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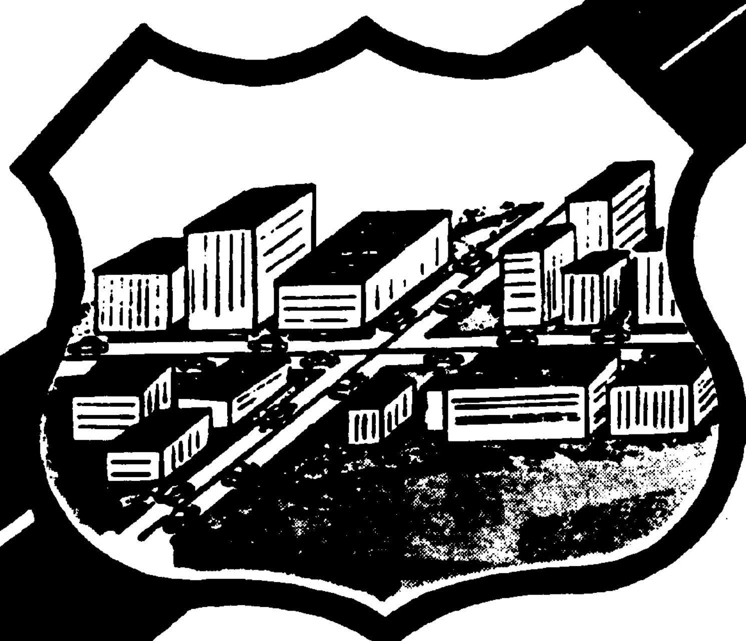
ANALYSIS OF URBAN ARTERIAL ROAD AND STREET ACCIDENT EXPERIENCE

September 1982

Vol. II. Final Report



Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Office of Safety and Traffic Operations
Research & Development
Washington, D.C. 20590

FOREWORD

The purpose of this study was to examine the specific characteristics of urban arterial traffic accidents, and to identify general causal elements and related countermeasures that can be used to reduce the rate and severity of these accidents. The report will be of interest to state and local highway officials involved in safety and traffic operations on urban roadways.

The results of the study provide further evidence that geometric, traffic control, volume, and environmental conditions influence the accident frequency and rate on urban roadways. Guidelines that can be used to identify accident related problems and to select appropriate countermeasures are provided in the report. One important product of this research was the development of a comprehensive computerized accident and roadway data base that can be used by highway officials and researchers to explore in detail specific urban arterial accident problems and possible solutions. Examples illustrating the use of the data base are given in the Appendixes.

Appreciation is given to the highway safety administrators and police officials who provided the accident data for this study.

Sufficient copies of the research report are being distributed to provide two copies to each regional office, one copy to each division office, and two copies to each State highway agency. Direct distribution is being made to each division office.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

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16. Abstract
The purpose of this research study was to examine the specific characteristics of urban arterial traffic accidents, and to identify general causal elements and related countermeasures that can be used to reduce the rate and severity of these accidents. Accident, geometric, traffic control, and volume data were collected and analyzed for 8,678 one-tenth-mile (0.16-km) roadway segments located in 19 metropolitan areas.

The result of the analyses provides further evidence that specific geometric, traffic control, volume, and environmental conditions influence accident frequency and rate on urban roadways. Guidelines that can be used to identify accident problems and to select countermeasures are provided in this report. One important product of this research was the development of a comprehensive computerized accident and roadway data base that can be used to explore in greater detail specific urban arterial accident problems and possible solutions.

This report is the second in a series. The series is comprised of:

FHWA/RD-82/136 - Volume I - Executive Summary
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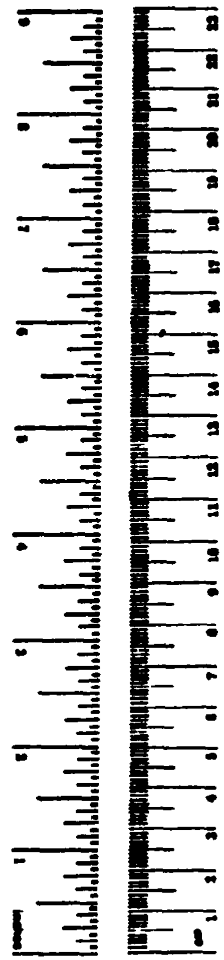
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

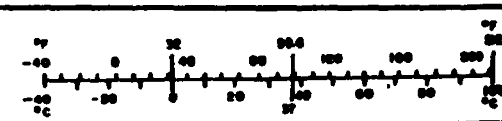
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

Many studies have been conducted to examine relationships between traffic accidents and specific geometric, environmental, and traffic conditions [1,2,3]. A majority of these studies pertain to rural highway situations, or a combination of rural and urban highway situations. A detailed study of accidents pertaining to urban roadway characteristics is important because the urban arterial road network is being taxed by several recent developments. The curtailment of urban freeway programs has contributed to high traffic volumes on many urban arterial roadways which has resulted in increases in congestion and traffic accidents. Additional demands on the urban arterial roadway network have occurred as a result of continued land development.

Urban arterial roads have experienced and are still experiencing significant safety problems. It has been estimated that one-third of all fatal motor vehicle accidents, and over one-half of all other motor vehicle accidents occur on the urban arterial road network [4]. As the urban arterial network represents only three percent of all highway mileage, it appears that a large safety problem exists on a relatively small system.

The operational and environmental characteristics of the urban arterial road network are varied and so are the attendant safety problems. Factors widely believed to influence traffic safety on urban arterial roadways include on-street parking conditions, traffic volume, access control, land use, and type of traffic control device. An assessment of previous research studies as well as a determination of the magnitude of existing traffic safety problems indicated the need for a detailed analysis of accident data on roads and streets functionally classified as urban arterials.

Little information is available from previous research that adequately defines the urban arterial accident problem. The use of historical accident data to identify safety deficiencies is difficult because of the following problems.

- Accident data files are not generally stratified by functional classes of highway.
- The operational and environmental characteristics of the urban arterial include extreme variances in design speed, traffic volumes, capacity, access points, land use, and traffic control.
- The urban arterial system acts as both a terminal and a transfer link between low and high volume routes.
- Information is lacking relative to the identification of hazardous locations on the urban arterial systems.

This study was conducted in response to the need to identify safety problems on urban arterial roadways. The objectives of the study were to:

- identify the general dimensions of the urban arterial accident problem relative to the overall motor vehicle accident problem;

- determine the distribution and specific characteristics of urban arterial accidents and identify causal elements, i.e., geometrics, operational, and environmental characteristics; and

- identify appropriate countermeasures that can be implemented to reduce the rate and severity of accidents occurring on urban arterials.

The study is viewed as a benchmark in the determination and analysis of the motor vehicle traffic accident problem in the urban environment. In addition to the discovery nature of the study, a computerized data base was developed to promote continued in-depth analysis and study. The data base is of a sufficient size to allow the designer, researcher, and traffic engineer to conduct statistical analyses for a variety of urban arterial roadway characteristics.

METHODOLOGY

The study consisted of two phases; data collection and data analysis. The data collection phase consisted of an extensive literature review; development of a sampling plan; selection of data items to be collected; development of the data collection plan; training of data collection personnel; collection of data; input of data into computerized files; and checking of data files. Data analysis consisted of the determination of the general dimensions of the urban arterial accident problem; determination of the distribution of accident characteristics; development of causal factors; and identification of countermeasures. The specific details of each of these phases is outlined below.

Data Collection

The data collection phase of the study resulted in the development of a computerized data file which contains urban arterial roadway network characteristics and accident experience. A comprehensive background review of the urban accident problem was conducted and is presented in the following section of this report. The review briefly summarizes the results of the literature survey which is presented in Appendix A. The purpose of the literature review was to summarize the results of studies conducted to date, and to identify relationships between traffic accidents and features of urban arterial roadways. Emphasis was placed on identification of research efforts undertaken to establish a relationship between accident experience, and specific roadway, environmental, and operational features. In addition, literature pertaining to types of countermeasures, or the evaluation of the effect of various countermeasures on accident frequency, type, and severity were identified. An annotated bibliography describing the details of each study included in the literature review is presented in Appendix B.

After completing an analysis of the literature, a comprehensive sampling plan was developed. The purpose of the sampling plan was to develop a computerized data base that would be representative of the accident and roadway characteristics of urban arterial highways in the United States. Several constraints prevent the true unbiased modeling of the system. Foremost among these constraints was the need to develop the data base from computerized accident records. Due to the large number of accidents desired (greater than 100,000), only those cities that could provide a computerized accident file were considered eligible for sample site selection. Data from 19 cities were eventually selected for the file, with the final determination based upon a number of considerations including: the availability of computerized accident records; the availability of sufficient locational data to enable assignment of individual accidents to 0.1-mile (0.16-km) segments of corresponding roadway; and the availability of sufficient information on severity, accident type, and other descriptive information that would allow the accidents to be used for the proposed analyses.

Stratified random sampling was employed in order to collect a manageable amount of data representative of the urban arterial roadway population. Because inferences were made from the results of the analyses, the sample included the following specifications.

- The segments must represent a cross section of urban arterials in the United States in terms of various regional, climatological, and terrain conditions.

- An adequate number of observations for each category of urban area population, type of land use, location within the urbanized area, and type of facility must be included in the sample.

- The segments selected should meet the target values for fatal accidents (1,000); injury accidents (40,000); and property damage accidents (60,000), as specified in the contract by the Federal Highway Administration.

Based on data availability and sampling requirements, the following 19 urban areas were selected for data collection and analysis.

- Big Rapids, Michigan
- Kalamazoo, Michigan
- Lansing, Michigan
- Saginaw, Michigan
- Birmingham, Michigan
- Farmington, Michigan
- Farmington Hills, Michigan
- Novi, Michigan
- Oak Park, Michigan

- Royal Oak, Michigan
- Southfield, Michigan
- Troy, Michigan
- Topeka, Kansas
- New Orleans, Louisiana
- Milwaukee, Wisconsin
- San Francisco, California
- Fort Wayne, Indiana
- Seattle, Washington
- Minneapolis, Minnesota

A roadway segment length of 0.1 mile (0.16 km) was selected as the unit for data collection and analysis. Data describing the characteristics of the 0.1-mile (0.16-km) roadway segments were either collected in the field or extracted from data files, maps, or other sources provided by city highway officials. Accident data were also obtained on computer tapes and coded for each 0.1-mile (0.16-km) segment.

A sampling plan was developed which defined the amount of data to be collected in each of the selected cities. An analysis plan defining the analysis techniques and the order in which these techniques were to be used was also developed prior to data collection. A complete discussion of the sampling plan and the data collection procedure utilized for the study is contained in Appendix C.

A major activity in this project was the identification of geometric, environmental, and traffic factors which are associated with urban arterial traffic accidents. The initial process of identification of roadway factors included a literature search and input based on the research experience of the study team members. Final selection of the factors included consideration of the following items: previously determined relationships between the factor and urban arterial accidents; availability of the element in the existing data files, suitability of the factor for collection in the field; and the amount of processing necessary to put the factor in a form for analysis.

