developed in this report, the variance adjustment factor, k, was selected to achieve an NB model for which the data show neither overdispersion nor underdispersion, as measured by the mean deviance (e.g., close to one). In addition, if the Pearson chi-square ratio is between 0.8 and 1.2, this is generally an indication that the model can be assumed to be appropriate in modeling the data.

Table 16 shows that the Pearson chi-square ratio (full model) is approximately 1.15 for total accidents and 1.62 for fatal and injury accidents. Two additional goodness-of-fit criteria are provided by R^2 and R^2_{FT}. These values range between approximately 15 percent and 16 percent for total and fatal and injury accidents.

The reduced model statistics for the NB reduced regression model are shown in the last column of table 16. Of the nine original independent variables considered, only four and the interaction term remain statistically significant in the reduced NB model for total accidents. Of the same set of nine variables, only six and the interaction term remain statistically significant in the final model for fatal and injury accidents. The Pearson chi-square ratios equal approximately 1.14 for total accidents, a value within the acceptable range of 0.8 to 1.2, showing that the choice of the NB model appears appropriate for total accidents. The Pearson chi-square ratio remains unchanged at 1.62 for fatal and injury accidents, a value well outside the acceptable range, showing that the NB model does not provide an adequate fit to the data.

The two additional measures of goodness of fit, R^2 and R^2_{FT}, range between 13 percent and 15 percent for either type of accident, indicating that these reduced NB models explain only a small fraction of the variance in accident frequencies.

Of the five independent variables considered in the full, but not reduced, NB model for total accidents, only two variables—right shoulder width (α=0.14) and ramp configuration (α=0.15)—were not significant at the 10-percent significance level, but would have been significant at the 20-percent level. Note that although ramp configuration is not a statistically significant variable on its own merit, the interaction term—ramp type by ramp configuration—is significant. In the model for fatal and injury accidents, none of the variables that were not statistically significant at the 10-percent significance level would have been significant at the 20-percent level.

Tables 17 and 18 summarize the regression results for the reduced NB model for total accidents and fatal and injury accidents, respectively. Each table identifies the:

- Statistically significant variables and interaction remaining in the reduced model.
- Chi-square statistic for each remaining variable; these chi-square statistics are statistically significant at the 10-percent significance level or better.
- Levels of each statistically significant categorical variable.
- Direction of the effect if the effect was inverse to the expected direction.
- Value of the regression coefficient for each continuous variable or each level of each categorical variable in the model.
- Relative effect of a unit change in each variable on the expected accident frequency in a 3-year period (this is simply e^{β}, where β is the coefficient given in the table).

Table 17. Negative Binomial Regression Results for Total Accidents on Ramp Proper Segments

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e] Lower	90% confidence limits[e] Upper
Intercept				-9.81		-11.14	-8.52
Ramp AADT (log)	249.70		-	0.93	2.54	0.83	1.05
Segment length (mi)	34.92		-	5.78	322.21	4.14	7.45
Ramp type	30.84	Off-ramp	-	0.78	2.17	-0.04	1.61
		On-ramp	-	0	-	-	-
Number of lanes	20.25	1	-	0.77	2.17	0.49	1.05
		2 or more	-	0	-	-	-
Ramp type by ramp configuration (two-way interaction)	15.82	Off, diamond	-	0.56	1.74	-0.07	1.13
		Off, loop	-	0.66	1.93	-0.07	1.36
		Off, outer connection	-	1.09	2.98	0.39	1.76
		Off, direct or semi-direct connection	-	0	-	-	-
		On, diamond	-	0.72	2.06	0.08	1.35
		On, loop	-	0.29	1.33	-0.44	1.01
		On, outer connection	-	-0.05	0.95	-1.01	0.90
		On, direct or semi-direct connection	-	0	-	-	-

NOTE: This analysis is based on the set of 737 ramp proper segments for which summary statistics are shown in table 15.
Conversion: 1 mi = 1.61 km.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

Table 18. Negative Binomial Regression Results for Fatal and Injury Accidents on Ramp Proper Segments

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e]	
						Lower	Upper
Intercept				-12.33		-13.96	10.77
Ramp AADT (log)	254.25		-	1.04	2.82	0.91	1.17
Ramp type	53.30	Off-ramp	-	1.45	4.26	0.62	2.32
		On-ramp	-	0	-	-	-
Segment length (mi)	28.13		-	5.20	180.37	3.59	6.81
Number of lanes	20.99	1	-	0.78	2.17	0.49	1.06
		2 or more	-	0	-	-	-
Ramp type by ramp configuration (two-way interaction)	17.48	Off, diamond	-	-0.81	0.45	-1.71	0.06
		Off, loop	-	-0.39	0.68	-1.42	0.62
		Off, outer connection	-	2.24	9.40	0.52	4.67
		Off, direct or semi-direct connection	-	0	-	-	-
		On, diamond	-	0	-	-	-
		On, loop	-	0	-	-	-
		On, outer connection	-	0	-	-	-
		On, direct or semi-direct connection	-	0	-	-	-
Ramp configuration	10.67	Diamond	-	0.99	2.70	0.29	1.75
		Loop	-	0.68	1.98	-0.12	1.53
		Outer connection	-	-1.62	0.20	-3.99	-0.03
		Direct or semi-direct connection	-	0	-	-	-
Right shoulder width (ft)	6.53		I	0.07	1.07	0.02	0.11

NOTE: This analysis is based on the set of 737 ramp proper segments for which summary statistics are shown in table 15.
Conversion: 1 mi = 1.61 km, 1 ft = 0.305 m.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

- Lower and upper 90-percent confidence limits of the regression coefficient. In each table, the independent variables are listed in decreasing order of their ability to explain the variation in accident frequencies at ramp proper segments as indicated by the chi-square values, which represent the strength of the relationship of each variable to accident frequency, taking into account all other variables in the model.

To predict the average accident frequency at ramp proper segments, the regression coefficients, β_0, β_1, β_2, ... β_q, are replaced with the estimated values found in the table, and the variables, X_1, X_2, ..., X_q, are replaced with their appropriate values or levels. For example, the expected 3-year total accident frequency can be estimated using the model presented in table 17 as:

$$Y = e^{-9.81} (X_1)^{0.93} \exp(5.76X_2) \exp(0.78X_3) \exp(0.77X_4) \exp(0.56X_5) \exp(0.66X_6) \exp(1.09X_7) \exp(0.72X_8) \exp(0.29X_9) \exp(-0.05X_{10}) \quad (14)$$

where:

Y = expected number of total accidents in a 3-year period at ramp segments
X_1 = AADT of the ramp segment (veh/day)
X_2 = length of the ramp segment (mi)
X_3 = 1 if the ramp segment is on an off-ramp; 0 otherwise
X_4 = 1 if the ramp segment has 1 lane; 0 otherwise
X_5 = 1 if the ramp segment is on a diamond off-ramp; 0 otherwise
X_6 = 1 if the ramp segment is on a loop off-ramp; 0 otherwise
X_7 = 1 if the ramp segment is on an outer connection off-ramp; 0 otherwise
X_8 = 1 if the ramp segment is on a diamond on-ramp; 0 otherwise
X_9 = 1 if the ramp segment is on a loop on-ramp; 0 otherwise
X_{10} = 1 if the ramp segment is on an outer connection on-ramp; 0 otherwise

Note that when the level of a categorical variable is 0, the multiplicative term in equation (14) becomes $e^0 = 1$, and it is therefore omitted from the model.

The relative effect of each variable (all other variables being held constant) can be calculated by simply taking the exponent of the corresponding coefficient. For example, the relative effect of the difference in accident frequency between ramp segments on off-ramps and ramp segments on on-ramps is exp(0.78) = 2.18. In other words, off-ramps tend to have more accidents than on-ramps by a factor of 2.18 or by 118 percent. The relative effect of the ramp AADT variable is more difficult to interpret since the relative effect of 2.54 means that an increase of one unit in the natural logarithm of the AADT would increase accidents by 154 percent.

The results of the NB regression modeling shown in tables 17 and 18 indicate that ramp AADT has a far stronger relationship to accident frequency than any other variable. For the total accident model in table 17, the other statistically significant variables, in descending order of their relationship to accident frequency, are segment length, ramp type, number of lanes, and the interaction of ramp type and ramp configuration. The effects of all of these variables are in the direction that would be expected based on existing knowledge about interchange safety.

The segment length variable in the model, which is statistically significant, represents primarily an exposure effect. In other words, this variable would be expected to be statistically significant because longer segments would be expected to have more accidents.

The statistical significance of the ramp AADT variable is expected because the literature has consistently shown traffic volumes to be the strongest predictor of accidents. The ramp AADT variable, in part, represents exposure because, as the traffic volume on the ramp increases, there are more opportunities for accidents to occur. However, the traffic volume is also a surrogate for congestion and, thus, accident frequencies may increase as the possibility of congestion increases.

The ramp type and number of lanes variables are statistically significant, indicating that ramp segments of off-ramps have more accidents than comparable ramp segments of on-ramps and that ramp segments on single-lane ramps have more accidents than ramp segments on multilane ramps.

The model in table 17 includes the significant main effect of the ramp type variable and the interaction of ramp type by ramp configuration without including the main effect of ramp configuration. This indicates that there is an overall ramp-type effect, regardless of ramp configuration, while there is no overall ramp configuration effect.

The significance of the interaction between ramp type and ramp configuration indicates that each combination of ramp type and ramp configuration has a unique effect on accident frequency that cannot be adequately explained by separate ramp type and ramp configuration effects. This means that the difference in safety performance between on- and off-ramps depends on the ramp configuration (i.e., diamond, loop, outer connection, or direct or semi-direct connection). In other words, for example, the difference in safety performance between diamond on-ramps and diamond off-ramps is not the same as that between loop off-ramps and loop on-ramps. Thus, each of the eight possible combinations of the two ramp types and the four ramp configurations requires its own term in the overall predictive equation of accident frequency [e.g., equation (14)]. The interaction effect shows an influence on accident frequency over and above the effect of ramp type alone, which is also statistically significant, as shown in table 17. The coefficients shown in table 17 can be used to quantify these effects as illustrated in equation (14).

The model for fatal and injury accidents shown in table 18 is similar to the model for total accidents in table 17 in that many of the same independent variables are statistically significant. One difference is that the main effects of both ramp type and ramp configuration, as well as their interaction, are statistically significant. In addition, the effect of right shoulder width is also statistically significant, except that the direction of this effect is opposite to that expected since it implies that there are more accidents on ramps with wider shoulders. Inverse effects of this kind are only too common in accident modeling and may indicate that, in this situation, shoulder width serves as a surrogate for some other variable for which data are not available. This apparently inverse effect is disappointing because determining the effects on accidents of geometric variables like shoulder width was one of the primary objectives of the research.

Ramp Proper Segments, Off-Ramps Only (Excluding Rear-End Accidents)

As explained earlier in this section, it was found that most of the rear-end accidents on off-ramps were related to the operation of the cross-road ramp terminal and not to the geometrics of the ramp proper. Therefore, a decision was made to model accidents on off-ramps using a dependent variable that excluded rear-end accidents and other accidents related to the cross-road ramp terminal. It was hoped that this approach could increase the explanatory power of the models, because the extraneous influence of the cross-road ramp terminals on the safety performance of the ramp would be excluded.

Of the 737 ramp segments used in the development of the previous model, a total of 434 segments (59 percent) were located on off-ramps. The 3-year average number of total accidents dropped from 2.04 to 1.14 accidents per ramp after excluding the rear-end accidents. The 3-year average number of fatal and injury accidents dropped from 0.90 to 0.41 accidents per ramp after excluding the rear-end accidents. Similarly, the 3-year total accident frequency dropped from 884 to 494 total accidents and from 390 to 178 fatal and injury accidents. The approach to modeling of total and fatal and injury accidents on ramp proper segments, excluding rear-end accidents, was identical to that for all accidents on ramp proper segments discussed above. The distribution of these accidents is shown in figure 9 in appendix D.

The selection of independent variables was done in a similar fashion to that described earlier. Table 19 identifies the variables selected for modeling accidents on ramp segments. The independent variables considered were:

- Ramp AADT.
- Segment length.
- Average lane width.
- Number of lanes.
- Right shoulder width.
- Left shoulder width.
- Area type (rural/urban).
- Ramp configuration.

Since only off-ramps are included in this analysis, consideration of the interaction between ramp type and ramp configuration was unnecessary. As before, parclo loops and free-flow loops were pooled into a single category. As shown in table 19, eight independent variables, both continuous and categorical, were considered in the full NB model. Of these eight variables, five were found to have a statistically significant effect on accidents (both

Table 19. Descriptive Statistics for Ramp Proper Segments on Off-Ramps (Rear-End Accidents Excluded)

Parameter	Level	Percent of ramps	Minimum	Mean	Median	Maximum	Total
Number of ramp segments: 434							
Total accidents: 1993 through 1995 combined			0	1.14	0	26	494
Fatal and injury accidents: 1993 through 1995 combined			0	0.41	0	13	178
Ramp AADT (veh/day)			27	4,950	4,052	24,365	
Segment length (mi)			0.01	0.12	0.12	0.5	53.89
Average lane width (ft)			10	14.86	14	36	
Right shoulder width (ft)			0	7.98	8	16	
Left shoulder width (ft)			0	4.24	4	16	
Area type	Rural	34.8					
	Urban	65.2					
Ramp configuration	Diamond	77.4					
	Loop	9.4					
	Outer connection	9.2					
	Direct or semi-direct connection	3.9					
Number of lanes	1	79.5					
	2 or more	20.5					

Conversion: 1 mi = 1.61 km, 1 ft = 0.305 m.

total and fatal and injury) at the 10-percent significance level. A reduced NB model was then rerun using only the five statistically significant variables.

The second column in table 20 shows the NB model statistics for the full model. The Pearson chi-square statistic of 1.28 is just outside the acceptable range for total accidents, and with a value of 1.72, far exceeds the acceptable upper limit of 1.2 for fatal and injury accidents. As was the case in the previous analysis of ramp proper segments, this shows that the NB model provides a reasonable choice for total accidents, but not for fatal and injury accidents. The two goodness-of-fit criteria, R^2 and R^2_{FT}, are relatively low, with values of approximately 17 percent and 20 percent for R^2 and approximately 16 percent and 11 percent for R^2_{FT}.

The third column in table 20 shows the NB model statistics for the reduced model, using only the five statistically significant variables. The Pearson chi-square statistics changed slightly from the full model, with values of 1.22 and 1.73 for total and fatal and injury accidents, respectively. Again, this shows that the NB model provides a reasonable choice for total accidents, but not for fatal and injury accidents. The two goodness-of-fit criteria, R^2 and R^2_{FT}, are again relatively low with values of approximately 18 percent for R^2 and approximately 16 percent and 10 percent for R^2_{FT}. Excluding rear-end accidents from the analyses resulted in a slight improvement in three of the four goodness-of-fit values from the earlier models for ramp segments, as seen when comparing table 20 with table 16.

Of the three independent variables considered in the full, but not reduced, NB model for total accidents, only one variable—right shoulder width (α=0.16)—was not significant at the 10-percent level, but would have been at the 20-percent level. Of the three independent variables considered in the full, but not reduced, NB model for fatal and injury accidents, none of the variables that were not significant at the 10-percent level would have been significant at the 20-percent level.

Tables 21 and 22 summarize the regression results for the reduced NB model for total accidents and fatal and injury accidents, respectively, at off-ramps and excluding all rear-end accidents. The tables show that the effects on accident frequency of ramp AADT, number of lanes, ramp configuration, ramp segment length, and average lane width are all statistically significant. Furthermore, these effects are all in the expected direction, including the effect of a key geometric variable—average lane width.

None of the models for ramp segments presented in tables 17, 18, 21, and 22 include more than one of the key cross-section dimensional variables and, in the one case when a shoulder width variable was statistically significant, its effect was in the opposite direction to that expected. Thus, it does not appear that predictive models can provide an adequate representation of the effects of the lane and shoulder widths on ramps.

Table 20. Model Diagnostics for Total and Fatal and Injury Accidents for Ramp Proper Segments of Off-Ramps (Rear-End Accidents Excluded)

Negative Binomial Regression Models	Full model	Reduced model
Total accidents (3-year period)		
Number of ramp segments (n)	434	434
Number of parameters in model	8	5
Parameters degrees of freedom[a] (p)	11	8
k factor	1.02	1.02
Deviance/(n-p)	1.00	1.00
Pearson chi-square/(n-p)	1.28	1.22
R^2 (%)	17	18
R^2_{FT} (%)	16	16
Fatal and injury accidents (3-year period)		
Number of ramp segments (n)	434	434
Number of parameters in model	8	5
Parameters degrees of freedom[a] (p)	11	8
k factor	0.25	0.30
Deviance/(n-p)	1.00	1.00
Pearson chi-square/(n-p)	1.72	1.73
R^2 (%)	20	18
R^2_{FT} (%)	11	10

[a] Includes 1 degree of freedom for the intercept.

Table 21. Negative Binomial Regression Results for Total Accidents for Ramp Proper Segments on Off-Ramps (Rear-End Accidents Excluded)

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e] Lower	Upper
Intercept				-5.50		-7.14	-3.88
Ramp AADT (log)	82.69		-	0.62	1.87	0.50	0.75
Number of lanes	22.39	1	-	1.03	2.80	0.67	1.39
		2 or more	-	0	-	-	-
Ramp configuration	13.79	Diamond	-	-0.15	0.86	-0.71	0.39
		Loop	-	-0.01	0.99	-0.67	0.64
		Outer connection	-	0.63	1.88	-0.001	1.25
		Direct or semi-direct connection	-	0	-	-	-
Ramp segment length (mi)	11.89		-	4.41	82.48	2.30	6.56
Average lane width (ft)	4.31		-	-0.06	0.94	-0.11	-0.01

NOTE: This analysis is based on the set of off-ramp proper segments for which summary statistics are shown in table 19.
Conversion: 1 mi = 1.61 km, 1 ft = 0.305 m.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

Table 22. Negative Binomial Regression Results for Fatal and Injury Accidents for Ramp Proper Segments on Off-Ramps (Rear-End Accidents Excluded)

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e] Lower	Upper
Intercept				-6.20		-8.09	-4.36
Ramp AADT (log)	64.29		-	0.68	1.97	0.52	0.84
Number of lanes	21.57	1	-	1.20	3.31	0.75	1.67
		2 or more	-	0	-	-	-
Ramp configuration	15.57	Diamond	-	-0.67	0.57	-1.15	-0.17
		Loop	-	-0.54	0.58	-1.16	0.07
		Outer connection	-	0.16	1.17	-0.38	0.72
		Direct or semi-direct connection	-	0	-	-	-
Average lane width (ft)	5.95		-	-0.08	0.92	-0.15	-0.02
Ramp segment length (mi)	4.96		-	2.98	19.74	0.79	5.13

NOTE: This analysis is based on the set of 737 ramp proper segments for which summary statistics are shown in table 19.
Conversion: 1 mi = 1.61 km, 1 ft = 0.305 m.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

Entire Ramps (Including All Accidents)

Accidents occurring on entire ramps (ramps as a whole rather than just specific segments) were analyzed in a manner similar to those occurring on ramp proper segments. However, when the ramp as a whole was considered, the segment-specific cross-section geometric variables (such as number of lanes, average lane width, and shoulder width) had to be excluded from the analysis. This analysis included 551 ramps with a total length of approximately 146 km (91 mi).

A total of 1,227 accidents of all severity levels and 533 fatal and injury accidents occurred within the 3-year period on the 551 ramps. Accident frequency distributions for the entire ramps are shown in figure 5 (presented earlier). Approximately 63 percent of the ramps considered experienced either zero or one accident in the 3-year study period. Approximately 80 percent of these ramps experienced either zero or one fatal and injury accident in the same period.

The selection of independent variables was done in a similar fashion to that described earlier for ramp segments. The independent variables considered were:

- Ramp AADT.
- Ramp length.
- Area type.
- Ramp type (off/on).
- Ramp configuration.
- Ramp type by ramp configuration interaction.

Table 23 presents descriptive statistics for these variables.

As shown in table 24, five independent variables, both continuous and categorical, and one interaction were considered in the full NB regression models. Of these factors, one—ramp length (α=0.95 for total accidents; α=0.86 for fatal and injury accidents)—was found not to be statistically significant at the 10-percent level. In addition, the interaction of ramp type by ramp configuration was not significant either (α=0.51 for total accidents; α=0.33 for fatal and injury accidents). A reduced NB was then rerun using only the four statistically significant variables.

The second column in table 24 shows the NB model statistics for the full model. The Pearson chi-square statistic of 0.99 is within the acceptable range for total accidents; however, the value of 1.46 exceeds the acceptable upper limit of 1.2 for fatal and injury accidents. As was the case for ramp proper segments, this shows that the NB model provides a reasonable choice for total accidents, but not for fatal and injury accidents. The two goodness-of-fit criteria, R^2 and R^2_{FT}, are relatively low, with values of approximately 22 percent and 20 percent for R^2 and approximately 23 percent and 20 percent for R^2_{FT}.

Table 23. Descriptive Statistics for Entire Ramps

Parameter	Level	Percent of ramps	Minimum	Mean	Median	Maximum	Total
Number of ramps: 551							
Total accidents: 1993 through 1995 combined			0	2.23	1	30	1,227
Fatal and injury accidents: 1993 through 1995 combined			0	0.97	0	16	533
Ramp AADT (veh/day)			27	4,497	3,537	24,365	
Ramp length (mi)			0.04	0.18	0.17	0.69	91
Area type	Rural	40.3					
	Urban	59.7					
Ramp configuration: off-ramps	Diamond	43.0					
	Parclo loop	2.2					
	Free-flow loop	4.5					
	Outer connection	5.4					
	Direct or semi-direct connection	2.7					
	All off-ramps	57.9					
Ramp configuration: on-ramps	Diamond	28.7					
	Parclo loop	3.4					
	Free-flow loop	4.7					
	Outer connection	2.0					
	Direct or semi-direct connection	3.3					
	All on-ramps	42.1					

Conversion: 1 mi = 1.61 km.