Based upon this work, the list of factors shown in Table 1 were identified. The factors are classified according to three major categories -- geometric, environmental, and operational. For analysis purposes these elements represent independent variables which are included in the computerized data base.

In summary, data collection consisted of the following steps.

- Identification of candidate cities by FHWA officials

- Initial contact with the city traffic engineer or appropriate representative

- In-depth field interview of city representatives by the project engineer

Table 1. Roadway factors selected for data collection.

Geometric Factors	
Lane width	Number of far-side bus stops per segment
Number of through lanes	Number of midblock bus stops per segment
Average shoulder width	Number of driveways per segment
Roadway classification	Curb lane usage
Pavement surface	Parking lane - right side
Median width	Parking lane - left side
Median curb	Number of right-turn bays at intersections
Median type	Number of left-turn bays at intersections
Curb type - right side	Number of right-turn bays at midblock driveways
Curb type - left side	Vertical alinement
Percent guardrail	Horizontal alinement
Number of signalized intersections per segment	Number of large obstacles per segment
Number of non-signalized intersections per segment	Number of small obstacles per segment
Number of bus stops per segment	Number of trees per segment
Bus stop type - curb	Number of utility poles per segment
Bus stop type - pullout	Land use
Number of near-side bus stops per segment	Midblock right-turn lanes
Environmental Factors	
Roadway lighting	Amount of rainfall
City size	Amount of snowfall
Operational Factors	
Average daily traffic (ADT)	Average cycle length
Roadway capacity	Posted speed limit
Location factor	Operating speed
Peak hour factor	Number of traffic sign faces per segment
Vehicle mix-percent commercial	Number of regulatory sign faces per segment
Vehicle mix-percent cars	Number of warning sign faces per segment
Parking turnover rate	Number of guide sign faces per segment
Number of local buses per hour	

- Collection of records, maps, and other data outlining the city street system
- Preliminary selection of roadway segments by the project staff
- Training the data collectors
- Assignment of the field crew to the city for data collection
- Interview of city traffic personnel by field crew personnel, and selection of the final segments to be surveyed
- Collection of the field data
- Collection of volume and other records
- Submission of field data to the project engineer
- Inspection and checking of the field data

All field data collected were examined for errors, omissions, reasonableness, and encoded for keypunching. The coded data were then entered onto the computer file and checked for errors utilizing several edit programs.

Accident data received from the cities were first checked, and then recoded and reformatted in accordance with the data file layout. Accidents were identified with the street segment identification number and assigned to the appropriate 0.1-mile (0.16-km) road segment.

As a final step the accident and roadway features data were merged into one data file. The file is based upon the 0.1-mile (0.16-km) street segments and consists of the roadway, environmental, and operational data for each 0.1-mile (0.16-km) segment. The file contains the descriptive roadway information, plus the appropriate accident data in the form of total numbers of fatal, personal injury, and property damage accidents, as well as the accident data categorized by accident type. The completed file consists of data for 8,678 one-tenth-mile (0.16-km) street segments. A description of the computerized data base including example program outputs is given in Appendix D.

Data Analysis

A review of accident statistics reveals that the urban roadway environment accounts for a large proportion of highway casualties. However, detailed information regarding the role of the individual factors and their relationship to accidents is not available. While part of this deficiency results from a general nonavailability of accident data by functional classification including urban arterials in particular, the high degree of variability with respect to urban arterial operational and environmental characteristics makes it extremely difficult to identify the causal factors associated with accident occurrences. It was imperative, therefore, that an appropriate experimental plan be designed to answer the two following critical questions.

- Is it possible to identify specific geometric, traffic, and environmental factors that contribute to accidents on the urban arterial system?

- If the answer to the above question is yes, is it possible to determine the relationship between the identified factors and accidents, and to assess the relative importance of each factor under various circumstances?

In an attempt to answer these questions, a systematic analysis plan combining three separate approaches was developed. The approaches include branching analysis, analysis of variance, and regression analysis. While none of these approaches, applied individually, provided answers to both critical questions, the insights obtained from their combined use did provide meaningful direction in identifying the various components of the urban arterial accident problem. Each approach is described below, followed by a discussion of the way in which the techniques were integrated to form the total analysis plan.

Branching Analysis

The Automatic Interaction Detection (AID) program in the Burroughs Advanced Statistical Inquiry System (BASIS) was used to conduct the branching analysis [5]. AID is a multivariate technique for determining the value of dependent variables (such as accident frequencies or rates) with a combination of several independent variables. The program makes dichotomous splits in the independent variables which maximize the reduction in the total sum of squares between the current branch and the previous cell. If the reduction in the total sum of squares is greater than a user specified reduction, the branch is maintained. If the specified reduction is not attained, the data are retained in a single cell until a new independent variable is input. Terminal cells are created when none of the independent variables reduces the total sum of squares beyond the specified limit. The objective of branching is to classify the observations into mutually exclusive groups such that the observations in each group are similar to one another, yet different from the observations in all other groups. The program requires no assumption regarding linearity or collinearity of the independent variables. Nominal and ordinal data can be used as independent variables. The technique is not intended to identify causal effects of accident occurrences, but simply to identify those variables which maximize the explained variance in the dependent variables, i.e., accident frequency or rate.

While the branching technique can be used to identify single factors that explain a difference in the variance, there may also be combinations of factors acting together that explain accident variations on urban arterials. To help identify these combinations analysis of variance was used.

Analysis of Variance

The analysis of variance (ANOVA) is a statistical technique used to identify sources of variation in dependent variables. It is also used to test if a significant fraction of the total variance can be explained by the relationship with the identified sources of variation. Typically, the technique lends itself to use in experiments under controlled conditions. However, by utilizing an appropriate experimental design and sampling strategy, it is possible to use this technique in situations where the experiment cannot be performed under controlled conditions e.g., traffic accident analysis.

A factorial design was selected for the accident data analysis using the analysis of variance technique. The selection of the factors along with their associated levels was based in part upon the findings of the literature review, with additional factors based on the judgement and experience of the project team members. Although it is theoretically possible to identify an unlimited number of factors and levels for analysis purposes, the results become difficult to comprehend and interpret when the experiment exceeds a particular size. In most experimental studies, a 3^n factorial design is considered as the maximum; i.e., no factor is generally considered in more than three levels. In accident data analysis, the factors are broadly classified into traffic, geometric, and environmental characteristics with sub-classifications within each group.

The advantage of the factorial approach in traffic accident analysis is that a number of factors can be considered in the same experiment. This makes it possible for the analyst to examine not only the significance of the individual factors, but also the possible interactions among the factors being tested. Such a design approach would appear to be quite appropriate when one considers the multitude of independent variables that need to be accounted for in accident data analyses.

Tests were performed to determine whether statistically significant differences exist between the calculated means in each category. The null hypothesis for these tests was that there are no differences between the means for each level. Differences in the means for each category were tested using the "t" test and a 95 percent level of confidence.

For this phase of the analysis plan the ANOVA subprogram contained in the Statistical Package for the Social Sciences (SPSS) was used [6]. This subprogram allows the use of up to five factors per design for factorial designs. In addition, a table for multiple classification analysis was produced. Multiple classification analysis is a method that can be used to display the results of the analysis of variance when there are no significant interaction effects. In particular the multiple classification analysis is used to illustrate the individual effects of each factor on the dependent variables.

In addition to the ANOVA subprogram, the subprogram ONEWAY was also used. Use of ONEWAY is limited to problems involving only one independent variable, but, in addition to the standard analysis provided for tests of trends across categories of the independent variable, a priori contrasts and a posteriori contrasts are possible.

Once the factors have been identified, determining the direction and strength of their correlation is important and multiple regression was used for this purpose.

Multiple Regression Analysis

Regression analysis is a technique for determining the best fit equation to a set of observed data. The equation developed using the method of least squares can then be used to predict future outcomes given estimates of the independent variables.

The independent variables and the accident data used in the regression analysis were classified into a number of groups based upon a preliminary analysis and review of the data. The purpose of this classification was to establish a set of homogeneous groups that could be used to determine the relationships between dependent and independent variables. For each group, multiregression equations were developed relating accident frequencies and rates to various traffic, environmental, and geometric factors.

In developing regression equations, it is important to remove independent variables with a high degree of correlation, as these variables decrease the validity of predictions. Research in the area of error propagation has shown that errors committed in the estimation of the independent variables are propagated in the prediction and, further, the effect is significantly more adverse when these variables are correlated.

Regression analysis was conducted utilizing the Statistical Package for the Social Sciences (SPSS) subprogram NEW REGRESSION [6]. NEW REGRESSION allows the options of simple multiple regression, regression with hierarchical inclusion of independent variables, stepwise inclusion of the independent variable using forward inclusion, and backward elimination of variables. In addition, residuals and predicted values can be calculated as well as special treatments applied in the cases where there are missing data.

The branching analysis, analysis of variance, and regression analysis techniques were utilized in a sequential manner where the application of each successive technique drew upon the results of the previous analysis. At each point, a review of the data and analysis findings was conducted to insure that all areas of concern were investigated and that the findings were reasonable. An overview of the analysis process is shown in Figure 1.

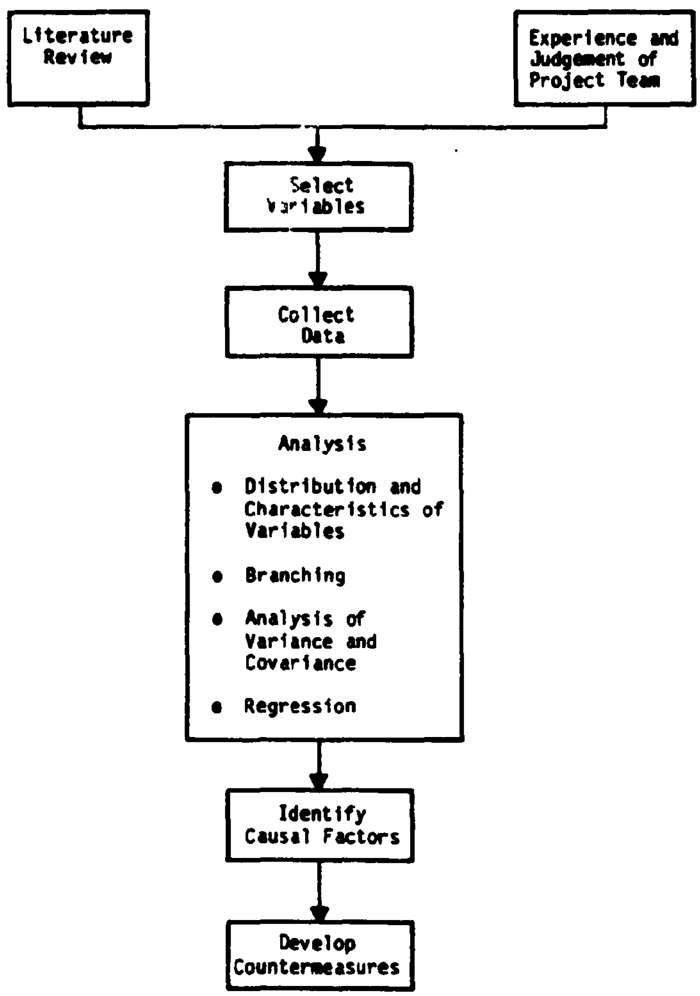


Figure 1. Data analysis process.

BACKGROUND OF THE URBAN ARTERIAL SAFETY PROBLEM

An extensive body of literature was collected, reviewed, and summarized during the early stages of this study. A summary of the accident studies identified during the literature review is given in Table 2. Most of the studies pertain to four-lane divided and multilane facilities. However, two-lane, multilane undivided roadways, and intersections also received considerable attention. Only five reports included investigations of accidents on one-way urban streets.

The reports included policy documents, guidelines, research results and synthesis reports. Policy and guideline reports were included because they are the key documents used to design and maintain operations and safety on urban arterial roadways. Many of the standards and criteria given in the documents are not necessarily based on specific research investigations but represent a consensus of opinion developed from experience and a synopsis of the best information available. The synthesis reports contain the results of studies conducted in specific areas. Examples of these documents are reports prepared by Box [7] on intersections and Azzeh, et al. [8] on access control techniques. Other studies pertain to the establishment of benchmarks for determining the hazardousness of urban roadways. Ricci [9] developed urban crash statistics based on roadway type, time of day, road condition, and other factors. Zegeer [10] determined critical accident frequencies for street sections and intersections for cities of various populations.

The methods used by the authors to examine relationships between accidents and urban roadway features included: correlation analysis; regression techniques; and comparative analysis. Correlation and regression techniques are often used because they permit the researcher to quantify the relationship between variables and derive a mathematical expression of the relationship. Comparative analysis techniques consist principally of methods which examine differences between two or more variables. An example of this technique is the study conducted by Frick [11] in which the accident characteristics of a raised median roadway segment are compared to the accident characteristics of another urban roadway segment which has a continuous two-way, left-turn median lane. A before and after study is another evaluation technique used by a number of investigators.

A major problem with much of the research conducted to date on urban arterial roadways is that there are deficiencies in the experimental design employed, the sample size used, and/or the analysis techniques. Specific problem areas are noted in the annotated bibliography presented in Appendix B.

In the following section, a brief summary of the relationship between traffic accidents and each roadway factor identified in the literature is

Table 2. Summary of urban arterial accident studies.

No.	Author	Yr.	Type of Urban Arterial: One-Way	Two-Lane	Four-Lane Undivided	Four-Lane Divided	Multi-Lane	Intersection	Combination or Other	Type of Report: Policy	Guideline	Research	Synthesis	Other	Analysis Method: Correlation	Regression	Comparisons	Cost-Effectiveness	Other	Geometrical Relationships: Access Control	Driveways	Traffic Signals	Intersections	Two-Way Median	Raised Median	Median Width	Pavement Width	Turn Lanes	Intersection Design	Median Openings	Sight Distance	Fixed Objects	Parking	Vertical Alignment	Horizontal Alignment	Utility Poles	Median Presence	One-Way Streets
01	AASHO	73	●	●	●	●	●	●	●		●																											
02	Auto Safety Foundation	63	●	●	●	●	●	●	●				●																									
03	Avery	60	●	●	●	●						●					●																					
04	Azzeh	75				●	●	●	●		●		●					●		●	●	●																
05	Babcock	78			●	●	●					●					●							●	●												●	
06	Berg	73			●							●				●							●															
07	Billion	58							●			●					●																					
08	Billion	62				●	●					●					●								●	●												
09	Bissell	66	●		●							●					●																					●
10	Blackburn	78		●			●					●				●	●	●																				
11	Bochner	78							●		●								●																			
12	Box	65			●							●					●								●												●	
13	Box	72							●			●					●										●											
14	Box	76					●					●					●																					
15	Box	70							●				●								●																	
16	Box	70						●					●								●							●	●									
17	Burritt	78		●	●							●					●	●						●														
18	Caylor	77							●		●		●											●	●													
19	Chapman	78		●		●	●					●					●						●															
20	Christiff	66							●			●							●																			
21	Clark	66							●			●				●																						
22	Clayton	77						●				●							●																			
23	Coleman	61							●			●					●					●					●											
24	Cribbins	67				●						●			●	●				●		●	●			●				●								
25	Cribbins	67				●						●			●	●				●		●	●			●		●		●								
26	David	75						●				●					●	●				●						●	●		●	●	●	●	●			
27	FHWA - 'MUTCD'	78	●	●	●	●	●	●	●	●																												
28	FHWA - 'Urban Traffic'	N/A						●	●				●																									
29	Fielding	55			●							●					●					●																
30	Fisher	77							●			●					●										●											
31	Foley	67			●							●					●								●												●	
32	Frick	68				●						●					●							●	●													
33	Glauz	80						●				●					●																					
34	Glennon	76							●			●				●			●													●						
35	Gupta	73		●								●				●											●				●			●	●			
36	Hanna	76						●				●					●					●									●			●				

Table 2. Summary of urban arterial accident studies (continued).

Reference			Type of Urban Arterial							Type of Report					Analysis Method					Geometrical Relationships																		
No.	Author	Yr.	One-Way	Two-Lane	Four-Lane Undivided	Four-Lane Divided	Multi-Lane	Intersection	Combination or Other	Policy	Guideline	Research	Synthesis	Other	Correlation	Regression	Comparisons	Cost-Effectiveness	Other	Access Control	Driveways	Traffic Signals	Intersections	Two-Way Median	Raised Median	Median Width	Pavement Width	Turn Lanes	Intersection Design	Median Openings	Sight Distance	Fixed Objects	Parking	Vertical Alignment	Horizontal Alignment	Utility Poles	Median Presence	One-Way Streets
37	Head	59		●		●						●			●	●					●	●	●				●											
38	Heimbach	60							●			●					●																					
39	Hoffman	74				●						●					●							●														
40	Holbrook	76						●				●				●																						
41	Humphreys	79							●			●					●																●					
42	ITE - 'Guidelines'	79							●		●		●																									
43	Jones	78							●			●				●	●															●				●		
44	King	75						●				●					●					●									●			●				
45	Leong	70							●			●					●									●											●	
46	May	59					●					●				●						●	●															
47	May	55		●		●						●					●			●																		
48	Mayer	71	●										●																									●
49	[illegible]	76						●				●					●																					
50	McQuirk	76	●	●	●							●				●					●	●	●															
51	Moore	75						●			●		●				●														●							
52	Mueller	70							●				●																									
53	Mulinazzi	67		●			●					●				●					●	●	●				●						●					
54	Nemeth	78		●		●						●					●							●														
55	Olson	74							●					●											●													
56	Parker	79			●	●						●				●					●	●	●	●	●					●							●	
57	Parker	75						●				●					●																					
58	Post	77							●		●								●																			
59	Ricci	79							●					●			●																					
60	Roy	78							●				●						●																			
61	Sawhill	60		●		●						●					●							●														
62	Shaw	68						●				●				●												●										
63	Snyder	74							●			●				●																						
64	Stark	73							●			●					●																					
65	Stover	70							●		●								●	●																		
66	Telford	53			●	●						●					●																				●	
67	Terry	68				●						●					●											●										
68	Thomas	66				●						●					●							●														
69	Torres	67							●			●					●					●					●						●					
70	Walton	79				●						●				●	●				●	●		●														
71	Webb	55						●				●					●												●						●			
72	Wootan	64				●						●					●								●													
73	Wright	76		●								●			●	●																			●			
74	Zegeer	75							●			●					●																					

Table 2. Summary of urban arterial accident studies (continued).

Reference			Environmental Relationships						Operational Relationships																		Human Factor			Accident Countermeasures on Urban Streets														
No.	Author	Yr.	Commercial Floor Area	Skid Number	Illumination Level	Roadside Development	Wet Time	Area Population	Speed	Volume	Travel Time	Traffic Signal Control	Yield Signs	Two-Way Stop	Four-Way Stop	Stopping Reversals	Brake Applications	Traffic Conflicts	V/C Ratio	Signal Timing	Level of Service	Street Signs	Vehicle Mix	Fuel Economy	Right Turn on Red	Signal Improvements	Sex of Driver	Skin Response	Age	Install Median	Convert to One-Way	Post Proper Speed Limit	Prohibit Parking	Improve Sight Distance	Limit Driveways	Limit Traffic Signals	Provide Two-Way Median	Provide Raised Median	Resurface	Install Illumination	Install Turn Lanes	Widen Pavement	Provide Delineation	Relocate Bus Stops
01	AASHO	73																																										
02	Auto Safety Foundation	63																																										
03	Avery	60							●																																			
04	Azzeh	75								●																				●	●	●	●	●	●	●	●	●						
05	Babcock	78																																			●	●						
06	Berg	73	●								●																																	
07	Billion	58																									●																	
08	Billion	62																												●														
09	Bissell	65								●	●															●		●			●		●											
10	Blackburn	78		●						●																													●					
11	Buckner	78																																	●									
12	Box	65																												●														
13	Box	72			●	●																																		●				
14	Box	76			●																																			●				
15	Box	70																														●	●	●	●		●				●	●		
16	Box	70										●	●	●	●																					●					●			
17	Burritt	70																																			●							
18	Caylor	77																																										
19	Chapman	78				●																																						
20	Christiff	66			●																																			●				
21	Clark	65								●	●					●	●																											
22	Clayton	77																●																										
23	Coleman	61								●	●	●							●	●																								
24	Cribbins	67							●	●											●																							
25	Cribbins	67							●	●																																		
26	David	75								●					●							●	●											●							●		●	●
27	FHWA - "MUTCD"	70																																										
28	FHWA - "Urban Traffic"	N/A																																										
29	Fielding	56									●	●														●																		
30	Fisher	77																																								●		
31	Foley	67																																										
32	Frich	60																																				●						
33	Glaus	60																●												●		●	●	●	●	●					●			
34	Glennon	76								●																																		
35	Gupta	73								●																																		
36	Hynes	76																																										

Table 2. Summary of urban arterial accident studies (continued).