Table 24. Model Diagnostics for Total and Fatal and Injury Accidents on Entire Ramps

Negative Binomial Regression Models	Full model with ramp type by ramp configuration interaction	Reduced model without interaction
Total accidents (3-year period)		
Number of ramps (n)	551	551
Number of parameters in model[a]	5	4
Parameters degrees of freedom[b] (p)	13	8
k factor	0.95	0.95
Deviance/(n-p)	1.00	1.00
Pearson chi-square/(n-p)	0.99	0.98
R^2 (%)	22	21
R^2_{FT} (%)	23	22
Fatal and injury accidents (3-year period)		
Number of ramps (n)	551	551
Number of parameters in model[a]	5	4
Parameters degrees of freedom[b] (p)	13	8
k factor	0.70	0.70
Deviance/(n-p)	1.01	1.01
Pearson chi-square/(n-p)	1.46	1.35
R^2 (%)	20	19
R^2_{FT} (%)	20	19

[a] Does not include interaction term.
[b] Includes 1 degree of freedom for the intercept and 4 degrees of freedom for the interaction term (full model only).

The third column in table 24 shows the NB model statistics for the reduced model, using only the four statistically significant variables. The Pearson chi-square statistics changed slightly from the full model, with values of 0.98 and 1.35 for total and fatal and injury accidents, respectively. Again, this shows that the NB model provides a reasonable choice for total accidents, but not for fatal and injury accidents. The two goodness-of-fit criteria, R^2 and R^2_{FT}, are again relatively low, with values of approximately 21 percent and 19 percent for R^2 and approximately 22 percent and 19 percent for R^2_{FT}. These values are slightly higher than those for the models using ramp segments (per table 16).

Tables 25 and 26 summarize the regression results for the reduced NB model for total accidents and fatal and injury accidents, respectively. Both tables show the same four independent variables as statistically significant—ramp AADT, ramp configuration, ramp type, and area type—and indicate that in both models, these factors have the same relative order for the strength of their relationship to accident frequency. As is consistently the case, ramp AADT has the strongest relationship to accidents. Ramp configuration and ramp type are about equally strong in their relationship to accidents and area type is much weaker. The relative effects show that parclo loop ramps have the highest accident experience, followed by cloverleaf outer connection ramps, diamond ramps, free-flow loop ramps, and direct and semi-direct connection ramps. Off-ramps were found to experience more accidents than on-ramps, and urban ramps experience more accidents than rural ramps.

Entire Ramps, Off-Ramps Only (Excluding Rear-End Accidents)

An analysis of the data for entire ramps was conducted that focused on the data for off-ramps only, with rear-end accidents and other accidents related to the cross-road ramp terminals excluded (as was the case for ramp proper segments). The analysis focused on off-ramps because it is most likely that rear-end accidents on off-ramps are related to the cross-road ramp terminals. The purpose of excluding these accidents was to reduce the influence of the cross-road ramp terminals and focus the analyses on accidents that are potentially related to the geometrics of the ramps themselves.

Of the 551 entire ramps for which data were available, a total of 319 (58 percent) were off-ramps. The 3-year average number of total accidents dropped from 2.43 to 1.42 accidents per ramp after excluding the rear-end accidents. The 3-year average number of fatal and injury accidents dropped from 1.09 to 0.53 accidents per ramp after excluding the rear-end accidents. Similarly, the 3-year total accident frequency dropped from 775 to 453 total accidents and from 348 to 168 fatal and injury accidents. The statistical approach to the analysis of total and fatal and injury accidents at off-ramps after excluding rear-end accidents was identical to that for the previous analyses discussed above. The distribution of these accidents is shown in figure 10 in appendix D.

Table 25. Negative Binomial Regression Results for Total Accidents on Entire Ramps

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e]	
						Lower	Upper
Intercept				-6.32		-7.51	-5.15
Ramp AADT (log)	127.69		-	0.76	2.14	0.64	0.88
Ramp configuration	21.81	Diamond	-	0.62	1.85	0.22	1.01
		Parclo loop	-	1.18	3.26	0.64	1.72
		Free-flow loop	-	0.15	1.16	-0.33	0.63
		Outer connection	-	0.89	2.44	0.40	1.38
		Direct or semi-direct connection	-	0	-	-	-
Ramp type	18.61	Off-ramp	-	0.50	1.65	0.31	0.70
		On-ramp	-	0	-	-	-
Area type	4.31	Rural	-	-0.35	0.71	-0.62	-0.07
		Urban	-	0	-	-	-

NOTE: This analysis is based on the set of 551 entire ramps for which summary statistics are shown in table 23.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

Table 26. Negative Binomial Regression Results for Fatal and Injury Accidents on Entire Ramps

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e] Lower	90% confidence limits[e] Upper
Intercept				-7.87		-9.34	-6.46
Ramp AADT (log)	111.81		-	0.85	2.33	0.70	1.00
Ramp configuration	20.72	Diamond	-	0.54	1.71	0.11	0.97
		Parclo loop	-	1.22	3.39	0.64	1.80
		Free-flow loop	-	0.01	1.01	-0.52	0.54
		Outer connection	-	0.80	2.22	0.27	1.33
		Direct or semi-direct connection	-	0	-	-	-
Ramp type	18.04	Off-ramp	-	0.55	1.73	0.33	0.76
		On-ramp	-	0	-	-	-
Area type	3.14	Rural	-	-0.34	0.71	-0.66	-0.02
		Urban	-	0	-	-	-

NOTE: This analysis is based on the set of 551 entire ramps for which summary statistics are shown in table 23.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

The selection of independent variables was done in a similar fashion to that described in the earlier analyses in this section. Table 27 identifies the variables selected for modeling accidents on entire ramps. The independent variables include:

- Ramp AADT.
- Ramp length.
- Area type (rural/urban).
- Ramp configuration.

Since only off-ramps are included in this analysis, consideration of the interaction between ramp type and ramp configuration is unnecessary. As shown in table 27, four independent variables, both continuous and categorical, were considered in the full NB models. Of these four independent variables, two were found to have a statistically significant effect on accidents (both total and fatal and injury) at the 10-percent significance level. A reduced NB model was then rerun using only the two statistically significant variables.

The second column in table 28 shows the NB model statistics for the full model. The Pearson chi-square statistic of 0.97 is well within the acceptable range for total accidents; however, the value of 1.34 for the Pearson chi-square statistic for fatal and injury accidents slightly exceeds the acceptable upper limit of 1.2. This shows that the NB model provides a reasonable choice for total accidents only. The two goodness-of-fit criteria, R^2 and R^2_{FT}, are relatively low, with values of approximately 17 percent and 16 percent for R^2 and approximately 14 percent and 10 percent for R^2_{FT} , for total and fatal and injury accidents, respectively.

The third column in table 28 shows the NB model statistics for the reduced model, using only the two statistically significant variables. The Pearson chi-square statistics changed only slightly from the full model, with values of 0.96 and 1.38 for total and fatal and injury accidents, respectively. Again, this shows that the NB model provides a reasonable choice for total accidents only. The two goodness-of-fit criteria, R^2 and R^2_{FT}, remained unchanged from the full models. When the analysis is limited to off-ramps only and rear-end accidents are excluded, the resulting model fits the data slightly less well than the comparable model for all ramps (compare tables 24 and 28). The models presented here also fit the data slightly less well than the comparable model for ramp segments (compare tables 20 and 28).

The two independent variables considered in the full, but not reduced, NB model for total or fatal and injury accidents that were not significant at the 10-percent level, would not have been significant at the 20-percent level either.

Table 29 summarizes the regression results for the reduced NB model for both total accidents and fatal and injury accidents, excluding rear-end accidents. Both models in table 29 show only two statistically significant variables—ramp AADT and ramp configuration. As is typically the case, ramp AADT has a much stronger relationship to accidents than does ramp configuration.

Table 27. Descriptive Statistics for Entire Off-Ramps (Rear-End Accidents Excluded)

Parameter	Level	Percent of ramps	Minimum	Mean	Median	Maximum	Total
Number of entire ramps: 319							
Total accidents: 1993 through 1995 combined			0	1.42	1	26	453
Fatal and injury accidents: 1993 through 1995 combined			0	0.53	0	13	168
Ramp AADT (veh/day)			27	4,169	3,024	24,365	
Ramp length (mi)			0.04	0.18	0.17	0.5	57.24
Area type	Rural	44.2					
	Urban	55.8					
Ramp configuration	Diamond	74.3					
	Parclo loop	3.8					
	Free-flow loop	7.8					
	Outer connection	9.4					
	Direct or semi-direct connection	4.7					

Conversion: 1 mi = 1.61 km.

Table 28. Model Diagnostics for Total and Fatal and Injury Accidents on Entire Off-Ramps (Rear-End Accidents Excluded)

Negative Binomial Regression Models	Full model	Reduced model
Total accidents (3-year period)		
Number of ramps (n)	319	319
Number of parameters in model	4	2
Parameters degrees of freedom[a] (p)	8	6
k factor	0.80	0.80
Deviance/(n-p)	1.01	1.00
Pearson chi-square/(n-p)	0.97	0.96
R^2 (%)	17	17
R^2_{FT} (%)	14	14
Fatal and injury accidents (3-year period)		
Number of ramps (n)	319	319
Number of parameters in model	4	2
Parameters degrees of freedom[a] (p)	8	6
k factor	0.40	0.40
Deviance/(n-p)	1.00	0.99
Pearson chi-square/(n-p)	1.34	1.33
R^2 (%)	16	16
R^2_{FT} (%)	10	10

[a] Includes 1 degree of freedom for the intercept.

Table 29. Negative Binomial Regression Results for Total and Fatal and Injury Accidents on Entire Off-Ramps (Rear-End Accidents Excluded)

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e] Lower	Upper
Total accidents							
Intercept				-3.97		-5.12	-2.86
Ramp AADT (log)	74.94		-	0.54	1.72	0.43	0.65
Ramp configuration	12.19	Diamond	-	-0.16	0.85	-0.69	0.34
		Parclo loop	-	0.11	1.12	-0.73	0.95
		Free-flow loop	-	-0.23	0.79	-0.86	0.38
		Outer connection	-	0.56	1.75	-0.03	1.15
		Direct or semi-direct connection	-	0	-	-	-
Fatal and injury accidents							
Intercept				-5.21		-6.74	-3.78
AADT (log)	56.04		-	0.61	1.84	0.46	0.77
Ramp configuration	14.29	Diamond	-	-0.56	0.57	-1.07	-0.03
		Parclo loop	-	0.01	1.01	-0.90	0.87
		Free-flow loop	-	-0.69	0.50	-1.39	-0.004
		Outer connection	-	0.28	1.32	-0.32	0.88
		Direct or semi-direct connection	-	0	-	-	-

NOTE: This analysis is based on the set of 319 entire ramps for which summary statistics are shown in table 27.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

Speed-Change Lanes

Modeling of the accident experience of speed-change lanes independent of the modeling of accidents on the ramps they adjoin was attempted for two reasons. First, the geometric elements that appear to be important in the safety performance of speed-change lanes are different than those that are important in the safety performance of ramps. The length of a speed-change lane is a critical safety-related design parameter, particularly for acceleration lanes, while the length of a ramp may be more a function of terrain and site conditions. Second, speed-change lanes and ramps were modeled separately in the well-known Interstate System Accident Research (ISAR) study performed by FHWA in the late 1960s, so there was precedent for separate treatment of speed-change lanes.[5,13] This approach was also recommended by Harwood et al. in the original conceptual plan for the FHWA Interactive Highway Safety Design Model (IHSDM).[24]

The initial review of the Washington data base identified 276 acceleration lanes and 192 deceleration lanes as suitable for analysis and as having complete data. Only conventional acceleration and deceleration lanes were considered; speed-change lanes associated with a mainline freeway lane drop, a mainline lane addition, or a mainline weaving area were excluded from the analysis. Separate models were developed for acceleration and deceleration lanes because these two types of speed-change lanes operate very differently and their safety performance would be expected to differ. Speed-change lanes for left-side ramps were excluded from the analysis. As in the case of ramp proper segments, available geometric parameters for speed-change lanes, including number of lanes, average lane width, and right shoulder width, were considered in the analyses.

Table 30 presents descriptive statistics for the variables selected for modeling accidents; acceleration and deceleration lanes are considered separately. The independent variables include:

- Ramp AADT.
- Mainline freeway AADT.
- Average lane width.
- Right shoulder width.
- Speed-change lane length.
- Area type (rural/urban).
- Ramp configuration.

It was found that all acceleration and deceleration lanes in the available sample had only a single traffic lane, so the number of lanes variable was not included in the models. In addition, since all acceleration lanes are located on on-ramps and all deceleration lanes are located on off-ramps, ramp type was not relevant in modeling accidents. A total of seven independent variables, both continuous and categorical, were considered in the full NB models for the two types of speed-change lanes when modeling total accidents. Of these seven independent variables considered in modeling acceleration and deceleration lanes, only four were found to have a statistically significant effect on total accidents at the 10-percent significance level for acceleration lanes and three were found to be significant for deceleration lanes. A reduced NB model was then rerun in each case using only the statistically significant variables.

Table 30. Descriptive Statistics for Speed-Change Lanes

Parameter	Level	Percent of ramps	Minimum	Mean	Median	Maximum	Total
Acceleration lanes (all ramp configurations)							
Number of acceleration lanes: 192							
Total accidents: 1993 through 1995 combined			0	1.34	0	15	257
Fatal and injury accidents: 1993 through 1995 combined			0	0.64	0	10	122
Ramp AADT (veh/day)			54	4,329	3,483	21,264	
Mainline freeway AADT (veh/day)			3,865	34,390	23,528	98,562	
Average lane width (ft)			12	15.01	14.00	25.00	
Right shoulder width (ft)			0	7.91	8.00	12.00	
Acceleration lane length (mi)			0.02	0.23	0.26	0.38	43.79
Area type	Rural	41.1					
	Urban	58.9					
Ramp configuration	Diamond	77.1					
	Parclo loop	8.9					
	Free-flow loop	2.6					
	Outer connection	5.2					
	Direct or semi-direct connection	6.3					
Acceleration lanes (diamond ramps only)							
Number of acceleration lanes: 148							
Total accidents: 1993 through 1995 combined			0	1.43	0	14	211
Fatal and injury accidents: 1993 through 1995 combined			0	0.68	0	8	101
Ramp AADT (veh/day)			54	4,183	3,480	16,924	
Mainline freeway AADT (veh/day)			3,865	33,616	23,243	98,562	
Average lane width (ft)			12	14.82	14.00	22.00	
Right shoulder width (ft)			0	7.97	8.00	12.00	
Acceleration lane length (mi)			0.02	0.23	0.26	0.38	34.72
Area type	Rural	43.2					
	Urban	56.8					

Table 30. Descriptive Statistics for Speed-Change Lanes (Continued)

Parameter	Level	Percent of ramps	Minimum	Mean	Median	Maximum	Total
Deceleration lanes (all ramp configurations)							
Number of deceleration lanes: 276							
Total accidents: 1993 through 1995 combined			0	0.57	0	23	158
Fatal and injury accidents: 1993 through 1995 combined			0	0.27	0	11	75
Fatal and injury accidents: 1993 through 1995 combined (222 diamond ramps only)			0	0.27	0	11	60
Ramp AADT (veh/day)			27	3,542	2,558	24,365	
Mainline freeway AADT (veh/day)			2,331	30,628	22,287	106,729	
Average lane width (ft)			13	14.66	14.00	27.00	
Right shoulder width (ft)			0	8.26	8.00	16.00	
Deceleration lane length (mi)			0.04	0.10	0.11	0.27	28.31
Area type	Rural	50.4					
	Urban	49.6					
Ramp configuration	Diamond	80.4					
	Parclo loop	3.3					
	Free-flow loop	1.8					
	Outer connection	10.1					
	Direct or semi-direct connection	4.3					

NOTE: All acceleration and deceleration lanes have only one lane.
Conversion: 1 mi = 1.61 km, 1 ft = 0.305 m.

The top portion of table 31 summarizes the model diagnostics for accidents at both types of speed-change lanes. The second and fourth columns in this table show the NB model statistics for the full model, for acceleration and deceleration lanes, respectively. The third and fifth columns show the NB model statistics for the reduced model, for acceleration and deceleration lanes, respectively.

Table 31. Model Diagnostics for Total and Fatal and Injury Accidents in Speed-Change Lanes

Negative Binomial Regression Models	Acceleration lanes		Deceleration lanes	
	Full model	Reduced model	Full model	Reduced model
Total accidents (3-year period)—all ramp configurations				
Number of speed-change lanes (n)	192	192	276	276
Number of parameters in model	7	4	7	3
Parameters degrees of freedom[a] (p)	11	5	11	4
k factor	0.60	0.60	0.47	0.47
Deviance/(n-p)	1.00	1.01	1.00	1.00
Pearson chi-square/(n-p)	1.35	1.36	3.11	2.81
R^2 (%)	33	36	18	15
R^2_{FT} (%)	40	38	20	16
Fatal and injury accidents (3-year period)—diamond ramps only				
Number of speed-change lanes (n)	148	148	-	-
Number of parameters in model	6	3	-	-
Parameters degrees of freedom[a] (p)	7	4	-	-
k factor	0.17	0.15	-	-
Deviance/(n-p)	1.00	1.00	-	-
Pearson chi-square/(n-p)	1.39	1.35	-	-
R^2 (%)	35	34	-	-
R^2_{FT} (%)	35	34	-	-

[a] Includes one degree of freedom for the intercept.

The Pearson chi-square statistics of 1.35 and 1.36 for the full and reduced models, respectively, for total accidents on acceleration lanes are outside the acceptable range (0.8 to 1.2). The two goodness-of-fit criteria, R^2 and R^2_{FT}, are high in comparison to previous models, with values of approximately 33 percent (full model) and 36 percent (reduced model) for R^2 and approximately 40 percent (full model) and 38 percent (reduced model) for R^2_{FT}, for total accidents in deceleration lanes. Although these values are relatively high, the high values for the Pearson chi-square statistics show a poor fit of these models to the data.

The Pearson chi-square statistics of 3.11 (full model) and 2.81 (reduced model) for total accidents on deceleration lanes far exceed the upper limit of the acceptable range (0.8 to 1.2). Also, the low values of R^2 (15 percent) and R^2_{FT} (16 percent) for the reduced model add to the fact that these models do not provide an adequate fit for total accidents in deceleration lanes.

In the modeling of fatal and injury accidents in speed-change lanes, only diamond ramps (the most predominant ramp configuration) could be considered, due to modeling difficulties that arose when including all five ramp configurations. Of the six independent variables considered in the full model for acceleration lanes, only three were found to be statistically significant at the 10-percent level. No adequate model could be fit to fatal and injury accidents in deceleration lanes, and thus no statistics are shown for this category.

As with the modeling of total accidents in acceleration lanes, the Pearson chi-square statistics of 1.39 (full model) and 1.35 (reduced model) for fatal and injury accidents in acceleration lanes exceed the upper limit of the acceptable range (0.8 to 1.2). Again, the two goodness-of-fit criteria, R^2 and R^2_{FT}, are high in comparison to previous models, with values of approximately 35 percent (full model) and 34 percent (reduced model) for R^2, and approximately 35 percent (full model) and 34 percent (reduced model) for R^2_{FT}. In combination, these statistics support the fact that modeling of both total and fatal and injury accidents at either type of speed-change lane is difficult.

Of the three independent variables considered in the full, but not reduced, model for total accidents in acceleration lanes, none that was not statistically significant at the 10-percent level would have been significant at the 20-percent level. Of the four independent variables considered in the full, but not reduced, model for total accidents in deceleration lanes, two variables—mainline freeway AADT (α=0.13) and deceleration lane length (α=0.13)—that were not statistically significant at the 10-percent level would have been significant at the 20-percent level.

Of the three independent variables considered in the full, but not reduced, model for fatal and injury accidents in the acceleration lanes of diamond ramps, none that was not statistically significant at the 10-percent level would have been significant at the 20-percent level.

Tables 32 and 33 summarize the regression results for the reduced NB models for total accidents and fatal and injury accidents, respectively, in speed-change lanes. All of the models presented in the tables include a key variable that would be expected to influence the safety performance of speed-change lanes—ramp AADT. The acceleration lane models also include two other key variables related to safety performance—mainline freeway AADT and acceleration lane length. It is natural that higher volume speed-change lanes should have more accidents. The effect of acceleration lane length is more complicated. Longer acceleration lanes would be expected to have more accidents due to increased exposure. However, longer acceleration lanes also represent more generous designs that would be expected to operate more safely. Based on the results shown in tables 32 and 33, the exposure aspect of acceleration lane length appears to outweigh the design aspect, because the models indicate that the accident frequency increases with

Table 32. Negative Binomial Regression Results for Total Accidents in Speed-Change Lanes

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e] Lower	Upper
Acceleration lanes (all ramp configurations)							
Intercept				-12.84		-16.52	-9.37
Ramp AADT (log)	47.54		-	0.98	2.67	0.73	1.25
Acceleration lane length (mi)	25.06		-	6.88	975.9	4.56	9.29
Area type	3.10	Rural	-	-0.59	0.56	-1.14	-0.04
		Urban	-	0	-	-	-
Mainline freeway AADT (log)	2.95			0.32	1.38	0.01	0.64
Deceleration lanes (all ramp configurations)							
Intercept				-9.73		-12.29	-7.32
Ramp AADT (log)	52.52		-	1.04	2.83	0.78	1.32
Area type	11.47	Rural	-	-1.21	0.30	-1.88	-0.60
		Urban	-	0	-	-	-
Right shoulder width (ft)	4.96		-	0.09	1.10	0.02	0.17

NOTE: This analysis is based on the set of 192 acceleration lanes and 276 deceleration lanes for which summary statistics are shown in table 30.
Conversion: 1 mi = 1.61 km, 1 ft = 0.305 m.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

Table 33. Negative Binomial Regression Results for Fatal and Injury Accidents in Acceleration Lanes (Diamond On-Ramps Only)

Independent variable[a]	Chi-square statistic[b]	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e] Lower	Upper
Acceleration lanes (diamond ramps only)						
Intercept			-15.81		-19.77	-12.12
Ramp AADT (log)	39.28	-	0.99	2.68	0.70	1.29
Acceleration lane length (mi)	11.18	-	5.32	203.91	2.64	8.15
Mainline freeway AADT (log)	7.73		0.56	1.76	0.22	0.92

NOTE: This analysis is based on the set of 148 acceleration lanes for which summary statistics are shown in table 30. No comparable model could be developed for deceleration lanes.
Conversion: 1 mi = 1.61 km.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

increasing acceleration lane length. The width of the speed-change lane was not statistically significant in any of the models. In any case, the goodness-of-fit measures indicate that the models of speed-change lanes, by themselves, do not provide an adequate fit to the data.

Entire Ramps and Adjacent Speed-Change Lanes Combined

In the preceding analyses in this report, accidents on ramps and speed-change lanes were modeled separately with the thought that accident predictions from the separate models could be added together to determine the combined safety performance of a ramp and its adjacent speed-change lane. The following modeling effort was devoted to developing a single model to predict accident experience for ramps and their adjacent speed-change lanes. The accidents occurring on both the entire ramp and those occurring in the adjacent speed-change lane were thus considered in the modeling.

The effort used the combined data for the 551 entire ramps, 276 deceleration lanes, and 192 acceleration lanes that have been described in previous modeling efforts. A total of 467 ramps were available that met the selection criteria discussed earlier and had data available for both the ramp and its adjacent speed-change lane. These ramps with their adjacent speed-change lanes had a total length of approximately 388 km (241 mi), including approximately 253 km (157 mi) of total ramp length and approximately 135 km (84 mi) of total speed-change lane length. The average 3-year accident frequency was

3.11 accidents per ramp for total accidents and 1.38 accidents per ramp for fatal and injury accidents. Three-year accident frequency totals were 1,452 for total and 644 for fatal and injury accidents.

The selection of independent variables was done in a similar fashion to the other modeling efforts described earlier. Table 34 identifies the variables selected for modeling accidents for combined ramps and speed-change lanes. The independent variables include:

- Ramp AADT.
- Mainline freeway AADT.
- Ramp length.
- Speed-change lane length.
- Area type (rural/urban).
- Ramp type (off/on).
- Ramp configuration.
- Ramp grade.
- Ramp type by ramp configuration interaction.
- Ramp type by ramp grade interaction.

As in previous analyses, the interaction between ramp type and ramp configuration was included in the combined ramp and speed-change lane modeling effort. In addition to independent variables considered in previous analyses, two new variables obtained from existing records were also introduced into this analysis. These were the general grade of the ramp (upgrade/downgrade) and the AADT of the mainline freeway section adjacent to the speed-change lane. The mainline freeway AADT used in modeling is the one-way AADT for the direction of travel in which the ramp and speed-change lane are located. The procedures used to obtain the variables are described in section 4 of this report. In this analysis, the interaction between ramp type and ramp grade was also considered.

As shown in table 34, eight independent variables, both continuous and categorical, plus the two interactions, were considered in the full NB model. Of these eight independent variables, three were found to have a statistically significant effect on total accidents and five had a statistically significant effect on fatal and injury accidents at the 10-percent significance level. A reduced NB model was then rerun using only the statistically significant variables. In both cases, the ramp type by ramp configuration and the ramp type by ramp grade interactions were not statistically significant.

The second column in table 35 shows the NB model statistics for the full model. The Pearson chi-square statistic of 0.95 for total accidents is well within the acceptable range; the Pearson chi-square statistic of 1.19 for fatal and injury accidents is at the upper limit of the acceptable range. These results show that the NB model provides a reasonable choice for both types of accidents. The two goodness-of-fit criteria, R^2 and R^2_{FT}, are high in comparison to previous models, with values of approximately 38 percent and 37 percent for R^2 and approximately 44 percent and 39 percent for R^2_{FT} for total and fatal and injury accidents, respectively.

Table 34. Descriptive Statistics for Entire Ramps, Including the Adjacent Speed-Change Lane

Parameter	Level	Percent of ramps	Minimum	Mean	Median	Maximum	Total
Number of ramps, including adjacent speed-change lanes: 467							
Total accidents: 1993 through 1995 combined			0	3.11	1	33	1,452
Fatal and injury accidents: 1993 through 1995 combined			0	1.38	0	18	644
Ramp AADT (veh/day)			27	3,859	2,957	24,365	
Mainline freeway AADT (veh/day)			2,331	32,117	22,829	106,729	
Length of ramp (mi)			0.14	0.34	0.32	0.82	157.10
Length of speed-change lane (mi)			0.04	0.18	0.17	0.50	83.68
Area type	Rural	46.7					
	Urban	53.3					
Ramp configuration, off-ramps	Diamond	47.5					
	Parclo loop	1.9					
	Free-flow loop	1.1					
	Outer connection	6.0					
	Direct or semi-direct connection	2.4					
	All off-ramps	58.9					
Ramp configuration, on-ramps	Diamond	31.7					
	Parclo loop	3.6					
	Free-flow loop	1.1					
	Outer connection	2.1					
	Direct or semi-direct connection	2.6					
	All on-ramps	41.1					
Ramp grade, off-ramps	Upgrade	36.6					
	Downgrade	22.3					
	All off-ramps	58.9					
Ramp grade, on-ramps	Upgrade	17.8					
	Downgrade	23.3					
	All on-ramps	41.1					

Conversion: 1 mi = 1.61 km.

Table 35. Model Diagnostics for Total and Fatal and Injury Accidents on Entire Ramps, Including the Adjacent Speed-Change Lane

Negative Binomial Regression Models	Full model[a]	Reduced model at 10% significance level[b]	Reduced model at 20% significance level[b]
Total accidents (3-year period)			
Number of ramps (n)	467	467	467
Number of parameters in model[c]	8	3	7
Parameters degrees of freedom[d] (p)	17	7	11
k factor	0.67	0.66	0.66
Deviance/(n-p)	1.00	1.00	1.00
Pearson chi-square/(n-p)	0.95	0.94	0.96
R^2 (%)	38	37	38
R^2_{FT} (%)	44	42	43
Fatal and injury accidents (3-year period)			
Number of ramps (n)	467	467	467
Number of parameters in model[c]	8	5	6
Parameters degrees of freedom[d] (p)	17	6	7
k factor	0.54	0.52	0.52
Deviance/(n-p)	0.99	1.00	1.00
Pearson chi-square/(n-p)	1.19	1.11	1.11
R^2 (%)	37	36	36
R^2_{FT} (%)	39	37	37

[a] Includes interaction between ramp type and ramp configuration and between ramp type and ramp grade.
[b] Model does not include interactions.
[c] Does not include interaction terms in full models.
[d] Includes 1 degree of freedom for intercept, 4 degrees of freedom for ramp type by ramp configuration interaction, and 1 degree of freedom for ramp type by ramp grade interaction for full models; includes 1 degree of freedom for intercept for reduced models.

The third column in table 35 shows the NB model statistics for the reduced model, including only the statistically significant variables. The Pearson chi-square statistics changed only slightly from the full model, with values of 0.94 and 1.11 for total and fatal and injury accidents, respectively. Again, this shows that the NB model provides a reasonable choice for both types of accidents. The two goodness-of-fit criteria, R^2 and R^2_{FT}, remain relatively high as compared to other models, with values of approximately 37 percent and 36 percent for R^2 and approximately 42 percent and 37 percent for R^2_{FT} for total and fatal and injury accidents, respectively. These goodness-of-fit measures are far superior to any of those found for the models of ramp segments and entire ramps presented earlier.

The reduced model for total accidents at the 10-percent significance level was obtained in a stepwise fashion, starting with the full model, which included eight variables and two interactions. In a first iteration, mainline freeway AADT (α=0.18), ramp grade (α=0.40), and the two interactions [ramp type by ramp configuration (α=0.66) and ramp type by ramp grade (α=0.98)] were excluded from the full model; the remaining six variables were all statistically significant at the 10-percent significance level in the full model. The result of this first iteration showed that of the six variables considered, one—ramp length (α=0.11)—was no longer significant at the 10-percent significance level, but was significant at the 20-percent significance level. A second iteration was performed in which ramp length was excluded from the model. As a result of this analysis, it was found that ramp type (α=0.14) and length of speed-change lane (α=0.39) were no longer statistically significant. A third and final iteration was then performed with the three remaining variables—ramp AADT, area type, and ramp configuration—all of which now remained statistically significant at the 10-percent significance level.

The reduced model for fatal and injury accidents at the 10-percent significance level was obtained in a similar fashion. From the full model with eight independent variables and two interactions, three independent variables—area type (α=0.25), ramp grade (α=0.32), and ramp configuration (α=0.55)—and two interactions—ramp type by ramp configuration (α=0.62) and ramp type by ramp grade (α=0.70)—were found not to be statistically significant at the 10-percent significance level. These variables and interactions were excluded in the first iteration to obtain a reduced model. As a result, the variable area type (α=0.17) was no longer significant at the 10-percent significance level, but was significant at the 20-percent significance level. A second and final iteration for the reduced model was performed without the area-type variable; thus, the model included five variables.

Tables 36 and 37 summarize the regression results for the reduced NB model for total accidents and fatal and injury accidents, respectively, at the 10-percent significance level. Table 36 shows the reduced model for total accidents with three statistically significant variables—ramp AADT, area type, and ramp configuration. Similarly, table 37 shows a model for fatal and injury accidents with five statistically significant variables—ramp AADT, length of speed-change lane, ramp length, ramp type, and mainline freeway AADT. Neither the ramp grade nor the two interactions considered were statistically significant.

In general, caution should be exercised in including variables that are not statistically significant at the 10-percent significance level in a predictive model because of the increased risk that they may appear to be statistically significant due to chance alone. In this case, however, because the variables in question appeared to be important to the objectives of the research and because they were statistically significant at the 20-percent significance level, it appeared to be desirable to include additional variables to the model. Therefore, a decision was reached to revise the models shown in tables 36 and 37 to include all variables that were statistically significant at the 20-percent significance level or better.

Table 36. Negative Binomial Regression Results for Total Accidents on Entire Ramps, Including the Adjacent Speed-Change Lane (Reduced Model at 10-Percent Significance Level)

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e]	
						Lower	Upper
Intercept				-5.75		-6.81	-4.72
Ramp AADT (log)	172.87		-	0.80	2.23	-0.69	0.91
Area type	9.93	Rural	-	-0.47	0.62	-0.71	-0.23
		Urban	-	0	-	-	-
Ramp configuration	9.72	Diamond	-	0.41	1.50	0.02	0.79
		Parclo loop	-	0.70	2.01	0.18	1.22
		Free-flow loop	-	-0.18	0.84	-0.88	0.54
		Outer connection	-	0.66	1.94	0.20	1.12
		Direct or semi-direct connection	-	0	-	-	-

NOTE: This analysis is based on the set of 467 ramps for which summary statistics are shown in table 34.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

Table 37. Negative Binomial Regression Results for Fatal and Injury Accidents on Entire Ramps, Including the Adjacent Speed-Change Lane (Reduced Model at 10-Percent Significance Level)

Independent variable[a]	Chi-square statistic[b]	Variable level	Direction of effect[c]	Coefficient	Relative effect[d]	90% confidence limits[e]	
						Lower	Upper
Intercept				-10.68		-12.37	-9.05
Ramp AADT (log)	143.91		-	0.91	2.49	0.77	1.05
Length of speed-change lane (mi)	8.11		-	-4.55	0.01	-7.21	-1.91
Ramp length (mi)	8.04		-	2.90	18.22	1.21	4.61
Ramp type	7.73	Off-ramp	-	0.49	1.63	0.20	0.78
		On-ramp	-	0	-		
Mainline freeway AADT (log)	7.66		-	0.29	1.33	0.12	0.46

NOTE: This analysis is based on the set of 467 ramps for which summary statistics are shown in table 34.
Conversion: 1 mi = 1.61 km.

[a] All variables significant at the 90% confidence level or higher.
[b] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[c] Direction of effect: I = Inverse of expected direction.
[d] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[e] 90% lower and upper confidence limits of the estimated coefficient.

This appeared to have the potential to create models for both total accidents and fatal and injury accidents that incorporate the same set of seven independent variables:

- Ramp AADT.
- Mainline freeway AADT.
- Area type (rural/urban).
- Ramp type (off/on).
- Ramp configuration.
- Length of speed-change lane.
- Ramp length.

The reduced models, including all variables significant at the 20-percent level, are presented in tables 38 and 39 for total and fatal and injury accidents, respectively. The model diagnostics for the models shown in tables 38 and 39 are presented in the fourth column of table 35 (with the heading, Reduced Model at 20-Percent Significance Level). The models in tables 38 and 39 contain the same set of independent variables except that ramp configuration, which was statistically significant in the model for total accidents in table 38, was not significant in the model for fatal and injury accidents in table 39.

The use of these models to predict accident frequencies is discussed below. To predict the average accident frequency for a ramp including the adjacent speed-change lane, the regression coefficients β_0, β_1, β_2,... β_q are replaced in equation (13) by the estimated values of the coefficients found in tables 38 and 39, and the variables X_1, X_2, ..., X_q are replaced by their appropriate values or levels. For example, the expected 3-year total accident frequency can be estimated using the model presented in table 38 as:

$$Y = e^{-7.27} (X_1)^{0.78} (X_2)^{0.13} \exp(0.45X_3) \exp(0.78X_4) \exp(-0.02X_5) \exp(0.69X_6) \exp(-0.37X_7) \exp(0.37X_8) \exp(-2.59X_9) \exp(1.62X_{10}) \quad (15)$$

where

Y = expected number of total accidents in a 3-year period on entire ramp plus adjacent speed-change lane
X_1 = ramp AADT (veh/day)
X_2 = mainline freeway AADT for the direction of travel in which the ramp is located (veh/day)
X_3 = 1 if the ramp is a diamond ramp; 0 otherwise
X_4 = 1 if the ramp is a parclo loop ramp; 0 otherwise
X_5 = 1 if the ramp is a free-flow loop ramp; 0 otherwise
X_6 = 1 if the ramp is an outer connection ramp; 0 otherwise
X_7 = 1 if the area type is rural; 0 otherwise
X_8 = 1 if the ramp is an off-ramp; 0 otherwise
X_9 = speed-change lane length (mi)
X_{10} = ramp length (mi)

Note that when the level of a categorical variable is 0, the multiplicative term in equation (15) becomes $e^0 = 1$, and is, therefore, omitted from the model.

Table 38. **Negative Binomial Regression Results for Total Accidents on Entire Ramps, Including the Adjacent Speed-Change Lane (Reduced Model at 20-Percent Significance Level)**

Independent variable	Chi-square statistic[a]	Variable level	Direction of effect[b]	Coefficient	Relative effect[c]	80% confidence limits[d] Lower	Upper
Intercept				-7.27		-8.69	-5.87
Ramp AADT (log)[e]	131.43			0.78	2.18	0.69	0.88
Ramp configuration[e]	9.55	Diamond	-	0.45	1.57	0.14	0.75
		Parclo loop	-	0.78	2.17	0.35	1.20
		Free-flow loop	-	-0.02	0.98	-0.59	0.56
		Outer connection	-	0.69	2.00	0.32	1.06
		Direct or semi-direct connection	-	0	-	-	-
Area type[e]	5.26	Rural	-	-0.37	0.69	-0.57	-0.16
		Urban	-	0	-	-	-
Ramp type[e]	5.26	Off-ramp	-	0.37	1.45	0.16	0.58
		On-ramp	-	0	-	-	-
Length of speed-change lane (mi)[e]	3.05		-	-2.59	0.07	-4.50	-0.69
Ramp length[e]	3.00		-	1.62	5.03	0.42	2.81
Mainline freeway AADT (log)	1.78		-	0.13	1.14	0.01	0.25

NOTE: This analysis is based on the set of 467 ramps for which summary statistics are shown in table 34.
Conversion: 1 mi = 1.61 km.

[a] Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
[b] Direction of effect: I = Inverse of expected direction.
[c] Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
[d] 80% lower and upper confidence limits of the estimated coefficient.
[e] Variable significant at the 90% confidence level or higher.

Table 39. Negative Binomial Regression Results for Fatal and Injury Accidents on Entire Ramps, Including the Adjacent Speed-Change Lane (Reduced Model at 20-Percent Significance Level)

Independent variable	Chi-square statistic[a]	Variable level	Direction of effect[b]	Coefficient	Relative effect[c]	80% confidence limits[d]	
						Lower	Upper
Intercept				-9.67		-11.28	-8.10
Ramp AADT (log)[e]	111.68		-	0.87	2.38	0.75	0.99
Ramp length (mi)[e]	7.76		-	2.85	17.35	1.54	4.18
Length of speed-change lane (mi)[e]	7.62		-	-4.42	0.01	-6.49	-2.36
Ramp type[e]	7.45	Off-ramp	-	0.48	1.62	0.25	0.71
		On-ramp	-	0	-	-	-
Mainline freeway AADT (log)[e]	4.24		-	0.23	1.26	0.09	0.38
Area type	1.87	Rural	-	-0.26	0.77	-0.50	-0.02
		Urban	-	0	-	-	-

NOTE: This analysis is based on the set of 467 ramps for which summary statistics are shown in table 34.
Conversion: 1 mi = 1.61 km.

a Chi-square likelihood ratio statistic for testing the significance of the effect of the variable, with 1 degree of freedom for continuous variables and (p-1) degrees of freedom for categorical variables with p levels.
b Direction of effect: I = Inverse of expected direction.
c Relative effect of unit change in the variable on the expected number of accidents, equals exp(coefficient).
d 80% lower and upper confidence limits of the estimated coefficient.
e Variable significant at the 90% confidence level or higher.

Similarly, the expected 3-year fatal and injury accident frequency for a ramp, including the adjacent speed-change lane, can be estimated using the model presented in table 40 as:

$$Y = e^{-9.67}\ (X_1)^{0.87}\ (X_2)^{0.23} \exp(2.85X_3) \exp(-4.42X_4) \exp(0.48X_5) \exp(-0.26X_6) \qquad (16)$$

where

Y = expected number of fatal and injury accidents in a 3-year period on entire ramp, including adjacent speed-change lane
X_1 = ramp AADT (veh/day)
X_2 = mainline freeway AADT for the direction of travel in which the ramp is located (veh/day)
X_3 = ramp length (mi)
X_4 = speed-change lane length (mi)
X_5 = 1 if ramp is an off-ramp; 0 otherwise
X_6 = 1 if the area type is rural; 0 otherwise

Numerical examples of the application of these models are presented later in this section.

Selected Urban Off-Ramps

A final set of models of selected ramp configurations was developed for urban off-ramps. The purpose of these analyses was twofold. First, this approach enabled the investigation of whether better models could be developed if modeling were focused on a single ramp type and configuration rather than across ramp types and configurations. Focusing on a single ramp type and configuration reduces the number of ramps and accidents in the available sample, but may increase the ability of models to predict accident experience. Urban off-ramps were selected for this modeling effort because they generally experience more accidents than any other combination of area type and ramp type. Second, this modeling effort was conducted to test the relationship to accidents of three alternative measures for characterizing the horizontal alignment of ramps (see section 4). Only a limited effort could be devoted to data collection for determining these measures, so it was decided to focus on a sample of approximately 200 urban off-ramps.

The data selected for this modeling effort included:

- 118 urban diamond off-ramps.
- 4 urban parclo loop off-ramps.
- 24 urban free-flow loop off-ramps.
- 19 urban outer connection off-ramps.

The data sets used for these four ramp configurations were those for entire ramps (i.e., these analyses used subsets of the data for 551 entire ramps whose analysis was described earlier). Models were developed for these four data sets and for a data set combining the parclo and free-flow loop off-ramps. However, because of the limited sample sizes in most of these groups, usable models were obtained only for the diamond off-ramps. The distributions of total and fatal and injury accidents for the urban diamond off-ramps are shown in figure 13 in appendix D. Similar accident distributions for urban loop and outer connection off-ramps are shown in figures 14 and 15, respectively, in appendix D.

Urban Diamond Off-Ramps

The selection of independent variables for the analysis of urban diamond off-ramps was done in a similar manner to that described for the previous modeling efforts. Table 40 identifies the variables selected for modeling accidents on urban diamond off-ramps. Two additional geometric features were considered in these models—the general grade of the ramp (upgrade/downgrade) and the horizontal alignment measures defined in section 4 (see table 8). A total of 115 urban diamond off-ramps, with both grade and curvature information, were available.

Since three alternative measures of horizontal alignment—the minimum radius of any curve on the ramp and two variations of the horizontal alignment index representing the curviness of the ramp—were defined in section 4, each analysis was repeated three times, once for each horizontal alignment measure. This approach allowed the relationship to accidents of the three alternative horizontal alignment measures to be compared.

Of the 115 urban diamond off-ramps, 42.6 percent experienced zero or one total accident, while 64.3 percent experienced zero or one fatal and injury accident during the 3-year study period. Both Poisson regression and NB regression models were fit to these data.

A total of 12 models were fit to these data for all combinations of:

- 2 modeling distributions—Poisson and NB.
- 2 dependent variables—total accidents and fatal and injury accidents.
- 3 horizontal alignment measures.

For all of these models, the regression results were very poor as measured by either the mean deviance, the Pearson chi-square, or the goodness-of-fit criteria (R^2 and R^2_{FT}).

Table 41 summarizes the Poisson and NB full regression model results (separately for total and fatal and injury accidents) using one of the three measures of horizontal alignment. As shown in table 39, four independent variables, both continuous and categorical, were considered in all the full models. The deviance (a measure of overdispersion) is large for all Poisson models, with a value of approximately 15 for total accidents and approximately 5 for fatal and injury accidents. The two goodness-of-fit criteria, R^2 and R^2_{FT}, are low, with values of approximately 10 to 11 percent for R^2 and approximately 4 to 5 percent for R^2_{FT}.

Table 40. Descriptive Statistics for Urban Diamond Off-Ramps

Parameter	Grade of ramp	Percent of ramps	Minimum	Mean	Median	Maximum	Total
Number of ramps: 115							
Total accidents: 1993 through 1995 combined			0	3.42	2	18	393
Fatal and injury accidents: 1993 through 1995 combined			0	1.53	1	12	176
Ramp AADT (veh/day)			89	6,080	5,168	17,368	
Ramp length (mi)			0.07	0.17	0.17	0.40	19.42
Minimum radius of horizontal curvature[a]			60	1,274	1,000	2,500	
Horizontal alignment index from equation (1)[a]			0	23.65	8.15	238.85	
Horizontal alignment index from equation (1) (modified)[a]			0	5.41	3.68	28.01	
Grade	Downgrade	39.1					
	Upgrade	60.9					

Conversion: 1 mi = 1.61 km.

[a] Refer to table 8 and accompanying text for definitions.