Reference			Environmental Relationships						Operational Relationships																		Human Factor			Accident Countermeasures on Urban Streets														
No.	Author	Yr.	Commercial Floor Area	Skid Number	Illumination Level	Roadside Development	Wet Time	Area Population	Speed	Volume	Travel Time	Traffic Signal Control	Yield Signs	Two-Way Stop	Four-Way Stop	Steering Reversals	Brake Applications	Traffic Conflicts	V/C Ratio	Signal Timing	Level of Service	Street Signs	Vehicle Mix	Fuel Economy	Right Turn on Red	Signal Improvements	Sex of Driver	Skin Response	Age	Install Median	Convert to One-Way	Post Proper Speed Limit	Prohibit Parking	Improve Sight Distance	Limit Driveways	Limit Traffic Signals	Provide Two-Way Median	Provide Raised Median	Resurface	Install Illumination	Install Turn Lanes	Widen Pavement	Provide Delineation	Relocate Bus Stops
37	Head	59				●			●	●																																		
38	Hatenbeck	68								●																																		
39	Hoffman	70																																		●							
40	Holbrook	76		●			●																																			
41	Humphreys	79				●																										●										
42	ITE - "Guidelines"	78																																								
43	Jones	78																																								
44	King	75																																								
45	Leong	70																																								
46	May	59									●													●																				
47	May	56				●			●								●							●																				
48	Mayer	71																													●													
49	McBee	76																							●																			
50	McGuirk	78						●		●																				●					●	●					●			
51	Moore	75																																●										
52	Mueller	70			●																								●		●									●				
53	Mulinazzi	67								●																																
54	Nemeth	76							●	●	●							●																		●							
55	Olson	78																																								
56	Parker	79						●		●																																
57	Parker	75																●							●																			
58	Post	77																																								
59	Ricci	79																																								
60	Roy	78																																								
61	Seahill	68																																		●							
62	Shaw	68								●																														●			
63	Snyder	74				●				●																			●															
64	Stark	73			●																																					
65	Stover	70																																								
66	Telford	53																																								
67	Terry	68																																						●			
68	Thomas	66																																		●							
69	Torres	67									●																															
70	Walton	79						●		●																																
71	Webb	56								●																																
72	Wooten	64																																			●						
73	Wright	76						●		●																																
74	Zegeer	75						●																																		

presented. The only roadway factors discussed are those that have been reported to have a significant relationship with accidents. A complete discussion of all roadway features can be found in Appendix A.

Geometric Factors

Roadway geometry consists of all physical elements within and along the highway. Roadway geometric factors include turn lanes, medians, intersections, pavement width, and horizontal alinement. A summary of the geometric factors are discussed below.

Turn Lanes

In a synthesis of accident studies at intersections, Box [12] noted that several studies indicate that the installation of left-turn lanes significantly reduces rear-end and left-turn type collisions. Shaw [13] concluded that installation of a median lane to provide storage space for left-turning vehicles significantly reduces delay time for through vehicles and also reduces accident frequency. Terry and Kassan [14] found that total accidents, injuries, left-turn, and rear-end crashes are significantly reduced after turn lanes are added, while Cribbins, et al. [15] reported that the presence of a turn lane has a significant effect on accidents at signalized and unsignalized intersections and that fewer rear-end collisions occur at median openings with storage lanes than at locations without storage lanes. Thomas [16] reported that rear-end type accidents decrease at locations which previously had no left-turn lanes. However, a study conducted by David and Norman [17] revealed that intersections with storage lanes had significantly higher accident rates than intersections without storage lanes. The authors attribute this finding to an increase in the number of nonturning accidents at intersections with storage lanes.

Generally, the results of research studies suggest that the addition of turn lanes at intersections reduces vehicle delay and accidents.

Median Presence

Foley [18] reported that the presence of a median reduces accident frequency in the range of 23 to 35 percent, while Box [19] reported a 50 percent decrease in the midblock accident rate. The major street improvement in the latter study consists of adding a median barrier, installing a RIGHT TURN ONLY sign at driveways, and providing three lanes in each direction. Leong [20] analyzed 3,400 accidents and reported that a narrow median may affect the type of collision on an arterial roadway, but the median does not appear to affect the short-term or long-term accident rate. Analysis of accident and operational data by Babcock and Foyle [21] revealed that four- and six-lane undivided highway segments have higher accident rates than divided highway segments. Parker [22] found no statistically significant difference in accident rates between raised and traversable median treatments. The accident severity rate on undivided highway segments was significantly higher than the severity rate on divided highway segments. Sawhill and Neuzil [23] reported the following findings.

- Median related accidents are less severe than non-median accidents.
- The number of head-on accidents in a center left-turn median lane is negligible.
- At one site accidents decreased from 66.7 per year to 49.5 per year, a reduction of 25.8 percent; most of the decrease was attributable to rear-end type accidents.

Frick [11] conducted a comparative analysis of accident data for a raised median roadway and a section with a continuous left-turn median lane and reported that curbed medians and intersection channelization should be used for urban arterial street improvements. However, there were a variety of factors, including differences in the number of traffic signals, driveways, roadside development, etc., that may explain the difference in the accident rates on the study sections. Hoffman [24] reported that providing a continuous left-turn median lane decreases total, injury and rear-end accidents. Burritt and Coppola [25] examined the effects of installing a continuous two-way, left-turn median lane on accidents and reported the following results.

- Total accidents were reduced by 35.9 percent
- Rear-end accidents decreased by 45.4 percent
- Left-turn accidents decreased by 20.4 percent
- Other accident types that were reduced included angle, sideswipe, parking, fixed object, and pedestrian/bicycle related crashes.

Accident and operational data collected and analyzed by Babcock and Foyle [21] provided evidence for the following conclusions.

- Accident rates on multilane roadways with a continuous, traversable, left-turn median lane are similar to accident rates on four- and six-lane divided highways.

- In all cases the continuous left-turn median lane on multilane facilities appears to handle traffic efficiently.

These studies indicate that a median is generally beneficial in reducing accidents and the severity of accidents.

Access Control

May [26] reported that urban roadways with no control of access have the highest accident rates. In another study May [27] found that when roadway features are expressed in terms of internal, medial, marginal, and intersectional friction the accident rate increases as the medial, marginal and intersectional friction increases. Cribbins [28] reported on the effects of an access-point index on accident rates. The access-point index is defined as the estimated total of all movements entering or leaving the site from commercial and industrial roadside development, private driveways, and intersecting roadways expressed on a per-mile (per-km) basis. Analysis of the data reveals that the number of total and injury accidents per mile is significantly related to the access-point index. The median opening accident rate is also related to the access-point index.

The results of safety studies provides substantial evidence that control of access has a significant effect on reducing accidents and injuries on urban roadways.

Driveways

Head [29] reported that on two-lane roadways carrying 10,000 vehicles per day or more, the number of commercial driveways per mile (per-km) is significantly related to the accident rate.

A comprehensive study of factors that influence driveway accidents was conducted by McGuirk and Satterly [30]. Analysis of the data provided the following results.

- Factors found to be significantly related to driveway accidents were commercial driveways per kilometer, number of through lanes, average daily traffic, and the total number of intersections per kilometer.

- For each commercial driveway added to an arterial street an additional 0.1 to 0.5 driveway-related accident per mile per year (0.06 to 0.31 accident/km/yr) can be expected.

Walton and Machemehl [31] also conducted a study to identify relationships between accidents and roadway features on urban arterial roadways. The study revealed that accidents per mile (per km) significantly increase as the number of driveways per mile (per km) on the roadway increases. A similar finding was reported by Parker [22] who found that driveway-related accident frequency increases with driveway density on undivided roadways. However, on divided highways Parker found that the number of driveways was not significantly related to accidents.

There is considerable evidence that the number of driveways on an urban arterial highway significantly affects accident frequency. The relationship appears to vary considerably depending upon the number of traffic lanes, the type of median treatment, and the traffic volume.

Traffic Signals

There is substantial evidence that the number of traffic signals on an urban highway directly influences the accident characteristics of the facility. Studies conducted by Mulinazzi and Michael [32], Head [29], Cribbins, et al. [15,28], Azzeh et al. [8], Parker [22], and Walton and Machemehl [31] revealed that as the number of traffic signals on an urban roadway increases, the accident frequency and rate increases.

Intersections

The number of signalized and unsignalized intersections on a roadway has been shown to affect traffic operations and safety. Chapman [33] reported that accidents along the main traffic routes of a town tend to cluster along relatively short sections of road passing through suburban shopping areas and at a few busy road junctions. Studies conducted by Head [29], Parker [22], Mulinazzi and Michael [32], and Cribbins, et al. [15,28] revealed that as the number of intersections per mile (per km) increases, the accident frequency also increases. Research conducted by May [27] on 41 sections of multilane urban roadways in Detroit and Lansing, Michigan indicated that intersectional friction, i.e., the number of intersections and number of traffic signals, has a greater effect on accident rates and travel time than other forms of roadway friction.

Intersection Design

A study conducted by Webb [34] revealed that fewer accidents occur at skewed intersections than at cross-type intersections. The study of

97 signalized intersections indicated that 7 of 8 semi-urban, skewed approaches had 43 percent fewer accidents than straight-legged approaches. In a synthesis of intersection accident studies conducted prior to 1970, Box [12] reported that cross-type intersections have significantly higher accident frequencies than tee-type intersections. An analysis of accident data conducted by David and Norman [17] indicated that for any given traffic volume level, cross-type intersections have higher accident rates than tee-type intersections; and signalized cross-type intersections have higher accident rates than stop-controlled cross-type intersections. Fatal and injury accident rates were found to be approximately equal for all intersection types.

Curb Type

Olson, et al. [35] conducted an investigation to examine the effects of 4- and 6-inch (10- and 15-cm) concrete curbs on vehicle behavior. Such curbs are commonly used on arterial divided routes in the United States. Eighteen full scale crash tests were conducted and simulated impacts were made using the Highway Vehicle Object Simulation Model. The major finding was that concrete curbs six inches (15-cm) high or less do not redirect vehicles travelling at speeds above 45 miles per hour (72 km per hour) and with encroachment angles greater than five degrees. The results suggest that the 6-inch (15-cm) concrete curbs commonly used on urban streets should not be used if traffic operating speeds are expected to exceed 45 miles per hour (72 km per hour). Other studies show that the installation of a curbed median on an undivided highway significantly reduces accidents.

Horizontal Alinement

Gupta and Jain [36] reported that accident rates on two-lane urban highways carrying 3,000 to 7,900 vehicles per day increase as the degree of curvature increases. Wright and Mak [37] analyzed accident data to determine relationships between single-vehicle, run-off-road, fixed-object accidents and traffic, roadway design, and socio-economic variables for urban two-lane roadways. They reported that run-off-road accident rates are most closely related to traffic volume, horizontal alinement, and population density. In a study of the relationship between accident involvement and traffic volumes at signalized intersections, Webb [34] reported that intersections with curved approaches have higher accident rates than those with tangent approaches. Based upon these studies there is some evidence that restrictive horizontal alinement may be related to an increase in accidents.

Vertical Alinement

Hanna, et al. [38] conducted a comparative analysis using two years of accident data at intersections that have poor driver sight distance on at least one traffic approach or that had an unusually steep grade (greater than 5 percent) as compared with all other intersections, and reported the following results.