Table 41. Model Diagnostics for Total and Fatal and Injury Accidents on Urban Diamond Off-Ramps

Poisson and Negative Binomial Regression Models	Measure of horizontal curvature considered[a]					
	Minimum radius		Horizontal alignment index from equation (1)		Horizontal alignment index from equation (1) (modified)	
	Full Poisson model	Full NB model	Full Poisson model	Full NB model	Full Poisson model	Full NB model
Total accidents (3-year period)						
Number of ramps (n)	115	115	115	115	115	115
Number of parameters in model	4	4	4	4	4	4
Parameters degrees of freedom[b] (p)	5	5	5	5	5	5
k factor	na[c]	1.35	na	1.30	na	1.32
Deviance/(n-p)	15.38	1.00	15.16	1.00	15.10	1.00
Pearson chi-square/(n-p)	15.38	0.65	15.16	0.64	15.10	0.64
R^2 (%)	10	nc[d]	11	nc	11	nc
R^2_{FT} (%)	4	nc	5	nc	5	nc
Fatal and injury accidents (3-year period)						
Number of ramps (n)	115	115	115	115	115	115
Number of parameters in model	4	4	4	4	4	4
Parameters degrees of freedom[b] (p)	5	5	5	5	5	5
k factor	na	1.25	na	1.25	na	1.25
Deviance/(n-p)	4.79	1.01	4.77	1.00	4.74	1.01
Pearson chi-square/(n-p)	4.79	0.84	4.77	0.84	4.74	0.84
R^2 (%)	10	3	10	6	10	5
R^2_{FT} (%)	5	1	5	4	5	3

[a] Refer to table 8 and accompanying text for definitions.
[b] Includes one degree of freedom for the intercept.
[c] Not applicable. The k factor does not apply to Poisson models.
[d] Not calculated. Statistic could not be estimated (negative value found).

An attempt was made to fit an NB regression model to each of the above sets of data. Using the variance adjustment factors (k) shown in table 39, the overdispersion of the data found in the Poisson models could be reduced. However, in all of the NB models for total accidents, the Pearson chi-square, with values of approximately 0.65, remained well below the lower limit of the acceptable range (0.8 to 1.2). Thus, neither the Poisson nor the NB models provide a good fit to these data. The Pearson chi-square values for fatal and injury accidents are approximately 0.84, just inside the acceptable range. The two goodness-of-fit criteria, R^2 and R^2_{FT}, could not be calculated for total accidents because the estimated values were negative in all cases. For fatal and injury accidents, these goodness-of-fit criteria had values generally below 6 percent.

Based on these poor regression results, it was decided not to pursue the reduced model of either type (i.e., exclude all variables that are not statistically significant in the full models). To summarize the above results, table 42 lists those variables that were statistically significant at the 10-percent level in each of the above 12 models. As shown in table 42, none of the models includes grade.

In all the Poisson models, horizontal alignment (in whatever form it was used) was statistically significant at the 10-percent significance level, while none of the NB models retained horizontal alignment in either form. All Poisson models for total accidents included ramp length, while none of the Poisson models for fatal and injury accidents did so. Finally, when modeling fatal and injury accidents using the NB model, only traffic volume (log of AADT) remained statistically significant at the 10-percent level.

Although the horizontal alignment variables were statistically significant in the Poisson models (as shown in table 42), these models did not fit the data well because of overdispersion. One of the effects of overdispersion is to underestimate the variance of the model coefficients. As a result, some variables may be found to be statistically significant when, in fact, they are not. Since the horizontal alignment variables were not statistically significant in the NB models, it seems that their apparent significance in the Poisson models may have been due to overdispersion.

Other Urban Off-Ramp Configurations

The results obtained from the analysis of urban diamond off-ramps presented above were disappointing because the models did not fit the data well and because no reliable safety effects could be found for the horizontal alignment variables. Because of the strong interest in quantifying the effect of horizontal alignment on safety, if possible, a decision was made to repeat the analyses presented in tables 40 through 42 using all 165 of the 4 types of urban off-ramps listed above, rather than just the 115 urban diamond off-ramps. This analysis was conducted omitting ramp configuration as an independent variable in the hope that the horizontal alignment variable might serve to distinguish between diamond

Table 42. Summary of Statistically Significant Variables in Modeling Accidents on Urban Diamond Off-Ramps

	Models with minimum radius[a]		Models with horizontal alignment index from equation (1)[a]		Models with horizontal alignment index from equation (1) (modified)[a]	
	Poisson model	NB model	Poisson model	NB model	Poisson model	NB model
Total accidents	Ramp AADT (log) Ramp length Minimum radius	Ramp AADT (log) Ramp length	Ramp AADT (log) Horizontal alignment index No. 1 Ramp length	Ramp AADT (log) Ramp length	Ramp AADT (log) Horizontal alignment index No. 2 Ramp length	Ramp AADT (log) Ramp length
Fatal and injury accidents	Ramp AADT (log) Minimum radius	Ramp AADT (log)	Ramp AADT (log) Horizontal alignment index No. 1	Ramp AADT (log)	Ramp AADT (log) Horizontal alignment index No. 2	Ramp AADT (log)

[a] Refer to table 8 and accompanying text for definitions.

ramps, which are generally straight, and loop and outer connection off-ramps, which are generally curved. However, the results of this analysis were similar to those reported above for urban diamond off-ramps in that the models did not fit the data well and none of the horizontal alignment variables were statistically significant. These efforts suggest that it is difficult to model accident frequency for specific ramp types, particularly when the available sample size is limited.

Discussion of Results

The statistical modeling results presented in this section suggest that the best models of the safety performance of interchange ramps and speed-change lanes can be obtained by combining the accident experience of ramps and their adjacent speed-change lanes into a single model. The models presented in tables 38 and 39 for total accidents and fatal and injury accidents, respectively, fit the available data better than other models developed during the research, based on the values of the goodness-of-fit criteria (R^2, R^2_{FT}) the scaled deviance, and the Pearson chi-square. These models include the effects of several key variables that are known from previous research to affect the safety performance of ramps and speed-change lanes. These models are also presented in equations (15) and (16).

The ramp and speed-change lane characteristics, whose relationship to accident frequency was documented in the research, were:

- Ramp AADT.
- Mainline freeway AADT.
- Area type (rural/urban).
- Ramp type (off/on).
- Ramp configuration.
- Ramp length.
- Speed-change lane length.

These seven independent variables are all statistically significant at the 20-percent significance level in the model for total accidents in table 38, and all of these independent variables, except ramp configuration, are significant in the model for fatal and injury accidents in table 39.

The models in tables 38 and 39 provide useful accident frequency predictions that show how safely ramps typically operate and that illustrate some of the important variations in safety performance among types of ramps. Table 43 presents expected values of annual accident frequency for rural off-ramps with various ramp lengths, speed-change lane lengths, ramp configurations, and various levels of ramp and mainline freeway AADT. The values of ramp length used in the table are typical of the individual ramp configurations, and the values of ramp and mainline freeway AADT were selected to cover a typical range. The expected values shown in the table range from 0.06 to 0.35 total accidents per ramp per year and from 0.02 to 0.24 fatal and injury accidents per ramp per year. All of these expected values of accident frequency include accidents on both the ramp and the adjacent speed-change lane.

Table 43. Expected Accident Experience for Rural Off-Ramps

Ramp AADT (veh/day)	300	500	800	1,000
Mainline AADT (veh/day)	2,500	2,500	4,000	6,000
Length of speed-change lane (mi)	0.2	0.2	0.2	0.2
Ramp length (mi)				
Diamond	0.3	0.3	0.3	0.3
Parclo loop	0.3	0.3	0.3	0.3
Free-flow loop	0.4	0.4	0.4	0.4
Outer connection	0.4	0.4	0.4	0.4
Direct or semi-direct connection	0.7	0.7	0.7	0.7
Expected number of total accidents per ramp per year[a]				
Diamond	0.08	0.12	0.19	0.23
Parclo loop	0.11	0.17	0.26	0.32
Free-flow loop	0.06	0.09	0.14	0.17
Outer connection	0.12	0.18	0.28	0.35
Direct or semi-direct connection	0.10	0.15	0.23	0.28
Expected number of fatal and injury accidents per ramp per year[b]				
Diamond	0.02	0.03	0.06	0.08
Parclo loop	0.02	0.03	0.06	0.08
Free-flow loop	0.03	0.05	0.08	0.10
Outer connection	0.03	0.05	0.08	0.10
Direct or semi-direct connection	0.07	0.11	0.18	0.24

Conversion: 1 mi = 1.61 km.

[a] Based on the model presented in table 38 and equation (15). The 3-year model prediction is divided by 3 to obtain accidents per ramp per year.

[b] Based on the model presented in table 39 and equation (16). The 3-year model prediction is divided by 3 to obtain accidents per ramp per year.

Tables 44 through 46 present analogous data for rural on-ramps, urban off-ramps, and urban on-ramps, respectively. The highest expected accident frequencies are those for urban off-ramps, which range from 0.27 to 1.46 total accidents per ramp per year. It should be noted that tables 43 through 46 are based on statistical models that contain some variables that were statistically significant at the 20-percent significance level, but were not statistically significant at the 10-percent significance level. The use of such effects was necessary in order to include the effect of as many of the variables of interest as possible, but, in general, the use of effects that are not statistically significant at the 10-percent significance level is not preferred.

The lack of a ramp configuration effect in the model for fatal and injury accidents has the effect of producing higher predicted frequencies of fatal and injury accidents on direct and semi-direct connection ramps than appears appropriate. Direct and semi-direct connection ramps have the highest accident frequencies in the fatal and injury accident model, but have accident frequencies that are lower, relative to other ramp configurations, in the total accident model.

Table 44. Expected Accident Experience for Rural On-Ramps

Ramp AADT (veh/day)	300	500	800	1,000
Mainline AADT (veh/day)	2,500	2,500	4,000	6,000
Length of speed-change lane (mi)	0.2	0.2	0.2	0.2
Ramp length (mi)				
Diamond	0.3	0.3	0.3	0.3
Parclo loop	0.3	0.3	0.3	0.3
Free-flow loop	0.4	0.4	0.4	0.4
Outer connection	0.4	0.4	0.4	0.4
Direct or semi-direct connection	0.7	0.7	0.7	0.7
Expected number of total accidents per ramp per year[a]				
Diamond	0.06	0.08	0.13	0.16
Parclo loop	0.08	0.12	0.18	0.22
Free-flow loop	0.04	0.06	0.09	0.12
Outer connection	0.08	0.13	0.19	0.24
Direct or semi-direct connection	0.07	0.10	0.16	0.20
Expected number of fatal and injury accidents per ramp per year[b]				
Diamond	0.01	0.02	0.04	0.05
Parclo loop	0.01	0.02	0.04	0.05
Free-flow loop	0.02	0.03	0.05	0.06
Outer connection	0.02	0.03	0.05	0.06
Direct or semi-direct connection	0.04	0.07	0.11	0.15

Conversion: 1 mi = 1.61 km.

[a] Based on the model presented in table 38 and equation (15). The 3-year model prediction is divided by 3 to obtain accidents per ramp per year.

[b] Based on the model presented in table 39 and equation (16). The 3-year model prediction is divided by 3 to obtain accidents per ramp per year.

Table 45. Expected Accident Experience for Urban Off-Ramps

Ramp AADT (veh/day)	1,000	1,500	2,000	3,000
Mainline AADT (veh/day)	10,000	15,000	20,000	30,000
Length of speed-change lane (mi)	0.2	0.2	0.2	0.2
Ramp length (mi)				
Diamond	0.3	0.3	0.3	0.3
Parclo loop	0.3	0.3	0.3	0.3
Free-flow loop	0.4	0.4	0.4	0.4
Outer connection	0.4	0.4	0.4	0.4
Direct or semi-direct connection	0.7	0.7	0.7	0.7
Expected number of total accidents per ramp per year[a]				
Diamond	0.36	0.52	0.67	0.97
Parclo loop	0.50	0.72	0.94	1.35
Free-flow loop	0.27	0.38	0.50	0.72
Outer connection	0.54	0.78	1.01	1.46
Direct or semi-direct connection	0.44	0.63	0.82	1.19
Expected number of fatal and injury accidents per ramp per year[b]				
Diamond	0.11	0.17	0.24	0.37
Parclo loop	0.11	0.17	0.24	0.37
Free-flow loop	0.15	0.23	0.32	0.50
Outer connection	0.15	0.23	0.32	0.50
Direct or semi-direct connection	0.35	0.55	0.75	1.17

Conversion: 1 mi = 1.61 km.

[a] Based on the model presented in table 38 and equation (15). The 3-year model prediction is divided by 3 to obtain accidents per ramp per year.

[b] Based on the model presented in table 39 and equation (16). The 3-year model prediction is divided by 3 to obtain accidents per ramp per year.

Table 46. Expected Accident Experience for Urban On-Ramps

Ramp AADT (veh/day)	1,000	1,500	2,000	3,000
Mainline AADT (veh/day)	10,000	15,000	20,000	30,000
Length of speed-change lane (mi)	0.2	0.2	0.2	0.2
Ramp length (mi)				
Diamond	0.3	0.3	0.3	0.3
Parclo loop	0.3	0.3	0.3	0.3
Free-flow loop	0.4	0.4	0.4	0.4
Outer connection	0.4	0.4	0.4	0.4
Direct or semi-direct connection	0.7	0.7	0.7	0.7
Expected number of total accidents per ramp per year[a]				
Diamond	0.25	0.36	0.46	0.67
Parclo loop	0.34	0.50	0.64	0.93
Free-flow loop	0.18	0.26	0.34	0.50
Outer connection	0.37	0.54	0.70	1.01
Direct or semi-direct connection	0.30	0.44	0.57	0.82
Expected number of fatal and injury accidents per ramp per year[b]				
Diamond	0.07	0.11	0.15	0.23
Parclo loop	0.07	0.11	0.15	0.23
Free-flow loop	0.09	0.14	0.20	0.31
Outer connection	0.09	0.14	0.20	0.31
Direct or semi-direct connection	0.22	0.34	0.46	0.72

Conversion: 1 mi = 1.61 km.

[a] Based on the model presented in table 38 and equation (15). The 3-year model prediction is divided by 3 to obtain accidents per ramp per year.

[b] Based on the model presented in table 39 and equation (16). The 3-year model prediction is divided by 3 to obtain accidents per ramp per year.

It should be understood that the accident frequencies presented in tables 43 through 46 are expected or average values. In fact, accident frequencies can vary widely, even between similar ramps. As shown in figures 5 through 8 and in appendix D, many ramps have no accidents in a 3-year period, while a few ramps experience large numbers of accidents. The models presented here, which focus on expected values, are not intended to predict which specific ramps will have extremely high accident frequencies. Indeed, from the point of view of this statistical modeling effort, such concentrations of accidents appear to be random; in other words, they are not explained by the independent variables considered in this research.

Although the models used here for illustrative purposes are the best among the models developed for this report, it should be noted that their predictive power is directly related to their goodness-of-fit values. As seen in the last column of table 35, the Pearson chi-square statistics are 1.11 and 0.95 for total and fatal and injury accidents, respectively. These values are within the acceptable range of 0.8 to 1.2, indicating that the NB model provides an acceptable fit to the data. The additional two goodness-of-fit criteria, R^2 and R^2_{FT}, have values of 37 percent and 42 percent, respectively, for total accidents. Similarly, the R^2 and R^2_{FT} values are 34 percent and 36 percent, respectively, for fatal and injury accidents. In other words, approximately 58 to 64 percent of the variability in accident frequency is not explained by these specific models.

6. FINDINGS AND CONCLUSIONS

The following findings and conclusions were reached as a result of the statistical analysis of relationships between traffic accidents and geometrics of interchange ramps and speed-change lanes conducted in this research:

1. Traditional multiple linear regression is generally not an appropriate statistical approach to modeling accident relationships because accidents are discrete, non-negative events that often do not follow a normal distribution.

2. The Poisson and negative binomial distributions appear to be better suited to the modeling of accident relationships than the normal distribution. In all cases, the form of the statistical distribution selected for any particular modeling effort should be chosen based on a review of the data to be modeled.

3. The choice between the Poisson and the negative binomial distributions should be based on the overdispersion observed in the accident data. Overdispersion results when the variance of the accident data exceeds the mean of the Poisson distribution. Extra variation or overdispersion in a Poisson model causes underestimation of the variance of the model coefficients. This, in turn, results in overstating the significance of the coefficients; in other words, some coefficients may be found to be statistically significant when, in fact, they are not. In the modeling of accidents for interchange ramps and speed-change lanes with Poisson regression, overdispersion was commonly observed and, therefore, the negative binomial distribution was preferred.

4. Regression models to determine relationships between accidents and the geometric design and traffic volume characteristics of ramps, based on the negative binomial distribution, explained between 10 percent and 42 percent of the variability in the accident data.

5. Accident frequencies on interchange ramps and speed-change lanes are so low at most locations that they are very difficult to model. Between 50 percent and 80 percent of the ramps studied experienced no accidents or only one accident in the 3-year study period. Only a very few ramps experienced a substantial number of accidents during the 3-year period.

6. Negative binomial regression models developed to predict total accidents generally performed slightly better than did models to predict fatal and injury accidents.

7. Negative binomial regression models developed to predict the combined accident frequency for an entire ramp, together with its adjacent speed-change lane, generally fit the available accident data better than separate models for ramps and speed-change lanes.

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8. The independent variables, whose effects on accident frequency were most often found to be statistically significant, were:

    - Ramp AADT.
    - Mainline freeway AADT.
    - Area type (rural/urban).
    - Ramp type (off/on).
    - Ramp configuration (diamond/loop/outer connection/direct or semi-direct connection).
    - Ramp length.
    - Speed-change lane length.

    The ramp AADT was the strongest predictor of accident frequency; the other variables, while they were generally statistically significant, had much less predictive ability.

9. A number of other geometric design variables for ramps and speed-change lanes were considered in modeling. These included:

    - Traveled-way width for ramps and speed-change lanes.
    - Right shoulder width for ramps and speed-change lanes.
    - Left shoulder width for ramps.
    - Ramp grade (upgrade/downgrade).
    - Radii of horizontal curves on ramp.

    However, none of these geometric design variables was found to have a statistically significant relationship to accident frequency, except in limited situations in models that were not ultimately recommended for use.

10. The best models obtained for predicting accident frequencies for ramps and speed-change lanes are the model presented in table 38 for total accidents and the model presented in table 39 for fatal and injury accidents. These models are also presented in equations (15) and (16), respectively.

11. A review of hard-copy police accident reports found that rear-end accidents on urban off-ramps of four configurations (diamond, parclo loop, free-flow loop, and outer connection ramps) were generally related to the operation of the cross-road ramp terminal, rather than to the geometric design of the ramp itself. Only 5 percent of the rear-end accidents reviewed were not related to the operation of the cross-road ramp terminals.

APPENDIX A

DEFINITIONS OF GEOMETRIC DESIGN AND TRAFFIC VOLUME VARIABLES

This appendix presents definitions of the geometric design, traffic volume, and other related variables considered in the statistical modeling of interchange ramp and speed-change lane accidents. These definitions are presented in table 47. Table 47 includes both variables that were available in the existing Washington data base and variables that were derived from that data base and other highway agency records. The table identifies the variables that were considered in the analyses and whether each variable was applicable to ramp segments, entire ramps, or speed-change lanes. The table also identifies whether each variable was continuous or categorical in nature. Continuous variables are those with quantitative values on a continuous scale. Categorical variables are those with a finite number of discrete levels or categories. For each categorical variable, the tables in this appendix also identify the levels or categories that were available for that variable. Not all levels were considered in the statistical modeling; in some cases, because of sample size considerations, a particular category had to be excluded from the analyses or merged with adjacent categories. This process is described in section 5 of the main text of this report.

Table 47. **Definitions of Variables Considered in Statistical Modeling of Ramp and Speed-Change Lane Accidents**

Variable	Available for: Ramp segments	Entire ramps	Speed-change lanes	Variable type	Levels for categorical variables
Geometric Design Features					
Ramp type	X	X		Categorical	On-ramp Off-ramp
Speed-change lane type			X	Categorical	Deceleration lane Acceleration lane
Ramp configuration	X	X	X	Categorical	Diamond Parclo loop Free-flow loop Outer connection Direct connection Semi-direct connection Trumpet loop Trumpet outer connection Scissors connection Buttonhook Slip ramp to parallel one-way frontage road Slip ramp to parallel two-way frontage road Collector/distributor (C/D) road Other ramp configuration
Ramp segment type	X			Categorical	Ramp proper Two-way ramp proper segment Merge area on-ramp Diverge area on-ramp Weaving area on-ramp
Speed-change lane type			X	Categorical	Conventional deceleration lane Deceleration lane with mainline lane drop Conventional acceleration lane Acceleration lane with mainline lane addition
Number of lanes	X		X	Categorical	Range: 1 to 3 lanes
Traveled-way width (ft)	X		X	Continuous	
Average lane width (ft)	X		X	Continuous	
Right shoulder width (ft)	X		X	Continuous	
Left shoulder width (ft)	X			Continuous	

Table 47. Definitions of Variables Considered in Statistical Modeling of Ramp and Speed-Change Lane Accidents (Continued)

Variable	Available for: Ramp segments	Entire ramps	Speed-change lanes	Variable type	Levels for categorical variables
Minimum radius for any horizontal curve (ft)		X		Continuous	
Horizontal alignment index based on equation (1)		X		Continuous	
Horizontal alignment index based on equation (1) with exponent of D_i term equal to 1.0		X		Continuous	
General grade of ramp		X		Categorical	Upgrade Downgrade

APPENDIX B

ACCIDENT SEVERITY DISTRIBUTIONS BY RAMP SEGMENT TYPE FOR EIGHT SELECTED RAMP TYPES

This appendix presents accident severity distributions (fatal, injury, and property-damage-only accidents) by ramp segment type for the following eight selected ramp types in tables 48 through 55, respectively:

- Rural diamond off-ramps.
- Rural diamond on-ramps.
- Urban diamond off-ramps.
- Urban parclo loop off-ramps.
- Urban free-flow loop off-ramps.
- Urban outer connection off-ramps.
- Urban direct and semi-direct connection ramps.
- Urban C/D roads.

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Table 48. Accident Severity Distribution by Ramp Segment Type for Rural Diamond Off-Ramps (1993 Through 1995)

		Number and percentage of accidents by severity level							
		Fatal		Injury		Property damage only		Total	
Ramp segment type	Total length (mi)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	20.4	0	0.0	6	1.8	15	4.4	21	6.2
Deceleration lane with mainline lane drop	0.3	0	0.0	1	0.3	0	0.0	1	0.3
Ramp proper	70.6	2	0.6	64	18.9	96	28.3	162	47.8
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	1	0.3	60	17.7	94	27.7	155	45.7
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0
Total	91.3	3	0.9	131	38.6	205	60.5	339	100.0

Conversion: 1 mi = 1.61 km.

Table 49. Accident Severity Distribution by Ramp Segment Type for Rural Diamond On-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Number and percentage of accidents by severity level: Fatal Frequency	Fatal (%)	Injury Frequency	Injury (%)	Property damage only Frequency	Property damage only (%)	Total Frequency	Total (%)
Normal deceleration lane	0.0	-	-	-	-	-	-	-	-
Deceleration lane with mainline lane drop	0.0	-	-	-	-	-	-	-	-
Ramp proper	36.6	0	0.0	2	1.4	8	5.6	10	7.0
Normal acceleration lane	47.8	1	0.7	24	16.8	44	30.8	69	48.3
Acceleration lane with mainline lane addition	0.4	0	0.0	0	0.0	0	0.0	0	0.0
Mainline weaving area	0.0	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	0	0.0	29	20.3	35	24.5	64	44.8
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0
Total	84.8	1	0.7	55	38.5	87	60.8	143	100.0

Conversion: 1 mi = 1.61 km.

Table 50. Accident Severity Distribution by Ramp Segment Type for Urban Diamond Off-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Number and percentage of accidents by severity level							
		Fatal		Injury		Property damage only		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	13.7	0	0.0	64	3.7	66	3.8	130	7.6
Deceleration lane with mainline lane drop	1.2	0	0.0	20	1.2	23	1.3	43	2.5
Ramp proper	32.7	4	0.2	372	21.6	447	26.0	823	47.9
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	0	0.0	0	0.0	2	0.1	2	0.1
Merge area on ramp	0.0	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	0	0.0	334	19.4	383	22.3	717	41.7
Cross-road ramp terminal (free-flow)	-	0	0.0	3	0.2	1	0.1	4	0.2
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0
Total	47.6	4	0.2	793	46.1	922	53.6	1,719	100.0

Conversion: 1 mi = 1.61 km.

Table 51. **Accident Severity Distribution by Ramp Segment Type for Urban Parclo Loop Off-Ramps (1993 Through 1995)**

Ramp segment type	Total length (mi)	Number and percentage of accidents by severity level							
		Fatal		Injury		Property damage only		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	0.4	0	0.0	4	3.7	3	2.8	7	6.4
Deceleration lane with mainline lane drop	0.0	-	-	-	-	-	-	-	-
Ramp proper	0.8	0	0.0	18	16.5	14	12.8	32	29.4
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-
Mainline weaving area	0.1	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.6	0	0.0	5	4.6	6	5.5	11	10.1
Cross-road ramp terminal (stop condition)	-	0	0.0	29	26.6	30	27.5	59	54.1
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0
Total	1.9	0	0.0	56	51.4	53	48.6	109	100.0

Conversion: 1 mi = 1.61 km.

Table 52. Accident Severity Distribution by Ramp Segment Type for Urban Free-Flow Loop Off-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Number and percentage of accidents by severity level							
		Fatal		Injury		Property damage only		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	0.9	0	0.0	8	2.8	8	2.8	16	5.6
Deceleration lane with mainline lane drop	0.1	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	6.8	1	0.4	53	18.7	70	24.6	124	43.7
Normal acceleration lane	0.8	0	0.0	9	3.2	9	3.2	18	6.3
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-
Mainline weaving area	0.2	0	0.0	3	1.1	8	2.8	11	3.9
Diverge area on ramp	0.0	0	0.0	0	0.0	1	0.4	1	0.4
Merge area on ramp	0.0	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.2	0	0.0	5	1.8	8	2.8	13	4.6
Cross-road ramp terminal (stop condition)	-	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	-	0	0.0	59	20.8	42	14.8	101	35.6
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0
Total	9.0	1	0.4	137	48.2	146	51.4	284	100.0

Conversion: 1 mi = 1.61 km.

Table 53. Accident Severity Distribution by Ramp Segment Type for Urban Outer Connection Off-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Number and percentage of accidents by severity level							
		Fatal		Injury		Property damage only		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.0	0	0.0	11	1.6	13	1.9	24	3.4
Deceleration lane with mainline lane drop	0.1	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	9.9	1	0.1	148	21.2	185	26.5	334	47.9
Normal acceleration lane	1.1	0	0.0	4	0.6	3	0.4	7	1.0
Acceleration lane with mainline lane addition	0.1	0	0.0	2	0.3	4	0.6	6	0.9
Mainline weaving area	0.0	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	0	0.0	5	0.7	5	0.7	10	1.4
Merge area on ramp	0.0	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-
Two-way roadway on ramp	1.8	0	0.0	23	3.3	18	2.6	41	5.9
Cross-road ramp terminal (stop condition)	-	0	0.0	61	8.8	70	10.0	131	18.8
Cross-road ramp terminal (free-flow)	-	0	0.0	77	11.0	67	9.6	144	20.7
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0
Total	16.0	1	0.1	331	47.5	365	52.4	697	100.0

Conversion: 1 mi = 1.61 km.

Table 54. Accident Severity Distribution by Ramp Segment Type for Urban Direct and Semi-Direct Connection Ramps (1993 Through 1995)

		Number and percentage of accidents by severity level							
		Fatal		Injury		Property damage only		Total	
Ramp segment type	Total length (mi)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.5	0	0.0	11	2.0	18	3.3	29	5.3
Deceleration lane with mainline lane drop	1.4	0	0.0	3	0.5	6	1.1	9	1.6
Ramp proper	16.5	0	0.0	138	25.2	167	30.5	305	55.8
Normal acceleration lane	7.6	0	0.0	43	7.9	28	5.1	71	13.0
Acceleration lane with mainline lane addition	2.4	0	0.0	6	1.1	15	2.7	21	3.8
Mainline weaving area	0.2	0	0.0	0	0.0	2	0.4	2	0.4
Diverge area on ramp	1.3	1	0.2	19	3.5	21	3.8	41	7.5
Merge area on ramp	1.9	0	0.0	20	3.7	13	2.4	33	6.0
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	0	0.0	2	0.4	4	0.7	6	1.1
Cross-road ramp terminal (free-flow)	-	0	0.0	16	2.9	14	2.6	30	5.5
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0
Total	34.8	1	0.2	258	47.2	288	52.7	547	100.0

Conversion: 1 mi = 1.61 km.

Table 55. Accident Severity Distribution by Ramp Segment Type for Urban C/D Roads (1993 Through 1995)

Ramp segment type	Total length (mi)	Number and percentage of accidents by severity level							
		Fatal		Injury		Property damage only		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.4	0	0.0	5	0.6	9	1.0	14	1.6
Deceleration lane with mainline lane drop	1.1	0	0.0	2	0.2	4	0.4	6	0.7
Ramp proper	10.9	3	0.3	280	31.3	275	30.7	558	62.3
Normal acceleration lane	7.9	0	0.0	11	1.2	19	2.1	30	3.4
Acceleration lane with mainline lane addition	1.7	0	0.0	2	0.2	7	0.8	9	1.0
Mainline weaving area	0.0	-	-	-	-	-	-	-	-
Diverge area on ramp	3.0	0	0.0	80	8.9	67	7.5	147	16.4
Merge area on ramp	2.0	0	0.0	0	0.0	0	0.0	0	0.0
Weaving area on ramp	3.3	0	0.0	55	6.1	76	8.5	131	14.6
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0
Total	33.3	3	0.3	435	48.6	457	51.1	895	100.0

Conversion: 1 mi = 1.61 km.

APPENDIX C

ACCIDENT TYPE DISTRIBUTIONS BY RAMP SEGMENT TYPE FOR EIGHT SELECTED RAMP TYPES

This appendix presents accident type distributions by ramp segment type for the following eight selected ramp types in tables 56 through 63, respectively:

- Rural diamond off-ramps.
- Rural diamond on-ramps.
- Urban diamond off-ramps.
- Urban parclo loop off-ramps.
- Urban free-flow loop off-ramps.
- Urban outer connection off-ramps.
- Urban direct and semi-direct connection ramps.
- Urban C/D roads.

In the tables, accident types are classified into the following categories:

- Single-vehicle noncollision accidents:
  - Ran off road
  - Overturned
  - Other

- Single-vehicle collision accidents with:
  - Parked vehicle
  - Pedestrian
  - Bicycle
  - Fixed object
  - Other collision

- Multiple-vehicle collision accidents:
  - Head-on
  - Sideswipe
  - Rear-end
  - Angle
  - Left turn
  - Right turn
  - Other collision

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Table 56. Accident Type Distribution by Ramp Segment Type for Rural Diamond Off-Ramps (1993 through 1995)

				Number and percentage of single-vehicle noncollision accidents							
	Total length	Total accidents		Ran off road		Overturned		Other		Total	
Ramp segment type	(mi)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	20.4	21	6.2	2	0.6	5	1.5	0	0.0	7	2.1
Deceleration lane with mainline lane drop	0.3	1	0.3	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	70.6	162	47.8	2	0.6	24	7.1	6	1.8	32	9.4
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	155	45.7	2	0.6	3	0.9	5	1.5	10	3.0
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	91.3	339	100.0	6	1.8	32	9.4	11	3.2	49	14.5

Conversion: 1 mi = 1.61 km.

Table 56. Accident Type Distribution by Ramp Segment Type for Rural Diamond Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle collision accidents with:											
				Parked vehicle		Pedestrian		Bicycle		Fixed object		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	20.4	21	6.2	1	0.3	0	0.0	0	0.0	5	1.5	0	0.0	6	1.8
Deceleration lane with mainline lane drop	0.3	1	0.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	70.6	162	47.8	0	0.0	1	0.3	0	0.0	37	10.9	8	2.4	46	13.6
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	155	45.7	0	0.0	2	0.6	1	0.3	11	3.2	0	0.0	14	4.1
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	91.3	339	100.0	1	0.3	3	0.9	1	0.3	53	15.6	8	2.4	66	19.5

Conversion: 1 mi = 1.61 km.

Table 56. Accident Type Distribution by Ramp Segment Type for Rural Diamond Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of multiple-vehicle collision accidents															
				Head-on		Sideswipe		Rear-end		Angle		Left turn		Right turn		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	20.4	21	6.2	0	0.0	0	0.0	2	0.6	5	1.5	0	0.0	0	0.0	1	0.3	8	2.4
Deceleration lane with mainline lane drop	0.3	1	0.3	0	0.0	0	0.0	1	0.3	0	0.0	0	0.0	0	0.0	0	0.0	1	0.3
Ramp proper	70.6	162	47.8	1	0.3	0	0.0	43	12.7	30	8.9	0	0.0	0	0.0	10	3.0	84	24.8
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	155	45.7	0	0.0	0	0.0	53	15.6	16	4.7	23	6.8	33	9.7	6	1.8	131	38.6
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	91.3	339	100.0	1	0.3	0	0.0	99	29.2	51	15.0	23	6.8	33	9.7	17	5.0	224	66.1

Conversion: 1 mi = 1.61 km.

Table 57. Accident Type Distribution by Ramp Segment Type for Rural Diamond On-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle noncollision accidents							
				Ran off road		Overturned		Other		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	0.0	-	-	-	-	-	-	-	-	-	-
Deceleration lane with mainline lane drop	0.0	-	-	-	-	-	-	-	-	-	-
Ramp proper	36.6	10	7.0	0	0.0	0	0.0	0	0.0	0	0.0
Normal acceleration lane	47.8	69	48.3	4	2.8	10	7.0	3	2.1	17	11.9
Acceleration lane with mainline lane addition	0.4	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	64	44.8	0	0.0	3	2.1	0	0.0	3	2.1
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	84.8	143	100.0	4	2.8	13	9.1	3	2.1	20	14.0

Conversion: 1 mi = 1.61 km.

Table 57. Accident Type Distribution by Ramp Segment Type for Rural Diamond On-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle collision accidents with: Parked vehicle		Pedestrian		Bicycle		Fixed object		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Deceleration lane with mainline lane drop	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ramp proper	36.6	10	7.0	0	0.0	0	0.0	0	0.0	2	1.4	2	1.4	4	2.8
Normal acceleration lane	47.8	69	48.3	1	0.7	0	0.0	0	0.0	11	7.7	0	0.0	12	8.4
Acceleration lane with mainline lane addition	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	64	44.8	0	0.0	0	0.0	0	0.0	14	9.8	0	0.0	14	9.8
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	84.8	143	100.0	1	0.7	0	0.0	0	0.0	27	18.9	2	1.4	30	21.0

Conversion: 1 mi = 1.61 km.

Table 57. Accident Type Distribution by Ramp Segment Type for Rural Diamond On-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of multiple-vehicle collision accidents: Head-on		Sideswipe		Rear-end		Angle		Left turn		Right turn		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Deceleration lane with mainline lane drop	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ramp proper	36.6	10	7.0	0	0.0	0	0.0	3	2.1	3	2.1	0	0.0	0	0.0	0	0.0	6	4.2
Normal acceleration lane	47.8	69	48.3	0	0.0	1	0.7	18	12.6	17	11.9	0	0.0	0	0.0	4	2.8	40	28.0
Acceleration lane with mainline lane addition	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	64	44.8	0	0.0	0	0.0	2	1.4	6	4.2	3	2.1	36	25.2	0	0.0	47	32.9
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	84.8	143	100.0	0	0.0	1	0.7	23	16.1	26	18.2	3	2.1	36	25.2	4	2.8	93	65.0

Conversion: 1 mi = 1.61 km.

Table 58. Accident Type Distribution by Ramp Segment Type for Urban Diamond Off-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle noncollision accidents							
				Ran off road		Overturned		Other		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	13.7	130	7.6	0	0.0	7	0.4	2	0.1	9	0.5
Deceleration lane with mainline lane drop	1.2	43	2.5	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	32.7	823	47.9	9	0.5	23	1.3	11	0.6	43	2.5
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	2	0.1	0	0.0	0	0.0	0	0.0	0	0.0
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	717	41.7	1	0.1	2	0.1	4	0.2	7	0.4
Cross-road ramp terminal (free-flow)	-	4	0.2	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	47.6	1,719	100.0	10	0.6	32	1.9	17	1.0	59	3.4

Conversion: 1 mi = 1.61 km.

Table 58. Accident Type Distribution by Ramp Segment Type for Urban Diamond Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle collision accidents with:											
				Parked vehicle		Pedestrian		Bicycle		Fixed object		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	13.7	130	7.6	0	0.0	1	0.1	0	0.0	15	0.9	0	0.0	16	0.9
Deceleration lane with mainline lane drop	1.2	43	2.5	0	0.0	1	0.1	0	0.0	3	0.2	0	0.0	4	0.2
Ramp proper	32.7	823	47.9	0	0.0	5	0.3	2	0.1	66	3.8	4	0.2	77	4.5
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	2	0.1	0	0.0	0	0.0	0	0.0	2	0.1	0	0.0	2	0.1
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	717	41.7	1	0.1	2	0.1	3	0.2	18	1.0	0	0.0	24	1.4
Cross-road ramp terminal (free-flow)	-	4	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	47.6	1,719	100.0	1	0.1	9	0.5	5	0.3	104	6.1	4	0.2	123	7.2

Conversion: 1 mi = 1.61 km.

Table 58. Accident Type Distribution by Ramp Segment Type for Urban Diamond Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of multiple-vehicle collision accidents																			
				Head-on		Sideswipe		Rear-end		Angle		Left turn		Right turn		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	13.7	130	7.6	0	0.0	0	0.0	83	4.8	18	1.0	0	0.0	0	0.0	4	0.2	105	6.1
Deceleration lane with mainline lane drop	1.2	43	2.5	0	0.0	0	0.0	25	1.5	14	0.8	0	0.0	0	0.0	0	0.0	39	2.3
Ramp proper	32.7	823	47.9	0	0.0	2	0.1	451	26.2	196	11.4	0	0.0	0	0.0	54	3.1	703	40.9
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	2	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	717	41.7	0	0.0	0	0.0	356	20.7	57	3.3	100	5.8	163	9.5	10	0.6	686	39.9
Cross-road ramp terminal (free-flow)	-	4	0.2	0	0.0	0	0.0	3	0.2	1	0.1	0	0.0	0	0.0	0	0.0	4	0.2
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	47.6	1,719	100.0	0	0.0	2	0.1	918	53.4	286	16.6	100	5.8	163	9.5	68	4.0	1537	89.4

Conversion: 1 mi = 1.61 km.

Table 59. Accident Type Distribution by Ramp Segment Type for Urban Parclo Loop Off-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle noncollision accidents							
				Ran off road		Overturned		Other		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	0.4	7	6.4	0	0.0	2	1.8	1	0.9	3	2.8
Deceleration lane with mainline lane drop	0.0	-	-	-	-	-	-	-	-	-	-
Ramp proper	0.8	32	29.4	0	0.0	2	1.8	1	0.9	3	2.8
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.6	11	10.1	1	0.9	0	0.0	0	0.0	1	0.9
Cross-road ramp terminal (stop condition)	-	59	54.1	1	0.9	0	0.0	0	0.0	1	0.9
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	1.9	109	100.0	2	1.8	4	3.7	2	1.8	8	7.3

Conversion: 1 mi = 1.61 km.

Table 59. Accident Type Distribution by Ramp Segment Type for Urban Parclo Loop Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle collision accidents with:											
				Parked vehicle		Pedestrian		Bicycle		Fixed object		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	0.4	7	6.4	0	0.0	0	0.0	0	0.0	3	2.8	0	0.0	3	2.8
Deceleration lane with mainline lane drop	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ramp proper	0.8	32	29.4	0	0.0	0	0.0	0	0.0	3	2.8	0	0.0	3	2.8
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.6	11	10.1	0	0.0	0	0.0	0	0.0	1	0.9	0	0.0	1	0.9
Cross-road ramp terminal (stop condition)	-	59	54.1	0	0.0	0	0.0	0	0.0	1	0.9	0	0.0	1	0.9
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	1.9	109	100.0	0	0.0	0	0.0	0	0.0	8	7.3	0	0.0	8	7.3

Conversion: 1 mi = 1.61 km.

Table 59. Accident Type Distribution by Ramp Segment Type for Urban Parclo Loop Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of multiple-vehicle collision accidents															
				Head-on		Sideswipe		Rear-end		Angle		Left turn		Right turn		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	0.4	7	6.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.9	1	0.9
Deceleration lane with mainline lane drop	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ramp proper	0.8	32	29.4	0	0.0	0	0.0	22	20.2	2	1.8	0	0.0	0	0.0	2	1.8	26	23.9
Normal acceleration lane	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Diverge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.6	11	10.1	0	0.0	0	0.0	7	6.4	2	1.8	0	0.0	0	0.0	0	0.0	9	8.3
Cross-road ramp terminal (stop condition)	-	59	54.1	0	0.0	0	0.0	37	33.9	1	0.9	16	14.7	3	2.8	0	0.0	57	52.3
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	1.9	109	100.0	0	0.0	0	0.0	66	60.6	5	4.6	16	14.7	3	2.8	3	2.8	93	85.3

Conversion: 1 mi = 1.61 km.

Table 60. Accident Type Distribution by Ramp Segment Type for Urban Free-Flow Loop Off-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle noncollision accidents							
				Ran off road		Overturned		Other		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	1.0	16	5.6	1	0.4	3	1.1	0	0.0	4	1.4
Deceleration lane with mainline lane drop	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	6.8	124	43.7	2	0.7	15	5.3	2	0.7	19	6.7
Normal acceleration lane	0.8	18	6.3	0	0.0	0	0.0	0	0.0	0	0.0
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.2	11	3.9	0	0.0	0	0.0	0	0.0	0	0.0
Diverge area on ramp	0.0	1	0.4	0	0.0	1	0.4	0	0.0	1	0.4
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.2	13	4.6	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (stop condition)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	-	101	35.6	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	8.9	284	100.0	3	1.1	19	6.7	2	0.7	24	8.5

Conversion: 1 mi = 1.61 km.

Table 60. Accident Type Distribution by Ramp Segment Type for Urban Free-Flow Loop Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle collision accidents with:											
				Parked vehicle		Pedestrian		Bicycle		Fixed object		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	1.0	16	5.6	0	0.0	0	0.0	0	0.0	10	3.5	0	0.0	10	3.5
Deceleration lane with mainline lane drop	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	6.8	124	43.7	0	0.0	0	0.0	2	0.7	29	10.2	1	0.4	32	11.3
Normal acceleration lane	0.8	18	6.3	0	0.0	0	0.0	0	0.0	1	0.4	0	0.0	1	0.4
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.2	11	3.9	0	0.0	0	0.0	0	0.0	1	0.4	0	0.0	1	0.4
Diverge area on ramp	0.0	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.2	13	4.6	0	0.0	0	0.0	0	0.0	1	0.4	0	0.0	1	0.4
Cross-road ramp terminal (stop condition)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	-	101	35.6	0	0.0	0	0.0	0	0.0	3	1.1	0	0.0	3	1.1
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	8.9	284	100.0	0	0.0	0	0.0	2	0.7	45	15.8	1	0.4	48	16.9

Conversion: 1 mi = 1.61 km.

Table 60. Accident Type Distribution by Ramp Segment Type for Urban Free-Flow Loop Off-Ramps (1993 Through 1995) (Continued)

				Number and percentage of multiple-vehicle collision accidents															
	Total length	Total accidents		Head-on		Sideswipe		Rear-end		Angle		Left turn		Right turn		Other collision		Total	
Ramp segment type	(mi)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	1.0	16	5.6	0	0.0	0	0.0	1	0.4	1	0.4	0	0.0	0	0.0	0	0.0	2	0.7
Deceleration lane with mainline lane drop	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	6.8	124	43.7	0	0.0	0	0.0	52	18.3	21	7.4	0	0.0	0	0.0	0	0.0	73	25.7
Normal acceleration lane	0.8	18	6.3	0	0.0	0	0.0	12	4.2	5	1.8	0	0.0	0	0.0	0	0.0	17	6.0
Acceleration lane with mainline lane addition	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mainline weaving area	0.2	11	3.9	0	0.0	0	0.0	7	2.5	3	1.1	0	0.0	0	0.0	0	0.0	10	3.5
Diverge area on ramp	0.0	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	0.2	13	4.6	0	0.0	0	0.0	10	3.5	1	0.4	0	0.0	0	0.0	1	0.4	12	4.2
Cross-road ramp terminal (stop condition)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	-	101	35.6	0	0.0	0	0.0	89	31.3	8	2.8	0	0.0	0	0.0	1	0.4	98	34.5
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	8.9	284	100.0	0	0.0	0	0.0	171	60.2	39	13.7	0	0.0	0	0.0	2	0.7	212	74.6

Conversion: 1 mi = 1.61 km.