- The accident rate for intersections with severe grades (0.97 per million entering vehicles) is unusually low when compared to the accident rate for all intersections (1.13 per million entering vehicles).

- Intersections with extremely severe grades have unusually low accident rates.

In contrast, King and Goldblatt [39] reported that grades significantly increase accidents in almost every case.

Based upon these studies, there is some evidence that vertical alinement is related to accident frequency, although this relationship is not strong.

Sight Distance

Gupta and Jain [36] studied the effects of restricted sight distance on the accident rates of two-lane, two-way urban roads. Although no statistically significant relationship was reported, restricted sight distance appears to be associated with high accident levels, and in particular, for single vehicle accidents. Analysis of accident data conducted by Hanna, et al. [38] indicated that intersections with poor sight distance on at least one approach have a higher accident rate when compared to the mean accident rate for all intersections. A high percentage of these accidents are angle collisions in which the driver was unable to properly view an approaching vehicle on the cross street. David and Norman [17] reported that an increase in sight distance resulted in a decrease in total accident rates, right-angle accident rates, and right-of-way violation accident rates. They found that intersections with a traffic volume greater than 15,000 and obstructions within 20 feet (6.1 m) of the pavement have 5.3 more accidents per year than intersections with unobstructed sight distances. Moore and Humphreys [40] reported that accidents decreased by 67 percent (from 39 to 13) at 5 intersections when sight distance obstructions were removed. King and Goldblatt [39] reported a statistically significant correlation between accidents and sight distance for most of the intersection conditions they studied.

There is some evidence that sight distance obstructions contribute to increasing the accident rate at urban intersections and on roadway sections. However, specific relationships have not been developed.

Fixed-Objects

Glennon and Wilton [41] examined the applicability of the roadside hazard model developed in NCHRP Report 148 in predicting the effectiveness of roadside safety improvements on all classes of highway, including urban arterial streets. Application of the roadside encroachment parameters developed for the hazard model revealed that little improvement can be expected by implementing common roadside safety improvements on urban streets. Although there is evidence that roadside obstacles contribute to accident rates on urban highways, the data are limited and specific relationships have not been quantified.

Jones and Baum [42] reported that as vehicle speeds increase, the percentage of utility pole accidents increases. Also, the number of utility pole accidents is a function of the relative density of utility poles in an area. As pole spacing increases, the frequency of utility pole accidents decreases. They also reported that utility pole accidents are a function of the distance the poles are located from the roadway. The proportion of utility pole accidents is high at low offsets, i.e., less than 5.5 feet (1.7 m) from the roadway, while beyond 5.5 feet (1.7 m), the frequency of accidents appears to remain constant (approximately 0.2 utility pole accidents per single-vehicle accident). Relationships between utility poles and total accidents have not been fully developed, however, the available data suggests that utility pole accidents may be a small percentage (2.2 percent) of total urban roadway accidents. Based on the study results, it appears that there is a significant relationship between utility pole frequency, offset, and single-vehicle, run-off-the-road accidents.

Parking

Mulinazzi and Michael [32] reported that permitting on-street parking significantly increases accident frequency on roadways carrying between 1200 and 5800 vehicles per day. David and Norman [17] reported that there is not a statistically significant relationship between peak-hour parking prohibitions, parking set-back, and accident frequency. The most comprehensive study undertaken to date concerning the effects of parking on accidents was conducted by Humphreys, et al., 1979 [43]. The purpose of the study was to examine the relationships between accidents reported on urban streets, parking configurations, land use, street width, and street classification. Analysis of Humphrey's data lead to the following conclusions.

- Parking use has the greatest effect on accident rate; i.e., as the parking use increases, the accident rate increases (up to approximately 1.0 million space hours per kilometer per year).

- Accident rates are lowest on roadway segments where parking is prohibited.

- The prohibition of on-street parking where the space use is approximately 300,000 hours per kilometer per year could reduce midblock accident rates by 19 percent. Where space usage is 600,000 hours per kilometer per year, mid-block accident rates could be reduced by 75 percent.

- For 300,000 space hours of use, total urban accident rates could be reduced by 8 percent and for 600,000 hours of use the reduction could be up to 30 percent if parking were removed.

- Parking configuration, i.e., parallel, angle, etc., does not have a significant effect on accident rate.

The available information on parking indicates that parking has a significant effect on accident rates, while parking configuration i.e., parallel vs. angle parking does not affect the accident rate. Prohibiting on-street parking would significantly reduce accidents on urban streets where parking is currently permitted.

One-Way Streets

A synthesis of the safety effects of converting two-way street systems into one-way operations was conducted by Mayer [44]. This synthesis reported that accidents can be reduced from 10 to 50 percent if two-way streets are converted to one-way operation. Initial operational and safety problems with the conversion are usually resolved within the first six months following implementation. It was also reported that accident severity is generally reduced, along with rear-end, sideswipe, turning, parking, and pedestrian accidents. One-way street systems have generally been shown to improve traffic operations and reduce accidents on urban streets. Consequently, this type of change may be regarded as an effective countermeasure, however, additional research is needed to determine the relationships between specific one-way street geometrics and traffic conditions on accidents.

Other Geometric Factors

Considerable research has also been conducted to examine the effects of other geometric factors on accidents. An analysis of these studies suggest that at least three elements, i.e., pavement width, number of median openings, and median width may have some effects on accidents, however, the effect does not appear to be significant.

Environmental Factors

For the purpose of this report, environmental factors are defined as measures which are external to the physical features of the roadway. Examples of these measures include climatic conditions, lighting, and roadside development. A summary of the environmental factors identified as having a significant relationship to roadway accidents is given below.

Skid Number

Data from numerous studies indicated that a general decrease in accident rate occurs as the coefficient of pavement friction increases. Accident statistics, skid number, and related data were analyzed by Blackburn, et al. [45] for a one-year period before and after resurfacing was performed on 428 roadway segments. The results indicated weak relationships between roadway type, traffic volume level, skid number, and wet pavement accident rates on urban highways. Holbrook [46] developed a model to estimate wet surface accidents at intersections based on skid number, wet time, and seasonal weather effects. Accident, skid number, and weather data were collected from 2,000 rural and urban intersections on State highways in Michigan. The results of the analysis provided the following results.

- Surface wet time and skid number are important factors in wet accident involvement.
- Below a skid value of 30, wet accident involvements increase as the pavement friction decreases.
- Monthly wet time has a significant effect on wet accident occurrences.
- Skid numbers alone will not lead to development of a plan which would optimally reduce wet surface accidents.

The study data indicated that wet pavement accidents are greatly influenced by the amount of time the pavement is wet and the skid number. The literature presents considerable evidence that sites (roadways and intersections) with low skid numbers have a significantly higher proportion of wet pavement accidents than sites with high skid numbers.

Illumination Levels

A study conducted by Christie [47] examined the effects of lighting improvements on traffic accidents. The measure of effectiveness used to determine the effect of the lighting was a ratio of daylight to darkness accidents before and after lighting was installed. With the exception of fatal accidents, differences in the ratios were statistically significant. A study of 97 miles (156 km) of street re-lighting in Kansas City, Missouri conducted by Stark [48] revealed that property damage accidents were reduced by 4 percent, injury accidents by 18 percent and fatal crashes by 28 percent. Based on the study findings, it is suggested that a serious night accident problem exists when the ratio of night-to-day accidents is more than 1.5 times the average ratio for similar locations or segments on the same system of road and streets. The study data tend to support the hypothesis that low illumination levels are associated with high accident occurrence. An investigation conducted by Box [49] determined the effect of lighting reduction on accidents and accident severity. The data revealed that, overall, night accidents increased 39.5 percent and night injury accidents increased 33 percent as a result of lighting reductions. Box [50] also investigated the effects of illumination on highway accidents in the City of Syracuse, New York and found the following results.

- Streets with little or no illumination have higher night-to-day accident ratios and costs than the average street in their category.

- Streets with extremely high illumination levels have higher night-to-day accident ratios and costs than the average street in their category.

- The most favorable illumination level is from 0.8 to 1.8 horizontal foot-candles (8.6 to 19.4 lumen/sq.m.).

These studies suggest that there is a relationship between roadway illumination level and accidents on urban streets. Roadways with low levels or no illumination and roadways with high levels of illumination appear to have higher accident rates than roadways with moderate illumination levels. Although additional data are needed to identify the reasons Box found that streets with extremely high illumination levels have high accident ratios, one hypothesis is that these sites previously had high accident rates and increasing the level of illumination to a higher level did not result in a further reduction in accidents.

Roadside Development

The effects of type of land use on roadway accidents have been examined by a number of investigators. Although each author defined roadside development in various terms, the overall conclusion from these studies is that changes in roadside development influence accidents on urban arterial roadways. Head [29], for example, counted the number of residential and commercial units on a roadway and found that the number of units was not related to accident frequency. However, Chapman [33] examined the effects of residential, open, industrial, and shopping space on accidents and found that roadways with shopping areas had significantly higher injury accident rates than sections with other types of land use. Humphreys [43] and Snyder [51] also found that accidents increased with the intensity of land use.

Other Environmental Factors

Studies have also been conducted to examine the effects of other environmental factors on traffic safety. None of the factors studied appear to be strongly related to accident involvement. For example, Wright and Mak [37] found that population density (persons per square mile) was significantly related to single-vehicle, fixed-object accidents. Walton and Machemehl [31] also found that the number of accidents per mile on roads with a continuous two-way, left-turn median lane was significantly affected by the population of an area. Parker [22] examined area population for roadways with continuous, two-way, left-turn median lanes and did not find a significant relationship to accidents. These studies appear to suggest that area population may have some affect on traffic accidents, however, the relationship is not significant.

Operational Factors

Operational factors include measures of the performance of the traffic stream and traffic controls which influence traffic flow. A summary of the operational measures significantly related to urban arterial accidents is given below.

Traffic Volume

Numerous authors, i.e., Azzeh [8], Cribbins, et al. [15,28], Head [29], Mulinazzi [32], Parker [22], and Walton [31] concluded that traffic volumes are more closely related to accident experience than any other non-accident factor or combination of non-accident factors. Further, most studies normally utilized ranges of volume in explaining the effects of other elements on accident experience. Although numerous studies have been conducted, the conclusions have not always been consistent. The absence of a consistent relationship between accidents and traffic volume may be due in part to the effects of other variables on accidents. Overall, the studies provided considerable evidence that increases in traffic volume will increase accidents on urban roadways.