Table 61. Accident Type Distribution by Ramp Segment Type for Urban Outer Connection Off-Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle noncollision accidents							
				Ran off road		Overturned		Other		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.0	24	3.4	0	0.0	0	0.0	0	0.0	0	0.0
Deceleration lane with mainline lane drop	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	9.9	334	47.9	5	0.7	25	3.6	3	0.4	33	4.7
Normal acceleration lane	1.1	7	1.0	0	0.0	0	0.0	0	0.0	0	0.0
Acceleration lane with mainline lane addition	0.1	6	0.9	0	0.0	0	0.0	0	0.0	0	0.0
Mainline weaving area	0.0	–	–	–	–	–	–	–	–	–	–
Diverge area on ramp	0.0	10	1.4	0	0.0	2	0.3	1	0.1	3	0.4
Merge area on ramp	0.0	–	–	–	–	–	–	–	–	–	–
Weaving area on ramp	0.0	–	–	–	–	–	–	–	–	–	–
Two-way roadway on ramp	1.8	41	5.9	0	0.0	1	0.1	0	0.0	1	0.1
Cross-road ramp terminal (stop condition)	–	131	18.8	0	0.0	0	0.0	1	0.1	1	0.1
Cross-road ramp terminal (free-flow)	–	144	20.7	0	0.0	1	0.1	0	0.0	1	0.1
Frontage road connection	–	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	15.9	697	100.0	5	0.7	29	4.2	5	0.7	39	5.6

Conversion: 1 mi = 1.61 km.

Table 61. Accident Type Distribution by Ramp Segment Type for Urban Outer Connection Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle collision accidents with: Parked vehicle		Pedestrian		Bicycle		Fixed object		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.0	24	3.4	0	0.0	0	0.0	0	0.0	2	0.3	0	0.0	2	0.3
Deceleration lane with mainline lane drop	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	9.9	334	47.9	1	0.1	4	0.6	1	0.1	55	7.9	1	0.1	62	8.9
Normal acceleration lane	1.1	7	1.0	0	0.0	0	0.0	0	0.0	1	0.1	0	0.0	1	0.1
Acceleration lane with mainline lane addition	0.1	6	0.9	0	0.0	0	0.0	0	0.0	1	0.1	0	0.0	1	0.1
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	10	1.4	0	0.0	0	0.0	0	0.0	5	0.7	0	0.0	5	0.7
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	1.8	41	5.9	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (stop condition)	-	131	18.8	0	0.0	0	0.0	1	0.1	2	0.3	1	0.1	4	0.6
Cross-road ramp terminal (free-flow)	-	144	20.7	0	0.0	0	0.0	0	0.0	3	0.4	0	0.0	3	0.4
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	15.9	697	100.0	1	0.1	4	0.6	2	0.3	69	9.9	2	0.3	78	11.2

Conversion: 1 mi = 1.61 km.

Table 61. Accident Type Distribution by Ramp Segment Type for Urban Outer Connection Off-Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of multiple-vehicle collision accidents															
				Head-on		Sideswipe		Rear-end		Angle		Left turn		Right turn		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.0	24	3.4	0	0.0	0	0.0	16	2.3	5	0.7	0	0.0	0	0.0	1	0.1	22	3.2
Deceleration lane with mainline lane drop	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	9.9	334	47.9	1	0.1	1	0.1	152	21.8	74	10.6	0	0.0	0	0.0	11	1.6	239	34.3
Normal acceleration lane	1.1	7	1.0	0	0.0	0	0.0	4	0.6	2	0.3	0	0.0	0	0.0	0	0.0	6	0.9
Acceleration lane with mainline lane addition	0.1	6	0.9	0	0.0	0	0.0	4	0.6	1	0.1	0	0.0	0	0.0	0	0.0	5	0.7
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	0.0	10	1.4	0	0.0	0	0.0	1	0.1	1	0.1	0	0.0	0	0.0	0	0.0	2	0.3
Merge area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weaving area on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Two-way roadway on ramp	1.8	41	5.9	0	0.0	0	0.0	23	3.3	14	2.0	0	0.0	0	0.0	3	0.4	40	5.7
Cross-road ramp terminal (stop condition)	-	131	18.8	0	0.0	0	0.0	55	7.9	6	0.9	13	1.9	50	7.2	2	0.3	126	18.1
Crossroad ramp terminal (free-flow)	-	144	20.7	0	0.0	1	0.1	120	17.2	19	2.7	0	0.0	0	0.0	0	0.0	140	20.1
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	15.9	697	100.0	1	0.1	2	0.3	375	53.8	122	17.5	13	1.9	50	7.2	17	2.4	580	83.2

Conversion: 1 mi = 1.61 km.

Table 62. Accident Type Distribution by Ramp Segment Type for Urban Direct and Semi-Direct Connection Ramps (1993 Through 1995)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle noncollision accidents							
				Ran off road		Overturned		Other		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.5	29	5.3	0	0.0	2	0.4	2	0.4	4	0.7
Deceleration lane with mainline lane drop	1.4	9	1.6	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	16.5	305	55.8	11	2.0	43	7.9	3	0.5	57	10.4
Normal acceleration lane	7.6	71	13.0	1	0.2	2	0.4	0	0.0	3	0.5
Acceleration lane with mainline lane addition	2.4	21	3.8	0	0.0	0	0.0	0	0.0	0	0.0
Mainline weaving area	0.2	2	0.4	0	0.0	0	0.0	0	0.0	0	0.0
Diverge area on ramp	1.3	41	7.5	0	0.0	6	1.1	0	0.0	6	1.1
Merge area on ramp	1.9	33	6.0	3	0.5	5	0.9	0	0.0	8	1.5
Weaving area on ramp	0.0	1	0.2	0	0.0	1	0.2	0	0.0	1	0.2
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	5	0.9	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	-	30	5.5	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	34.7	547	100.0	15	2.7	59	10.8	5	0.9	79	14.4

Conversion: 1 mi = 1.61 km.

Table 62. Accident Type Distribution by Ramp Segment Type for Urban Direct and Semi-Direct Connection Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle collision accidents with:											
				Parked vehicle		Pedestrian		Bicycle		Fixed object		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.5	29	5.3	0	0.0	0	0.0	0	0.0	9	1.6	0	0.0	9	1.6
Deceleration lane with mainline lane drop	1.4	9	1.6	0	0.0	0	0.0	0	0.0	1	0.2	0	0.0	1	0.2
Ramp proper	16.5	305	55.8	1	0.2	0	0.0	0	0.0	137	25.0	2	0.4	140	25.6
Normal acceleration lane	7.6	71	13.0	0	0.0	0	0.0	0	0.0	8	1.5	1	0.2	9	1.6
Acceleration lane with mainline lane addition	2.4	21	3.8	0	0.0	0	0.0	0	0.0	8	1.5	0	0.0	8	1.5
Mainline weaving area	0.2	2	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Diverge area on ramp	1.3	41	7.5	1	0.2	0	0.0	0	0.0	23	4.2	0	0.0	24	4.4
Merge area on ramp	1.9	33	6.0	0	0.0	0	0.0	0	0.0	12	2.2	1	0.2	13	2.4
Weaving area on ramp	0.0	1	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	5	0.9	0	0.0	0	0.0	0	0.0	1	0.2	0	0.0	1	0.2
Cross-road ramp terminal (free-flow)	-	30	5.5	0	0.0	0	0.0	1	0.2	2	0.4	0	0.0	3	0.5
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	34.7	547	100.0	2	0.4	0	0.0	1	0.2	201	36.7	4	0.7	208	38.0

Conversion: 1 mi = 1.61 km.

Table 62. Accident Type Distribution by Ramp Segment Type for Urban Direct and Semi-Direct Connection Ramps (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of multiple-vehicle collision accidents															
				Head-on		Sideswipe		Rear-end		Angle		Left turn		Right turn		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.5	29	5.3	0	0.0	0	0.0	6	1.1	9	1.6	0	0.0	0	0.0	1	0.2	16	2.9
Deceleration lane with mainline lane drop	1.4	9	1.6	0	0.0	0	0.0	4	0.7	3	0.5	0	0.0	0	0.0	1	0.2	8	1.5
Ramp proper	16.5	305	55.8	0	0.0	0	0.0	66	12.1	39	7.1	0	0.0	0	0.0	3	0.5	108	19.7
Normal acceleration lane	7.6	71	13.0	0	0.0	0	0.0	38	6.9	21	3.8	0	0.0	0	0.0	0	0.0	59	10.8
Acceleration lane with mainline lane addition	2.4	21	3.8	0	0.0	0	0.0	7	1.3	5	0.9	0	0.0	0	0.0	1	0.2	13	2.4
Mainline weaving area	0.2	2	0.4	0	0.0	0	0.0	1	0.2	1	0.2	0	0.0	0	0.0	0	0.0	2	0.4
Diverge area on ramp	1.3	41	7.5	0	0.0	0	0.0	10	1.8	1	0.2	0	0.0	0	0.0	0	0.0	11	2.0
Merge area on ramp	1.9	33	6.0	0	0.0	0	0.0	8	1.5	3	0.5	0	0.0	0	0.0	1	0.2	12	2.2
Weaving area on ramp	0.0	1	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	5	0.9	0	0.0	0	0.0	2	0.4	1	0.2	1	0.2	0	0.0	0	0.0	4	0.7
Cross-road ramp terminal (free-flow)	-	30	5.5	0	0.0	0	0.0	20	3.7	6	1.1	0	0.0	0	0.0	1	0.2	27	4.9
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	34.7	547	100.0	0	0.0	0	0.0	162	29.6	89	16.3	1	0.2	0	0.0	8	1.5	260	47.5

Conversion: 1 mi = 1.61 km.

Table 63. Accident Type Distribution by Ramp Segment Type for Urban C/D Roads (1993 Through 1995)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle noncollision accidents							
				Ran off road		Overturned		Other		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.4	14	1.6	0	0.0	0	0.0	1	0.1	1	0.1
Deceleration lane with mainline lane drop	1.1	6	0.7	0	0.0	0	0.0	0	0.0	0	0.0
Ramp proper	10.9	558	62.3	1	0.1	19	2.1	9	1.0	29	3.2
Normal acceleration lane	7.9	30	3.4	0	0.0	2	0.2	0	0.0	2	0.2
Acceleration lane with mainline lane addition	1.7	9	1.0	0	0.0	1	0.1	0	0.0	1	0.1
Mainline weaving area	0.0	–	–	–	–	–	–	–	–	–	–
Diverge area on ramp	3.0	147	16.4	0	0.0	4	0.4	2	0.2	6	0.7
Merge area on ramp	2.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Weaving area on ramp	3.3	131	14.6	2	0.2	2	0.2	1	0.1	5	0.6
Two-way roadway on ramp	0.0	–	–	–	–	–	–	–	–	–	–
Cross-road ramp terminal (stop condition)	–	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	–	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	–	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	33.3	895	100.0	3	0.3	28	3.1	13	1.5	44	4.9

Conversion: 1 mi = 1.61 km.

Table 63. Accident Type Distribution by Ramp Segment Type for Urban C/D Roads (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of single-vehicle collision accidents with: Parked vehicle		Pedestrian		Bicycle		Fixed object		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.4	14	1.6	0	0.0	0	0.0	0	0.0	7	0.8	0	0.0	7	0.8
Deceleration lane with mainline lane drop	1.1	6	0.7	0	0.0	0	0.0	0	0.0	2	0.2	0	0.0	2	0.2
Ramp proper	10.9	558	62.3	0	0.0	0	0.0	0	0.0	61	6.8	3	0.3	64	7.2
Normal acceleration lane	7.9	30	3.4	0	0.0	0	0.0	0	0.0	5	0.6	0	0.0	5	0.6
Acceleration lane with mainline lane addition	1.7	9	1.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	3.0	147	16.4	1	0.1	0	0.0	0	0.0	19	2.1	1	0.1	21	2.3
Merge area on ramp	2.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Weaving area on ramp	3.3	131	14.6	0	0.0	0	0.0	0	0.0	35	3.9	1	0.1	36	4.0
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	33.3	895	100.0	1	0.1	0	0.0	0	0.0	129	14.4	5	0.6	135	15.1

Conversion: 1 mi = 1.61 km.

Table 63. Accident Type Distribution by Ramp Segment Type for Urban C/D Roads (1993 Through 1995) (Continued)

Ramp segment type	Total length (mi)	Total accidents		Number and percentage of multiple-vehicle collision accidents: Head-on		Sideswipe		Rear-end		Angle		Left turn		Right turn		Other collision		Total	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Normal deceleration lane	3.4	14	1.6	0	0.0	0	0.0	4	0.4	2	0.2	0	0.0	0	0.0	0	0.0	6	0.7
Deceleration lane with mainline lane drop	1.1	6	0.7	0	0.0	0	0.0	3	0.3	1	0.1	0	0.0	0	0.0	0	0.0	4	0.4
Ramp proper	10.9	558	62.3	1	0.1	1	0.1	381	42.6	77	8.6	0	0.0	0	0.0	5	0.6	465	52.0
Normal acceleration lane	7.9	30	3.4	0	0.0	0	0.0	17	1.9	6	0.7	0	0.0	0	0.0	0	0.0	23	2.6
Acceleration lane with mainline lane addition	1.7	9	1.0	0	0.0	0	0.0	5	0.6	3	0.3	0	0.0	0	0.0	0	0.0	8	0.9
Mainline weaving area	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diverge area on ramp	3.0	147	16.4	0	0.0	1	0.1	89	9.9	30	3.4	0	0.0	0	0.0	0	0.0	120	13.4
Merge area on ramp	2.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Weaving area on ramp	3.3	131	14.6	0	0.0	0	0.0	62	6.9	28	3.1	0	0.0	0	0.0	0	0.0	90	10.1
Two-way roadway on ramp	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cross-road ramp terminal (stop condition)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cross-road ramp terminal (free-flow)	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Frontage road connection	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	33.3	895	100.0	1	0.1	2	0.2	561	62.7	147	16.4	0	0.0	0	0.0	5	0.6	716	80.0

Conversion: 1 mi = 1.61 km.

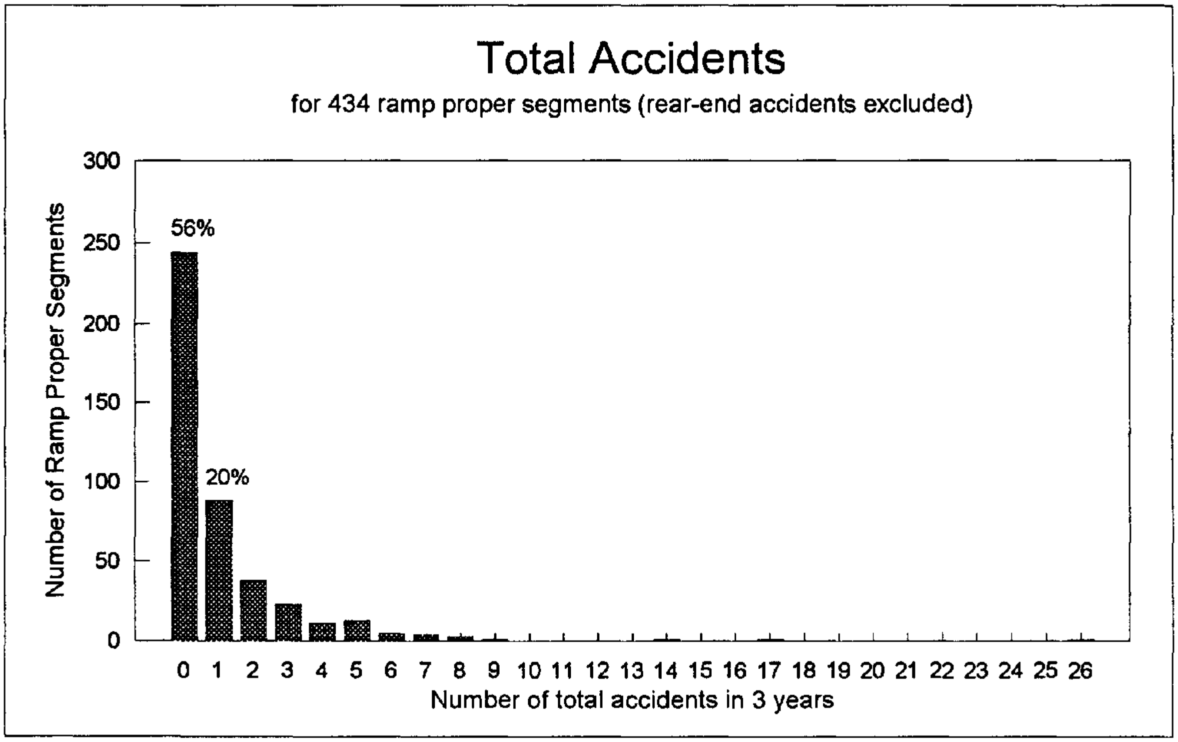
APPENDIX D

ACCIDENT FREQUENCY DISTRIBUTIONS FOR SELECTED INTERCHANGE ELEMENTS

This appendix presents a series of accident distribution plots for ramp segments, ramps, speed-change lanes, and combinations thereof. These include:

- Ramp proper segments, off-ramps only (rear-end accidents excluded from frequency distributions) in figure 9.
- Entire ramps, off-ramps only (rear-end accidents excluded from frequency distributions) in figure 10.
- Speed-change lanes (total and fatal and injury accidents) in figure 11.
- Entire ramps plus adjacent speed-change lane (total and fatal and injury accidents) in figure 12.
- Urban diamond off-ramps (total and fatal and injury accidents) in figure 13.
- Urban parclo and free-flow loop off-ramps (total and fatal and injury accidents) in figure 14.
- Urban outer connection off-ramps (total and fatal and injury accidents) in figure 15.

In addition, 1-year accident frequencies (total and fatal and injury accidents) for the 551 entire ramps and the 737 ramp proper segments studied in this report are presented in figures 16 and 17, respectively, comparing the 3 years of accident data for 1993 through 1995.



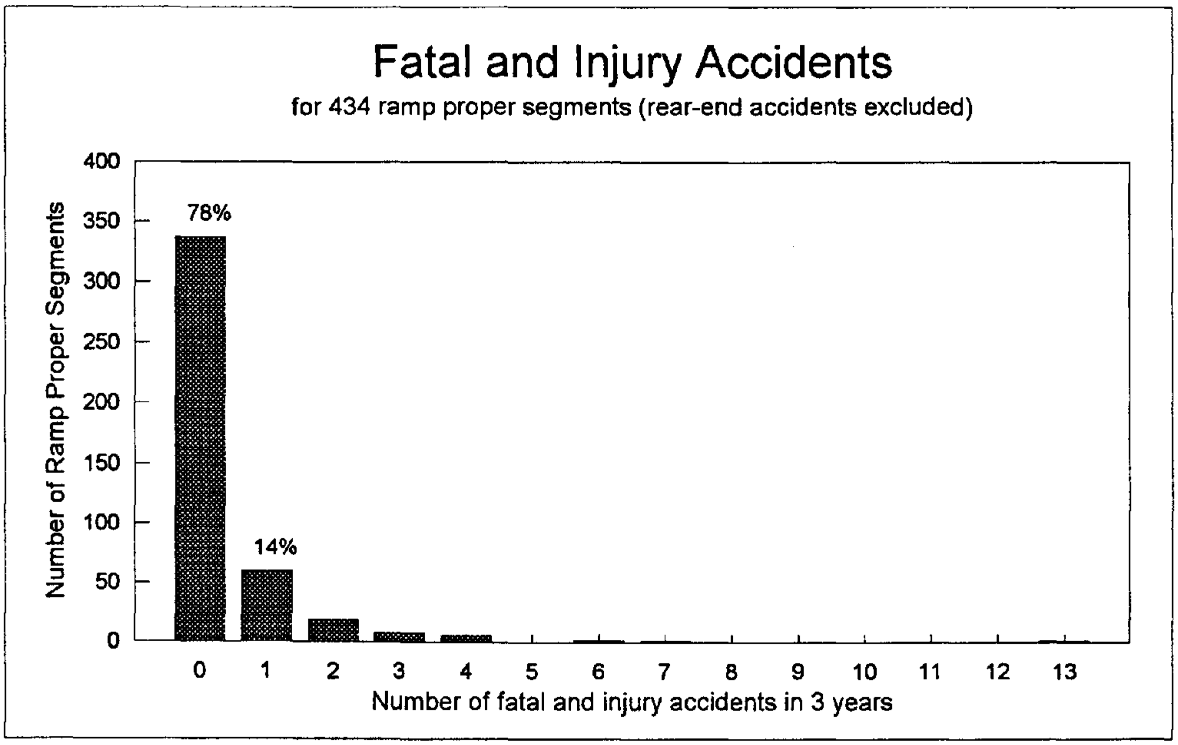
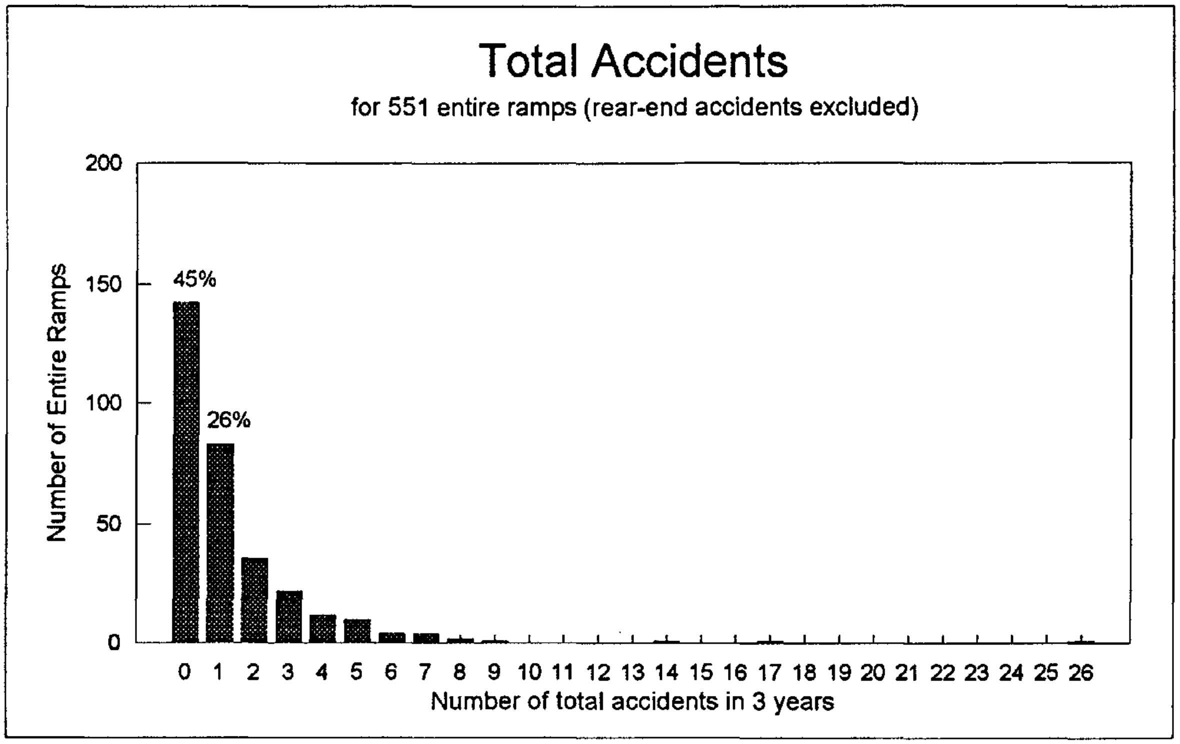


Figure 9. Accident Frequency Distribution for Ramp Proper Segments, Off-Ramps Only (Rear-End Accidents Excluded)



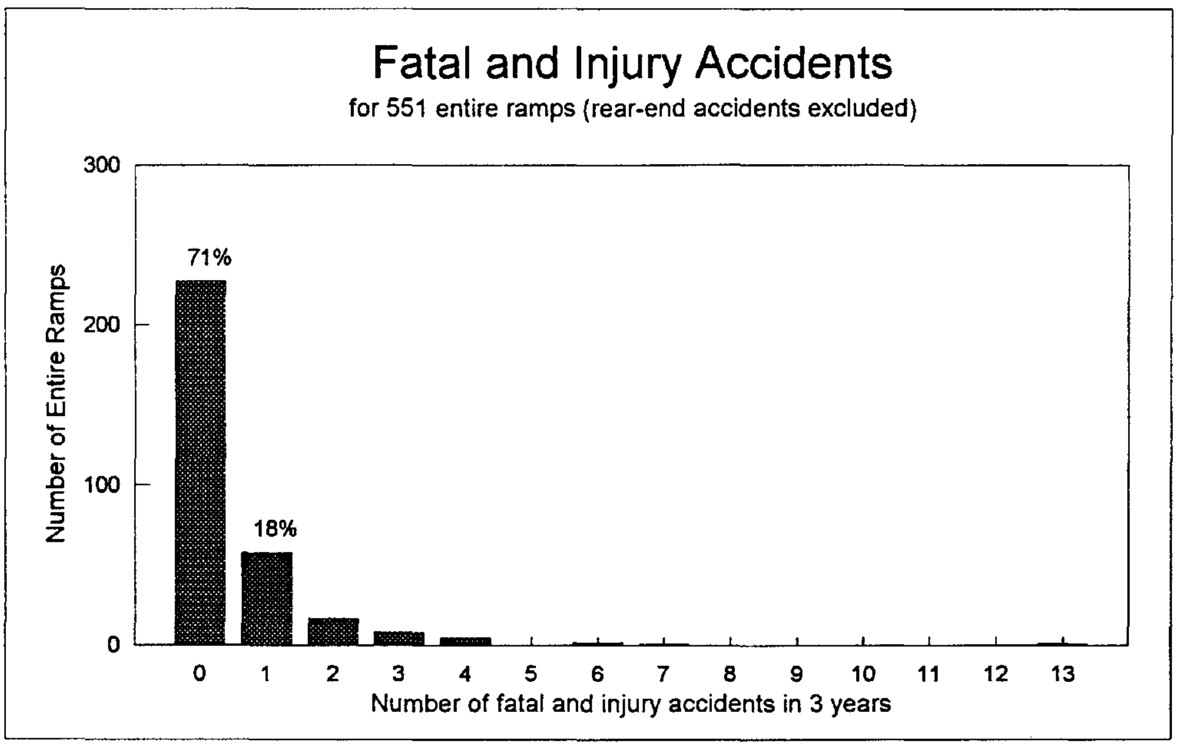
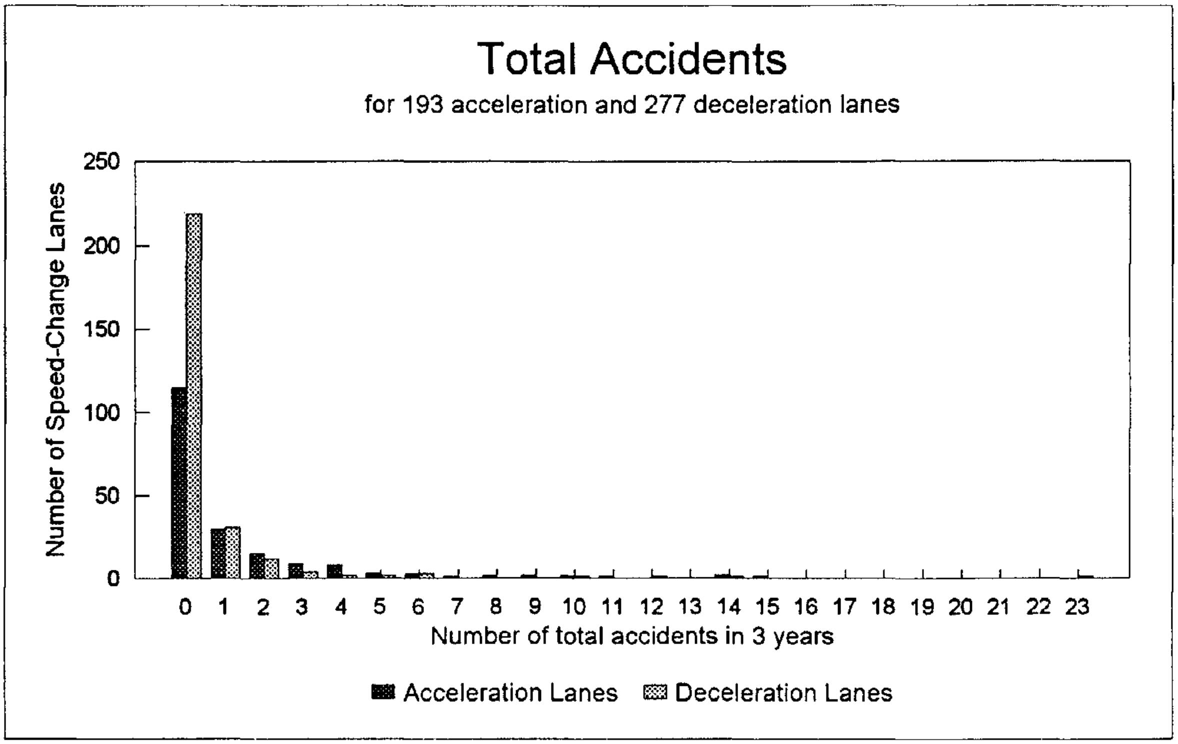


Figure 10. Accident Frequency Distribution for Entire Ramps, Off-Ramps Only (Rear-End Accidents Excluded)



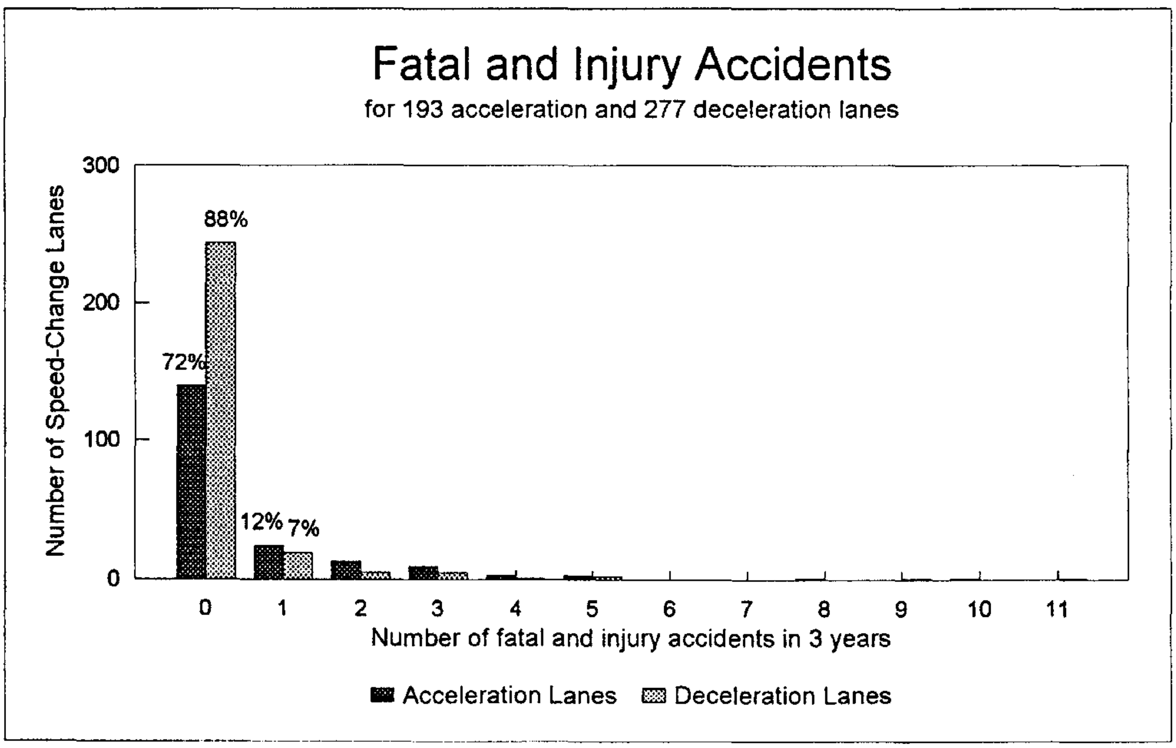
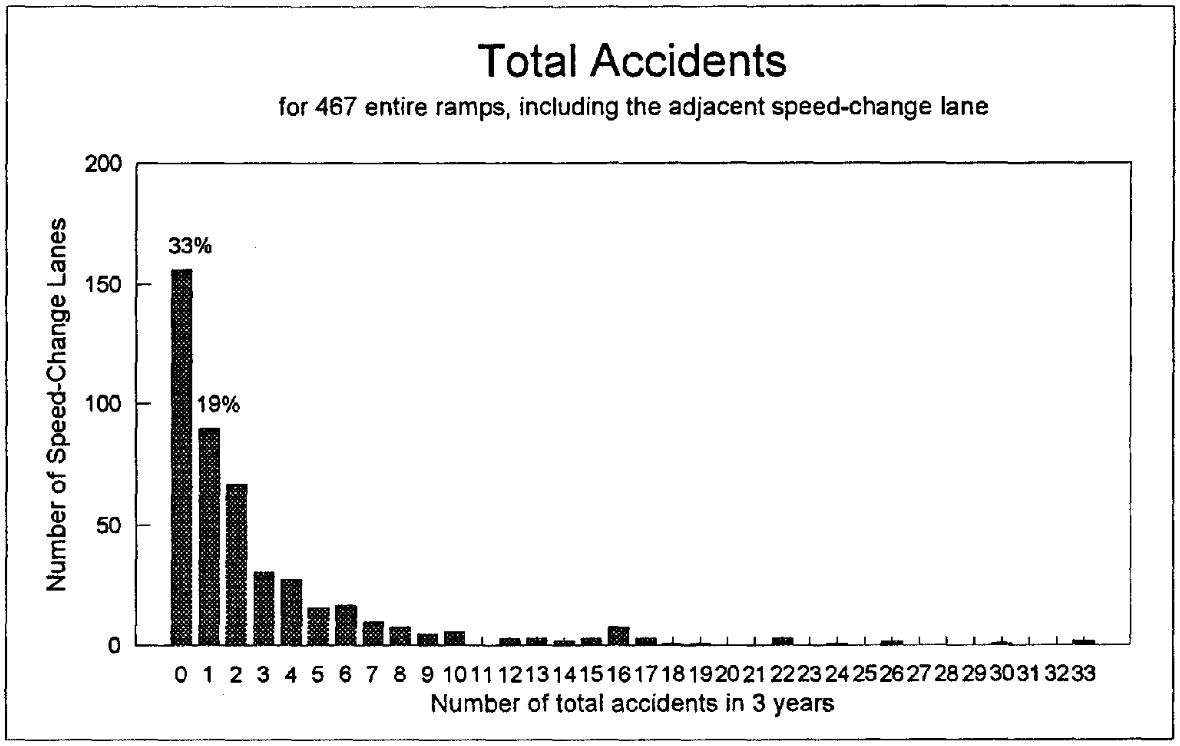


Figure 11. Accident Frequency Distributions for Speed-Change Lanes



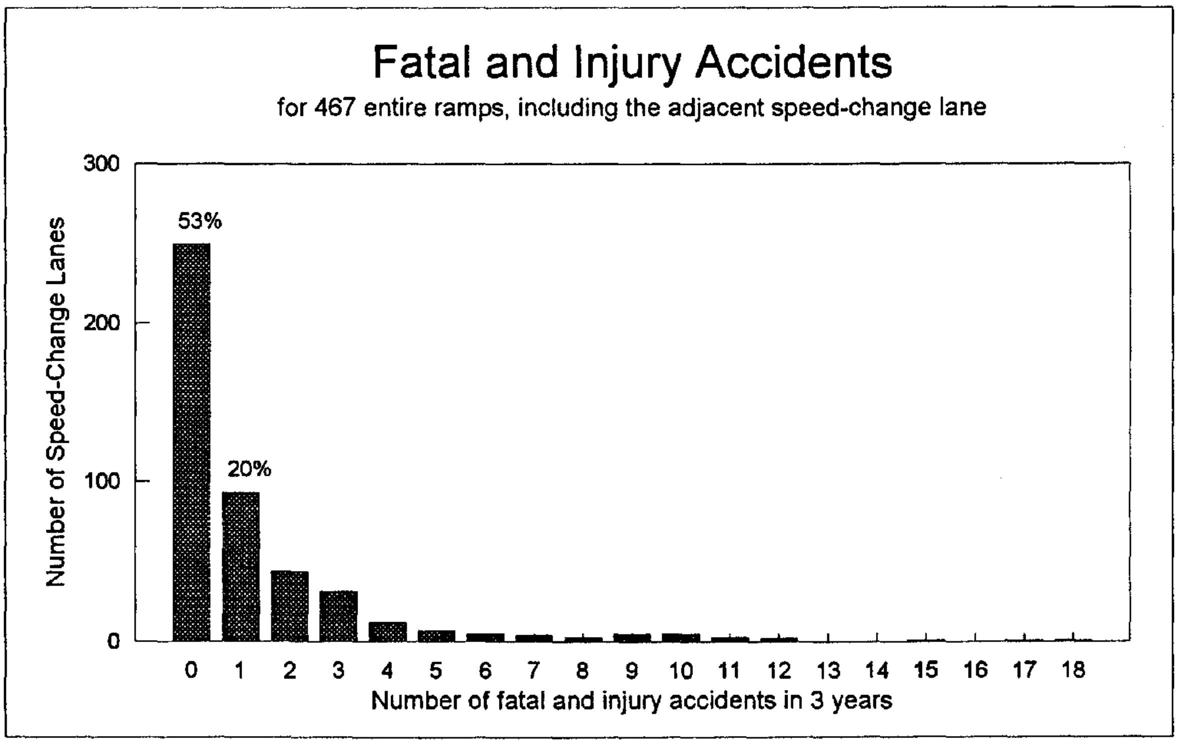
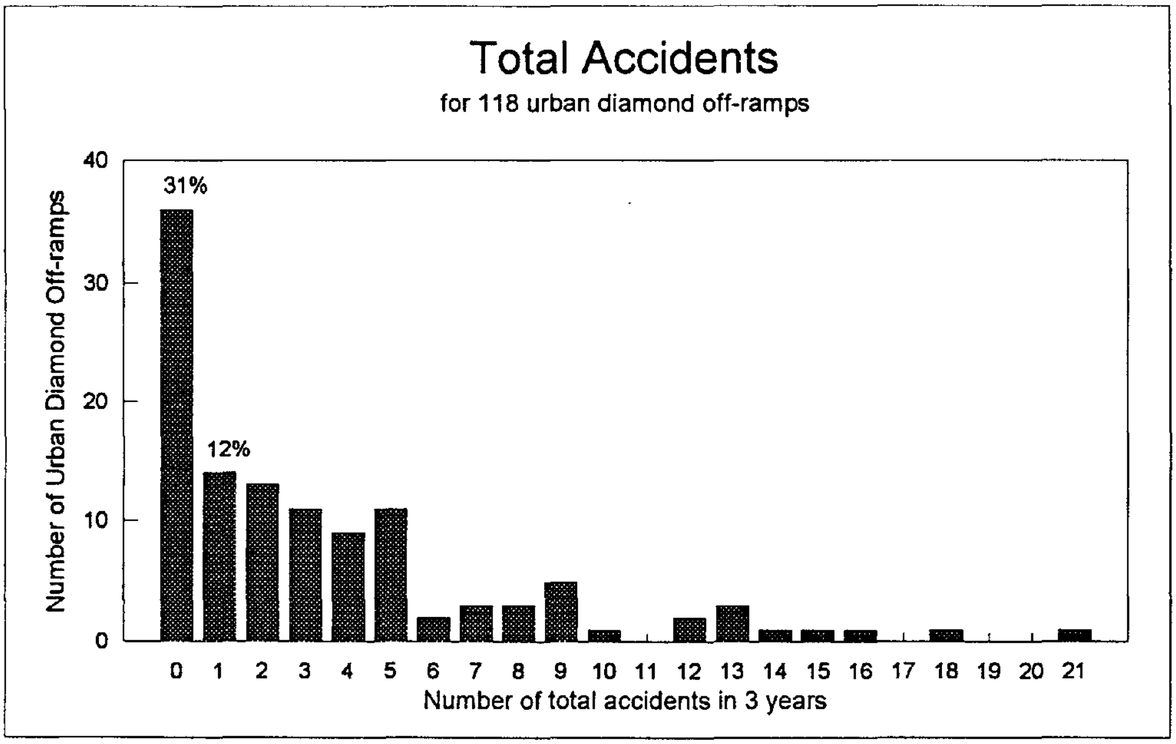


Figure 12. Accident Frequency Distributions for Entire Ramps, Including the Adjacent Speed-Change Lane



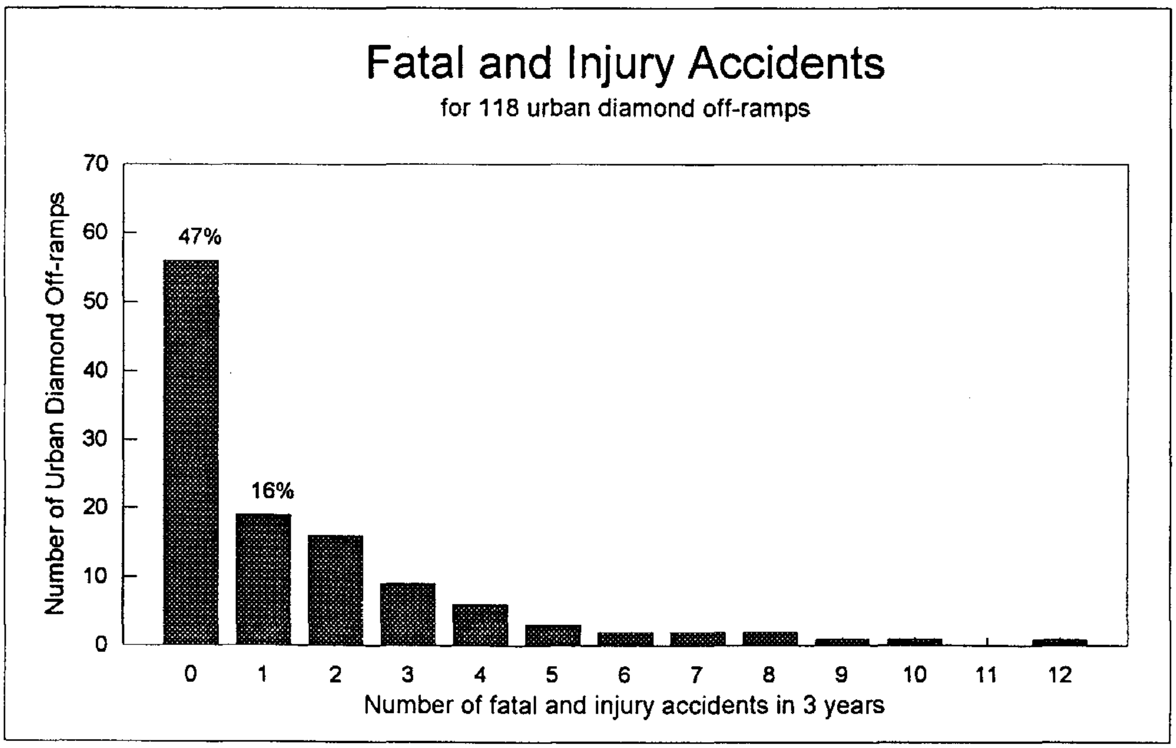
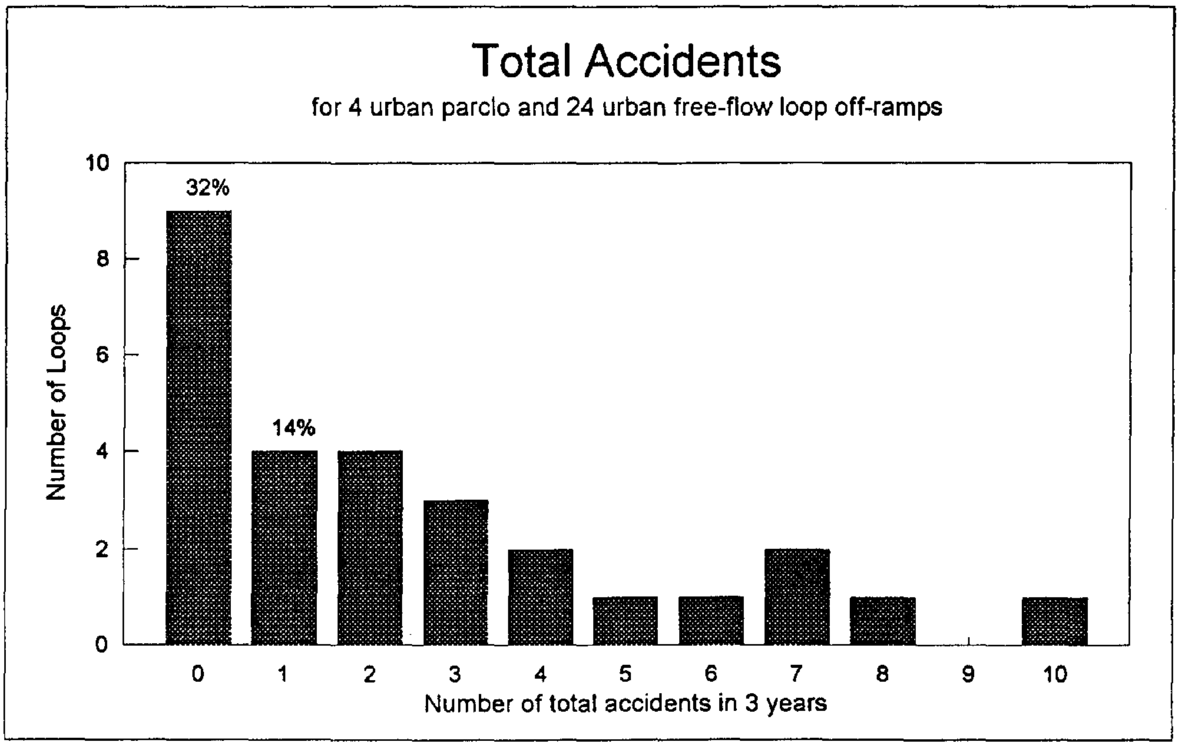