Signal Improvements

Fielding and Young [52] conducted a study to evaluate the effects of traffic signal modifications on accident frequency, traffic volume, capacity, delay, and speeds on a 3.85 mile (6.20-km) section of four-lane urban arterial highway in Cincinnati. They reported that as a result of traffic signal modifications which included installation of a new signal, increasing cycle length, and synchronizing controls and other changes such as restriping, installing parking signs, etc., the total number of accidents on the section decreased 3.5 percent (from 749 in 1952 to 723 in 1953). No statistical test results were provided, but this difference does not appear to be significant. Accidents at signalized intersections decreased 21 percent while accidents at locations other than at traffic signals increased 22.6 percent. During the study period, traffic volumes increased from 10 to 15 percent. However, average trip times decreased 7.5 percent and speed increased from 19.5 to 21.1 miles per hour (31.4 to 34.0 km per hour). There is a need to examine the specific effects of signal improvements on urban arterial roadway accidents.

Traffic Conflicts

Traffic conflicts have been used by Clayton and Deen [53] to identify traffic hazards at intersections and by Parker [54] to evaluate the effects of implementing right-turn-on-red regulations at signalized intersections. Glauz and Migletz [55] suggested that a relationship between traffic conflicts and accidents exists, however, conclusive evidence of this relationship does not exist.

Level of Service

The relationship between level of service and accidents was examined by Cribbins, et al. [28]. It should be noted by the reader that Cribbins did not define level of service as a measure of the capacity of a roadway. Travel time through a section divided by the section length was defined by Cribbins as the level of service. The results of the analysis indicate that level of service (travel time divided by section length) is significantly related to the number of injury accidents per mile (per km); i.e., as the travel time on a section increases, the injury accident rate increases.

Type of Intersection Control

Studies conducted in the U.S. and abroad for many years indicated that type of control at intersections located on urban roadways affects the accident rate. Yield signs, two- and four-way stop controls, as well as traffic signal control can significantly reduce accidents and increase travel times when properly used at intersections. Traffic signals were especially identified as influencing the type of accident but not the adverse effects of accidents [39].

Street Signs

A study conducted by David and Norman [17] revealed that high volume intersections with street signs which had white letters on a dark background have an average of 5.1 more accidents per year than intersections with signs which have dark lettering on a white background. Holahan, et al., [56] examined the relationship between traffic signs and accidents at 60 intersections in Austin, Texas and found that the number of signs was strongly related to accidents at stop-sign intersections. The data also revealed that large, private signs at the intersections may be distracting motorist attention from the roadway which may lead to the higher accident frequency.

Other Operational Factors

Studies have also shown that traffic accidents may be related to a variety of other operational factors. Among these factors, some evidence suggests that posted speed limit, acceleration noise, travel time, volume-capacity ratio, and fuel consumption may be significantly related to accidents on urban arterial roadways. Further research is needed to identify and quantify these relationships.

Summary

The purpose of the literature review was to identify studies which examined the relationships between accidents and urban roadway features. Although a number of investigators have identified accident relationships for urban arterial roadways, each study was conducted to accomplish specific objectives and differed from other studies in scope, method, and/or purpose. Due to the differences in study techniques, it is not possible to quantify specific relationships between roadway features and accidents. Nevertheless, the literature can be used to identify elements which appear to be related to traffic accidents on urban arterial roadways. Each of the roadway elements identified in the literature was placed in one of the following categories.

Definite Relationship

A roadway feature was placed in this category when a large number of studies revealed that a statistically significant relationship existed between the variable and accidents. The factors in this group included turn lanes, traffic signals, medians, parking, one-way street operation, and traffic volume.

Probable Relationship

A roadway feature was placed in this category when several studies identified a relationship between the variable and accidents. Further research is needed to establish the relationship.

Possible Relationship

A roadway feature was placed in this category when there was some evidence to suggest a link between the feature and accidents. Additional research is needed to establish the relationship.

Results

Based on these definitions, each roadway feature was subjectively rated and classified into the appropriate category. A summary of the results is given in Table 3.

Table 3. Summary of relationships between accidents and roadway features for urban arterial streets based on the literature review findings.

Roadway Features	Type of Relationship		
	Definite	Probable	Possible
Geometrical Factors			
Pavement width		•	
Turn lanes	•		
Median presence		•	
Median width		•	
Median openings		•	
Driveways		•	
Traffic signals	•		
Intersection design		•	
Intersections		•	
Traversable median lanes	•		
Raised medians	•		
Horizontal alinement		•	
Vertical alinement		•	
Sight distance		•	
Fixed-objects		•	
Parking	•		
Utility poles		•	
One-Way streets	•		
Access control	•		
Environmental Factors			
Area population			•
Roadside development		•	
Skid number	•		
Illumination level	•		
Pavement wet time			•
Commercial floor area			•
Operational Factors			
Speed limit		•	
Traffic volume	•		
Travel time			•
Signal improvements			•
Traffic signal control		•	
Traffic conflicts			•
Signal timing			•
Level of service			•
Street signs			•
Acceleration noise			•
Volume/capacity ratio			•
Vehicle mix			•
Fuel consumption			•
Intersection control devices		•	
Right-turn-on-red		•	

ANALYSIS OF DATA

As described earlier, this study consisted of the collection and analysis of comprehensive accident and roadway features data. A number of statistical tests were used to identify differences in, and relationships between, accidents and various geometric, environmental, and operational characteristics of urban roadways. The selection of a particular test depended upon the type and amount of data, the level of measurement, and the hypothesis being tested. The procedures utilized in this study included the following statistical tests:

- Chi-square
- Branching
- Analysis of variance
- Analysis of covariance
- t-test
- Z-test
- Multiple regression

The data were first analyzed using all 8,678 segments in the data base. Separate analyses were conducted for each of the following functional roadway groups.

- One-way streets
- Two-lane, two-way streets
- Multilane divided roadways
- Multilane undivided roadways

The final determination of causal factors was based on these analyses coupled with the experience and knowledge of the project team members. The results of the tests are presented in the following sections of the report. Each section provides a synopsis of the procedure utilized and the significant or noteworthy results obtained. A summary table is presented at the end of each section to report the overall results of that process. No attempt has been made to report in detail all of the specific findings of the tests. The Appendixes contain detailed information concerning these findings. The sections of the report are described below.

- Independent Variables - A description of the fifty-three independent variables utilized in the analysis is presented.

- Characteristics of Urban Arterial Roadway Accidents - This section presents a summary of the general characteristics of urban arterial accidents. No attempt was made to consider the effects of other influencing characteristics such as traffic volume, land use, etc. in this section.

- Macroscopic Analysis - This section presents the results of a series of tests conducted to identify specific roadway characteristics which are over or underrepresented in terms of urban arterial accidents. Chi-square tests were used to determine if the frequency of accidents with regard to a specific variable was distributed in proportion to the number of roadway segments that describe the variable. A contingency coefficient was also used to identify the effects of sample size on the Chi-square statistic. The Z-test was used to determine specific levels of the variable that account for the over or underrepresentation of accidents. In this section, confounding factors such as traffic volume, land use, etc., were not examined.

- Branching Analysis - This multivariate analysis process was employed to identify independent variables that explain the variation in accident rate and frequency and to establish an interrelational framework among the roadway variables. The branching program selected independent variables that accounted for the highest amount of explained variation. This process provided guidelines for later analysis work, including the selection of independent variables for regression analysis, the analysis of variance, and the main partitioning of the data file to identify key classification variables. Interpretation of the results of the branching analysis did account, in part, for the effects of confounding factors on accident rates and frequencies.

- Regression Analysis - Multiple linear regression analysis was utilized to identify independent variables that explain the greatest amount of accident variation. The selection of independent variables used for analysis input was based upon the literature review, the identification work performed in the macroscopic and branching analyses, and the experience of the project team members. From ten to twenty independent variables were included in each step-wise multiple regression run. A final selection of the most meaningful independent variables was made based upon the t statistic. No attempt was made to develop equations that could be used for accident prediction but only to identify independent variables that can be used to explain the greatest amount of variation in the accident rate or frequency for each functional roadway group.

- Analysis of Variance and Covariance - These tests were used to identify differences in the mean accident rates and frequencies for the independent variable groupings. In addition, the analysis of variance was used to account for such influencing factors as traffic volume. Covariates tested for their influencing effects were selected from the branching analysis results, the literature review findings, and the experience of the project team.

  While an attempt was made to account for all influencing factors that can reasonably be expected to affect the accident rate and frequency, it must be recognized that an almost infinite number of influencing factors and combinations can be developed. This analysis included the results of only a small number of combinations.

The data base developed in this study can be used for further research utilizing many other combinations.

- Primary Accident Relationships - This section presents the project teams' identification of the primary accident causal factors based on the results of each of the previous tests. These results are presented in two sub-sections; the first containing continuous type variables and their identified relationships, and the second, discrete situations such as parking vs. no parking conditions.

- Causal Factors - Based upon the results of the various tests, conclusions were drawn concerning the independent variable relationships with accident rates and frequencies. Those independent variables with a previously defined relationship were specifically reviewed to determine if the data base supported causal factor relationships with urban arterial accidents.

- Countermeasures - Each causal factor was reviewed in detail utilizing the analysis results and, based on this review, appropriate countermeasures were identified. The countermeasures are presented in four tables representing the four roadway groupings previously listed. In each table a summary is presented of causal factors and countermeasures for the following accident types.

    - Head-on
    - Rear-end
    - Sideswipe
    - Angle

- Research Results - The data base collected for the study and the extensive testing have produced a valuable resource for design, research, and traffic operations engineers. While it is not possible to display all possible combinations of dependent and independent variables, this section presents several tables and graphs to aid the highway engineer in making decisions to enhance safety on urban arterial roadways.

- Recommended Research - Only a small portion of the potential areas of interest have been explored and are presented in this report. Several recommendations are given for future studies utilizing the computerized accident and roadway data base.

INDEPENDENT VARIABLES

In this section descriptions of the independent variables utilized in the analysis are presented. Based upon the findings of the literature review and the input received from project team members and FHWA personnel, a final list of independent variables was selected for data collection. The variables are grouped in three categories; geometric, environmental, and operational as shown in Table 1. The following discussion provides a brief description of these variables. Data for several of the variables are presented in graphical form for illustrative purposes. Histograms for all fifty-three variables used in the study are presented in Appendix E.

Geometric Factors

Thirty-four independent variables were classified as geometric factors which describe those items that contribute to the physical makeup of urban arterial roadways.

Lane Width

Lane width was defined as the average width of the through lanes on the roadway segment. Width was coded both as a continuous variable and a discrete variable in the data set to permit its use as a factor and as a covariate where appropriate. The predominant lane width contained in the file was 12 feet (3.7 m), however, 11- (3.4-m) and 14-foot (4.3-m) lanes are also well represented as shown in Figure 2. The number of segments for each lane width category is given in Table 4. The lane width category labeled as no data available represents roadway segments where lane width was either not collected or erroneously recorded.

Number of Through Lanes

This factor was defined as the number of mainline, through travel lanes contained in the segment. The number of through lanes does not include continuous left-turn lanes or curb lanes used for parking or exclusive bus use. Two- and fourlane segments characterize over 80 percent of the sample.