Figure 13. Accident Frequency Distributions for Urban Diamond Off-Ramps



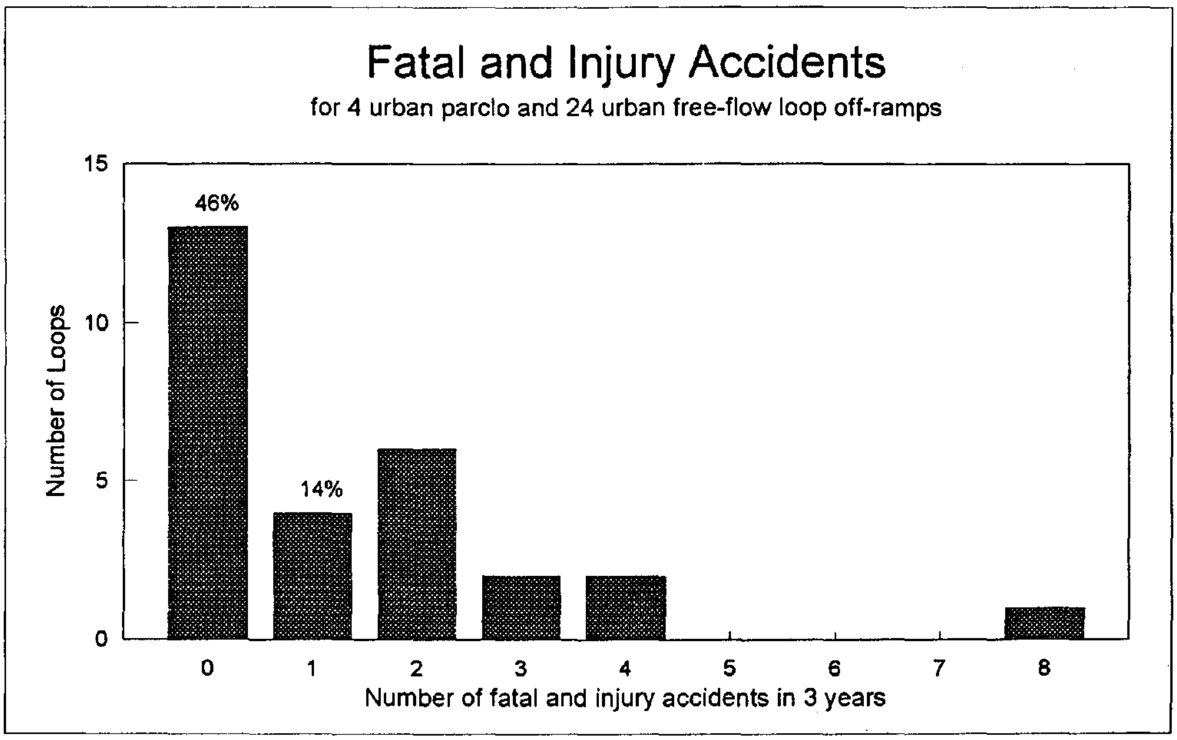
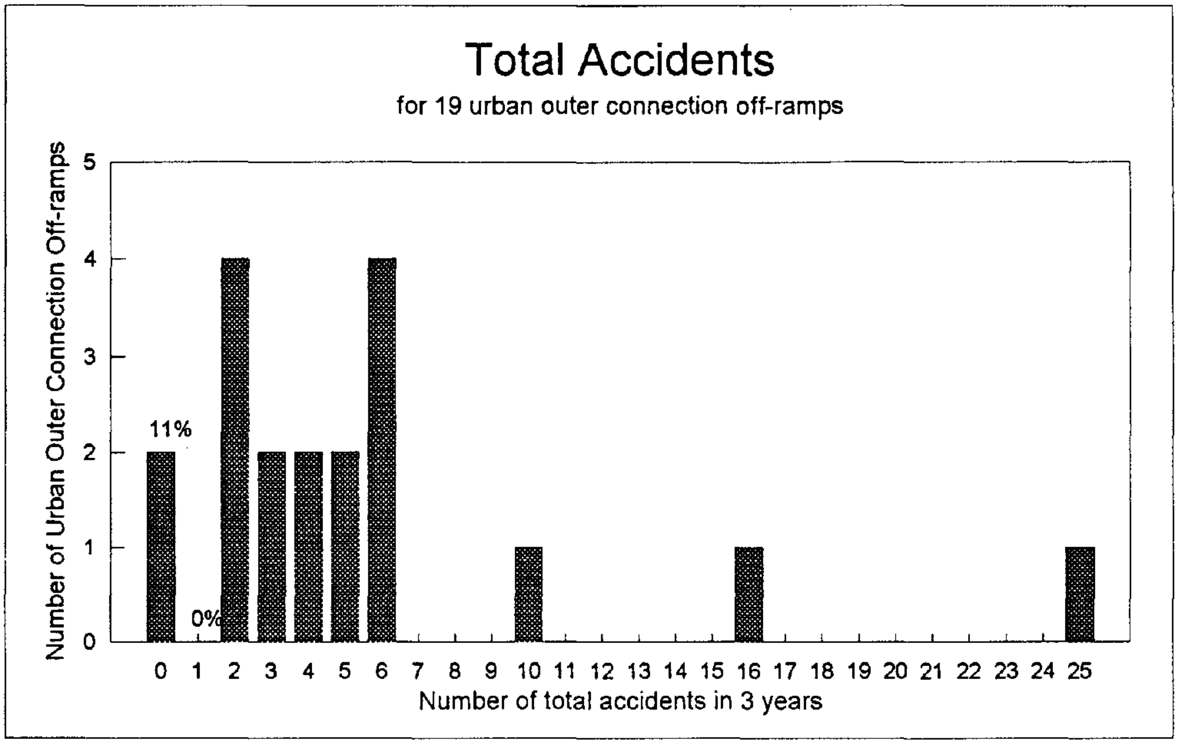


Figure 14. Accident Frequency Distributions for Urban Parclo and Free-Flow Loop Off-Ramps



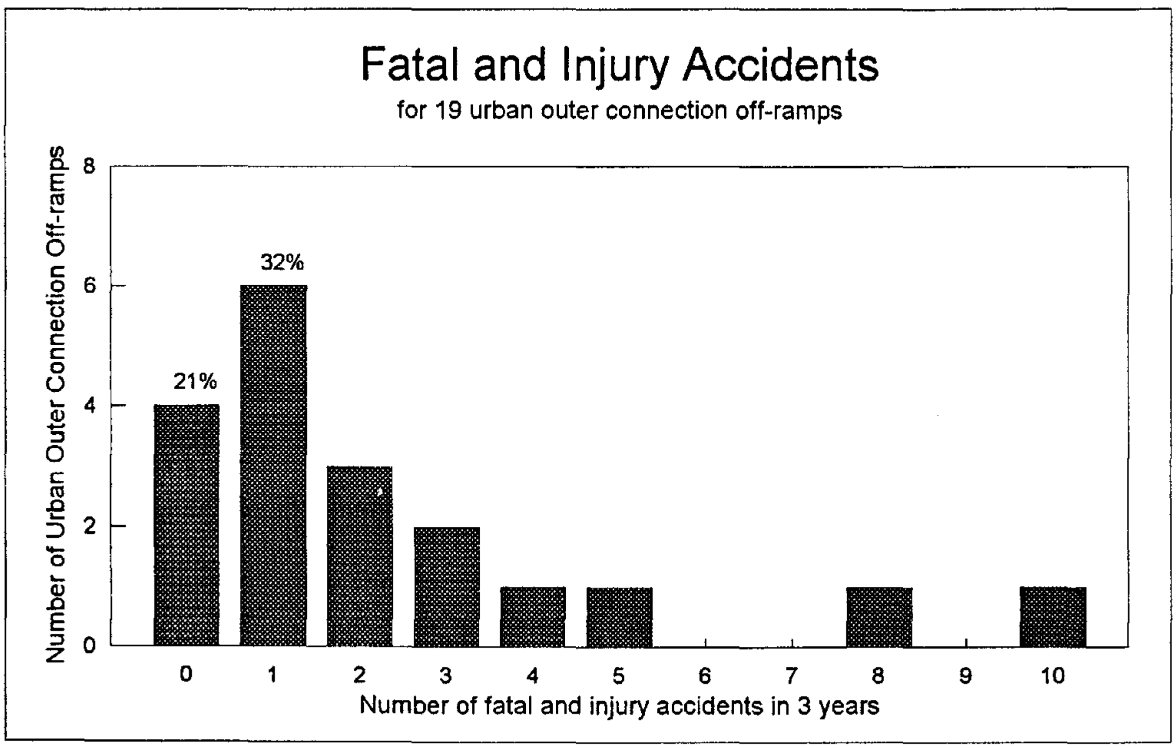
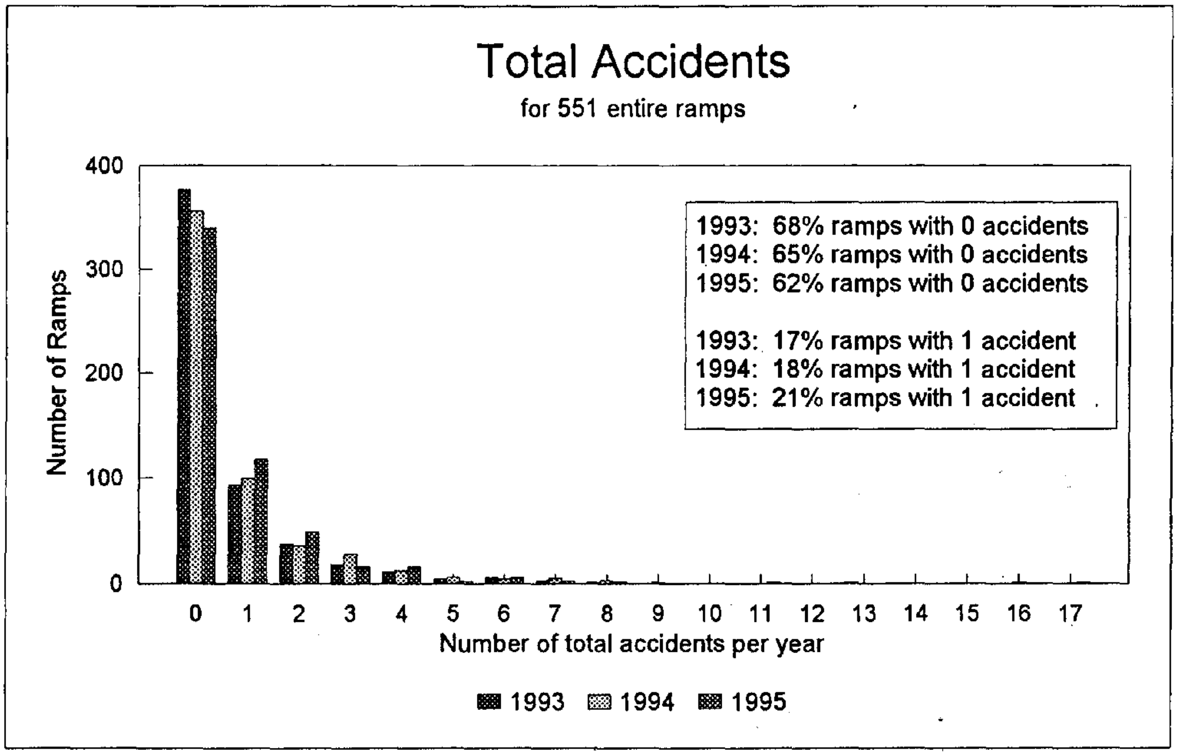


Figure 15. Accident Frequency Distributions for Urban Outer Connection Off-Ramps



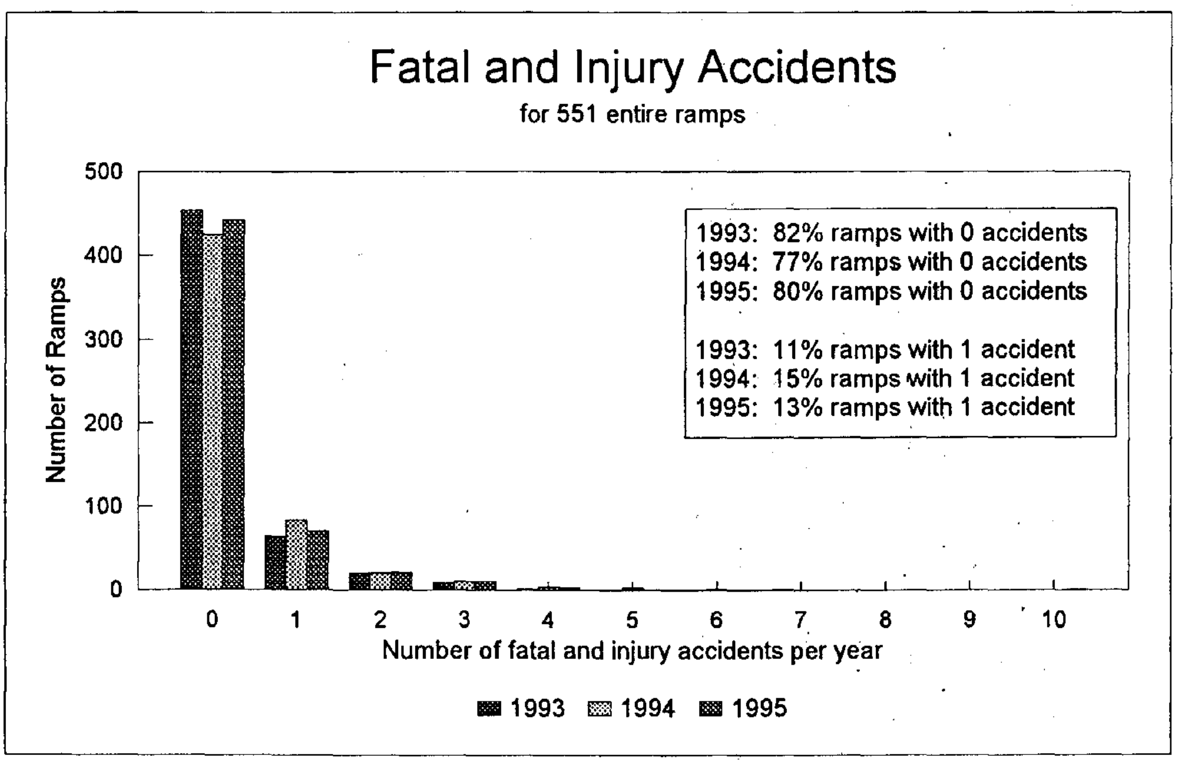
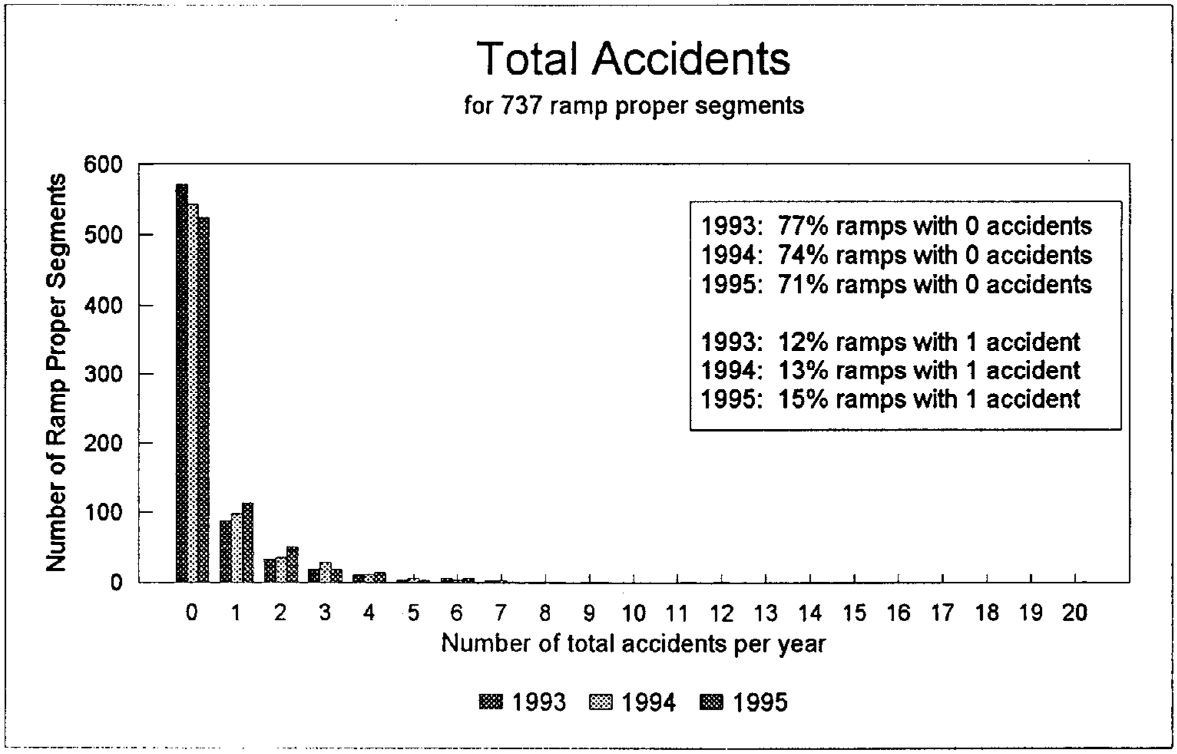


Figure 16. Annual Accident Frequency Distributions for Entire Ramps (1993-1995)



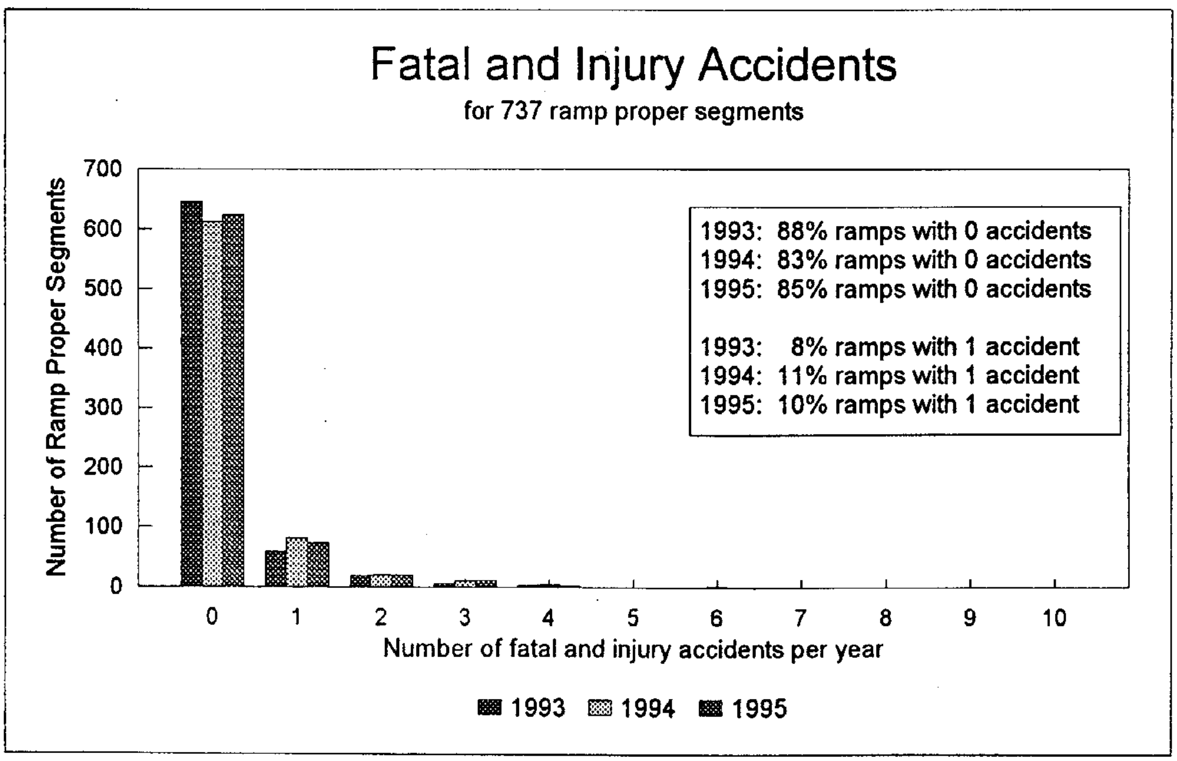


Figure 17. Annual Accident Frequency Distributions for Ramp Proper Segments (1993-1995)

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