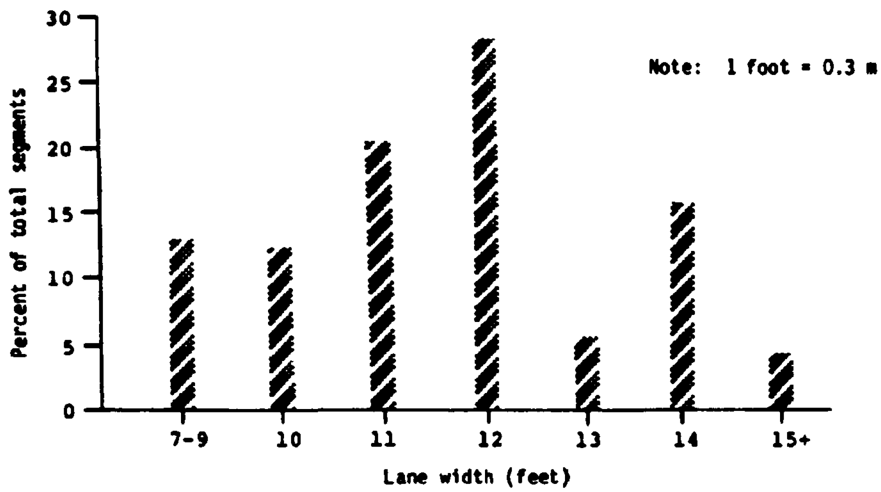


Figure 2. Distribution of roadway segments by lane width.

Table 4. Frequency of roadway segments by lane width.

Lane Width (feet)	Number of Segments	Relative Frequency (Pct.)	Adjusted Frequency (Pct.)	Cumulative Frequency (Pct.)
7-9	1,082	12.5	12.9	12.9
10	1,020	11.8	12.1	25.0
11	1,718	19.8	20.5	45.5
12	2,386	27.5	28.4	73.9
13	457	5.3	5.4	79.3
14	1,348	15.5	16.0	95.4
15+	388	4.7	4.6	100.0
No data available	279	3.2	-	
Total	8,678	100.0	100.0	

Note: 1 foot = 0.3 m

Average Shoulder Width

The width of the shoulder for the 1,414 segments of roadway with a shoulder was defined as the average shoulder width. Over 50 percent of the shoulders are narrow as the shoulder width ranges between 1 and 6 feet (0.3 and 1.8 m) wide as shown in Figure 3 and Table 5. It should be noted that 84 percent of the roadway segments did not have a shoulder as the majority of urban roadway designs employ curb and gutter cross sections. The average shoulder width for the 1,414 segments was 6.14 feet (1.87 m).

Roadway Classification

All road segments were assigned a functional classification, i.e., either one-way; two-way, two-lane; multilane divided; or multilane undivided. Forty percent of the roadway segments were classified as two-lane, two-way while one-way segments comprised only 8.4 percent of the total number of segments.

Pavement Surface

All road surfaces were classified as portland cement concrete, bituminuous concrete, or other. Bituminous surfaces constituted 78.8 percent of the urban arterial roadway surfaces.

Median Width

Where a median exists, three characteristics were identified, i.e., the median width, whether the median is bounded by a curb or shoulder, and if the median is paved or unpaved. The majority of medians (51 percent) are in excess of 20 feet (6.1 m) in width while 95 percent of the medians are bounded by a curb and 97 percent of all the medians are paved.

Land Use

Predominate land use along the segment was classified into one of four categories: commercial, residential, vacant, and other. The largest number of segments (49 percent) are bounded by predominately residential land uses as shown in Figure 4 and Table 6.

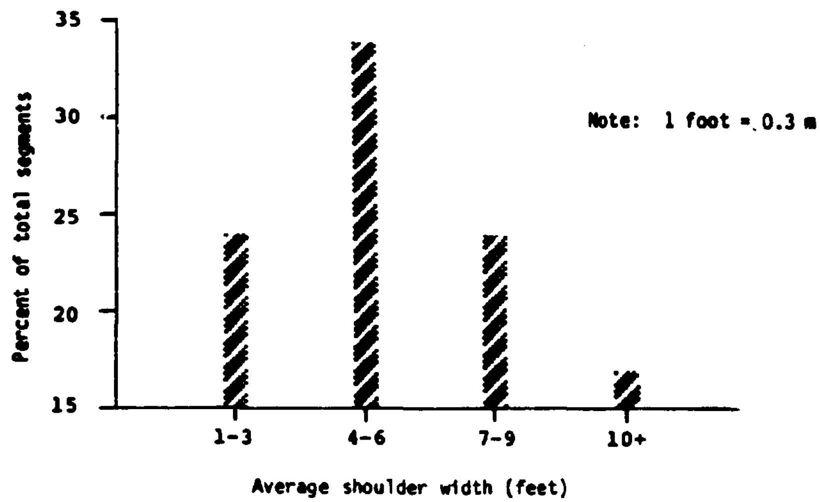


Figure 3. Distribution of roadway segments by average shoulder width.

Table 5. Frequency of roadway segments by average shoulder width.

Average Shoulder Width (feet)	Number of Segments	Adjusted Frequency (Pct.)	Cumulative Frequency (Pct.)
1-3	343	24.3	24.3
4-6	479	33.8	58.1
7-9	340	24.1	82.2
10+	252	17.8	100.0
No data available and/or no shoulders	7,264	-	
Total	8,678	100.0	

Note: 1 foot = 0.3 m

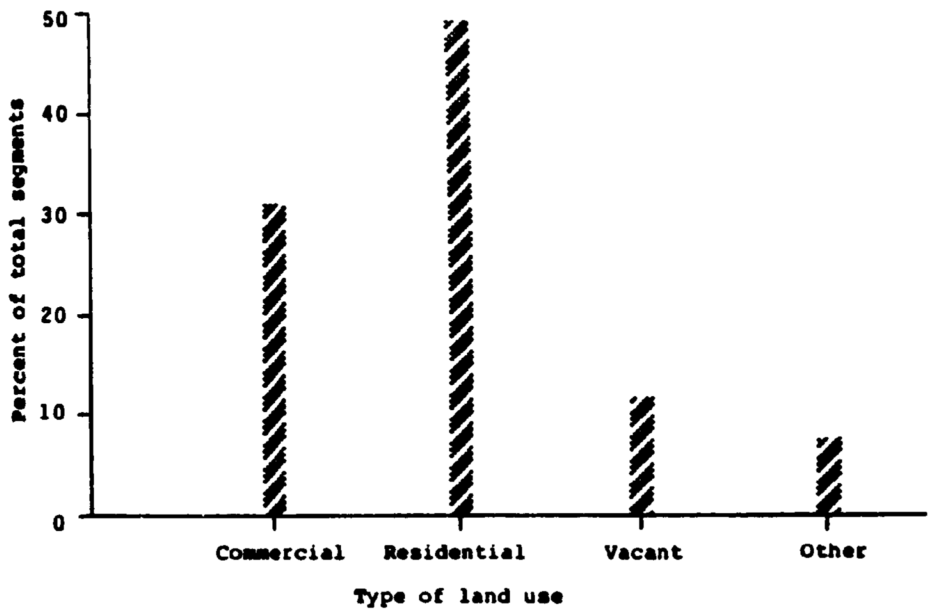


Figure 4. Distribution of roadway segments by type of land use.

Table 6. Frequency of roadway segments by type of land use.

Type of Land Use	Number of Segments	Relative Frequency (Pct.)	Adjusted Frequency (Pct.)	Cumulative Frequency (Pct.)
Commercial	2,618	30.2	30.8	30.8
Residential	4,194	48.3	49.4	80.2
Vacant	992	11.4	11.7	91.9
Other	688	7.9	8.1	100.0
No data available	186	2.1	-	
Total	8,678	100.0	100.0	

Curb Type

For roadways with curbs, the curbs were classified as either vertical or mountable. For divided and one-way segments, left-hand curbs were also identified. Approximately 70 percent of the segments had vertical curbs on both sides of the roadway.

Percent Guardrail

For each 0.1-mile (0.16-km) roadway segment, an assessment was made on the amount of coverage of guardrail along the road edge. The coverage was expressed as a percent of the total segment length. For multilane divided and one-way roadways the coverage percentage is an average for both sides of the roadway over 96 percent of the segments did not have guardrails.

Number of Intersections

The number of intersections in each segment was counted and classified as either signalized or nonsignalized. The number of signalized intersections ranged from 0 to 3. Seventy-four percent of the segments did have a signalized intersection, however, 45 percent of the segments had one nonsignalized intersection.

Bus Stops

The following six items related to bus stops were recorded.

- Total number of bus stops within the segment
- Type of curb at the bus stop
- Type of bus stop pullout
- Number of near-side bus stops
- Number of far-side bus stops
- Number of midblock bus stops

Number of Driveways

The number of driveways intersecting the road segment were recorded and are summarized in Figure 5 and Table 7. Over 50 percent of the segments have 5 or fewer driveways. The mean number of driveways on the urban segments was 5.07 driveways per segment.

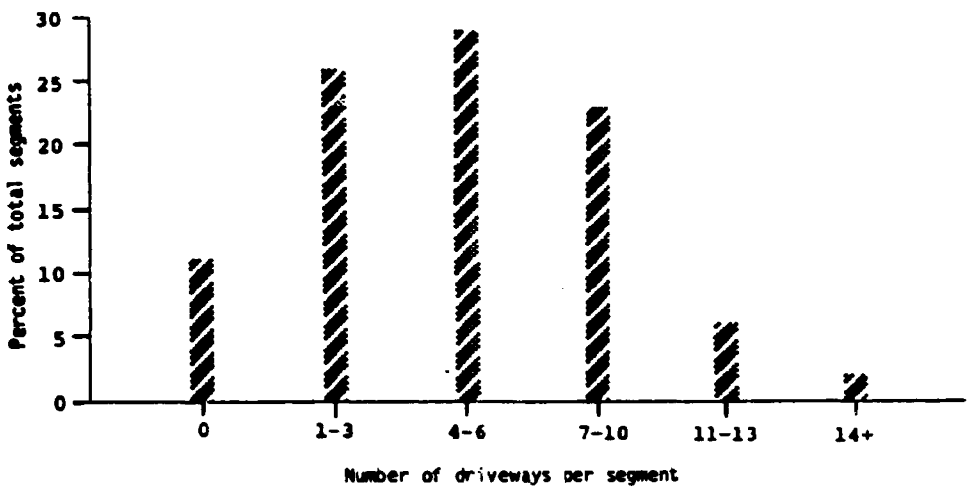


Figure 5. Distribution of roadway segments by the number of driveways per segment.

Table 7. Frequency of roadway segments by the number of driveways per segment.

Number of Driveways	Number of Segments	Adjusted Frequency (Pct.)	Cumulative Frequency (Pct.)
0	996	11.5	11.5
1-3	2,289	26.4	37.9
4-6	2,550	29.4	67.3
7-10	2,113	24.4	91.7
11-13	542	6.2	97.9
14+	188	2.1	100.0
Total	8,678	100.0	

Curb Lane Usage

The curb or right-hand lane was classified by type of traffic usage as shown below.

- Through traffic
- Reserved bus lane
- Restricted lane, i.e., loading permitted, etc.
- Full-time unrestricted parking
- Limited lane usage
- Other.

Through traffic usage is the predominate classification found in the data base.

Median Left-Turn Lane Usage

For roadway segments with a median left-turn lane, the segment was classified as either one direction or bidirectional, i.e., a continuous two-way, left-turn median lane. Left-turn bays at intersections were classified as separate turning lanes.

Parking Lane

In some areas a separate lane reserved for parking is generally delineated by the existence of a mountable curb. Parking lanes were classified by the side of street they occupied and whether parking was permitted continuously or intermittently along the segment.

Turn Lanes at Intersections

Separate right- and left-turn turn lanes at street intersections and at midblock driveway locations were recorded. Less than 10 percent of all sample segments contained at least one right- or left-turn lane.

Small Obstacles

Items such as u-channel sign posts, small trees, and parking meter posts were classified as small obstacles and the distribution is shown in Figure 6 and Table 8. Lateral distances to individual obstacles were not recorded.

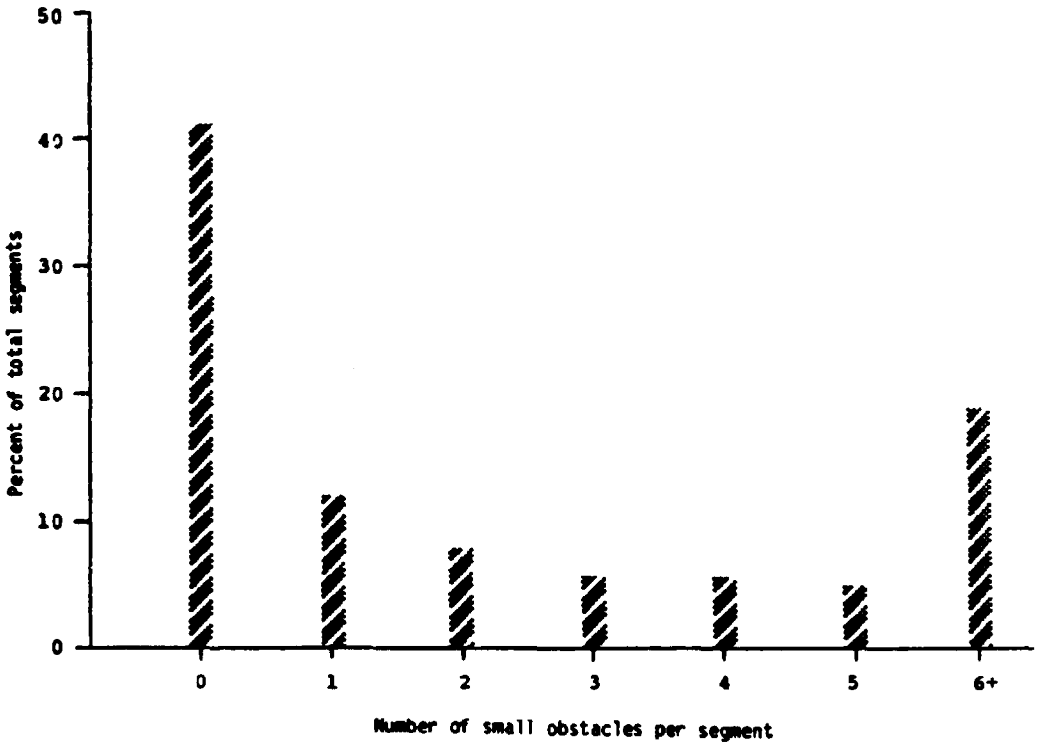


Figure 6. Distribution of roadway segments by the number of small obstacles per segment.

Table 8. Frequency of roadway segments by the number of small obstacles per segment.

Number of Small Obstacles	Number of Segments	Adjusted Frequency (Pct.)	Cumulative Frequency (Pct.)
0	3,524	40.6	40.6
1	1,071	12.3	52.9
2	721	8.3	61.2
3	563	6.5	67.7
4	551	6.4	74.1
5	471	5.4	79.5
6+	1,777	20.5	100.0
Total	8,678	100.0	

Horizontal Alinement

Road segments were classified into two categories with reference to horizontal alinement, i.e., either straight or curved. Over 12 percent of the sample segments are classified as curved.

Vertical Alinement

Road segments were classified into three groups for vertical alinement, i.e., level, moderate, or steep. Fifty-nine percent of the segments were classified as level.

Large Obstacles

Items such as utility poles, hydrants, and large sign supports were recorded as large obstacles if they were within 15 feet (4.6 m) from the edge of the roadway. Lateral distances to individual large obstacles were not recorded. Over 32 percent of the roadway segments had 15 or more large obstacles.

Number of Trees

Trees greater than 3 inches in diameter and within 15 feet (4.6 m) from the edge of roadway were recorded. Sixty-four percent of the segments did not have a tree within 15 feet (4.6 m) from the edge of pavement.

Utility Poles

Ornamental light poles, as distinguished from wood poles, were recorded as a separate item. Only poles whose primary purpose is to support luminaires are classified in this category.

Environmental Factors

The following independent variables were classified as environmental factors.

Roadway Lighting

Road segments were classified as to the existence or non-existence of street lighting. Eighty-nine percent of the segments were illuminated.

City Size

Road segments were classified as being either small (less than 50,000 population), medium (50,000 to 250,000 population) or large (more than 250,000 population). Over 50 percent of the segments were located in large cities.

City Population

The 1978 estimated population for each city is included in the segment descriptive data. This information provides the analyst with a continuous form of data on city size, whereas city size data are discrete.

Rainfall

Inches of rainfall (per year) were included for each segment, based upon the average annual rainfall in the city.

Snowfall

Inches of snowfall (per year) were included for each segment, based upon the average annual snowfall in the city.

Operational Factors

Fifteen independent variables were classified as operational factors as shown below.

Average Daily Traffic

An average daily traffic volume was assigned to each segment based upon records supported by a manual or machine count. Traffic volumes on the segments ranged from 650 to 50,392 vehicles per day.

Capacity

Traffic capacity for each segment was calculated using procedures outlined in the 1965 Highway Capacity Manual.

Volume-To-Capacity Ratio

The average daily traffic and the calculated capacity were used to calculate a volume-to-capacity ratio for each segment.

Location Factor

A location factor was estimated for each segment based on the location of the segment within the urban area.

Peak Hour Factor

A peak hour factor was estimated for each segment based on the traffic volume during peak periods.

Vehicle Mix

The percentage of cars and commercial vehicles were estimated for each segment based upon field data.

Parking Turnover Rate

An estimate of parking turnover was made based upon either previously collected data or field inspections.

Local Buses Per Hour

The average local bus volume per hour was recorded for each segment with bus traffic. The data were obtained from bus route schedule information.

Average Cycle Length

A determination of the average cycle length for each segment containing a traffic signal was made by field measurement or from a review of city records.

Posted Speed Limit

The posted speed limit for each segment was recorded. The frequency of segments with specific posted speed limits are shown in Figure 7 and Table 9. Nearly 40 percent of the segments have a posted speed limit of 30 miles per hour (48 km per hr).

Operating Speed

A determination of the operating speed on the roadway segment was made based upon previously collected data or field samples of vehicle speeds.

Traffic Sign Faces

The number of traffic sign faces on each roadway segment were recorded and are summarized in Figure 8 and Table 10. The traffic sign face data were classified into the following categories.

- Total number of traffic sign faces
- Number of regulatory sign faces
- Number of warning sign faces
- Number of guide sign faces

Summary

A summary of selected descriptive characteristics of the urban arterial segments is given in Table 11 for the independent variables collected during the study. A detailed description of each variable is given in Appendix E.

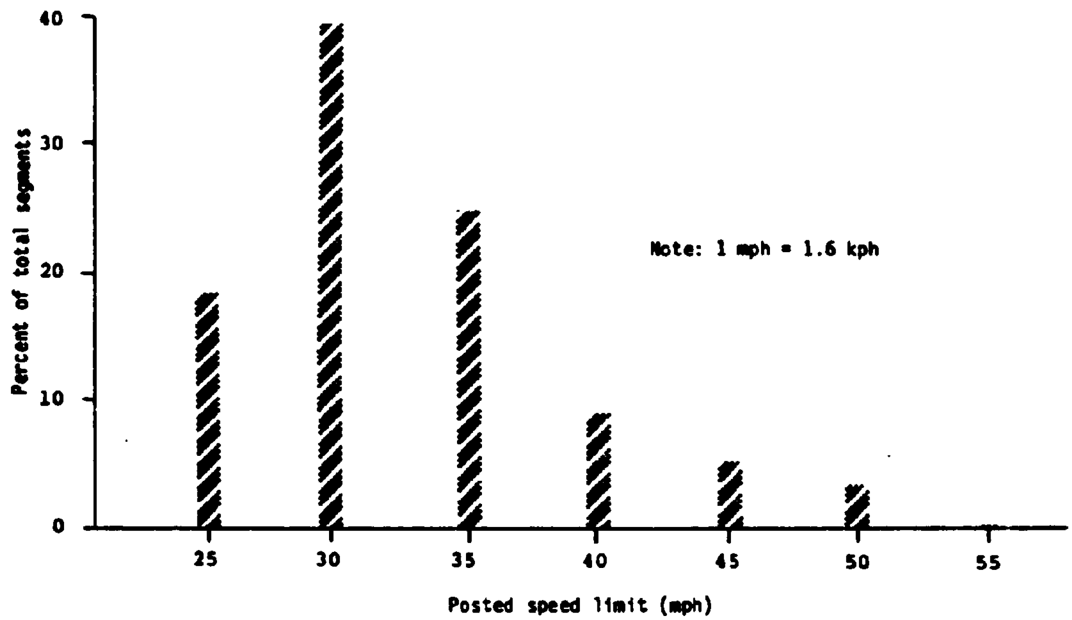


Figure 7. Distribution of roadway segments by posted speed limit.

Table 9. Frequency of roadway segments by posted speed limit.

Posted Speed Limit (mph)	Number of Segments	Relative Frequency (Pct.)	Adjusted Frequency (Pct.)	Cumulative Frequency (Pct.)
≤ 25	1,609	18.5	18.5	18.5
30	3,427	39.5	39.5	58.1
35	2,152	24.8	24.8	82.9
40	748	8.6	8.6	91.5
45	439	5.1	5.1	96.6
50	274	3.2	3.2	99.7
55	25	0.3	0.3	100.0
No data available	4	0.0	-	
Total	8,678	100.0	100.0	

Note: 1 mph = 1.6 kph

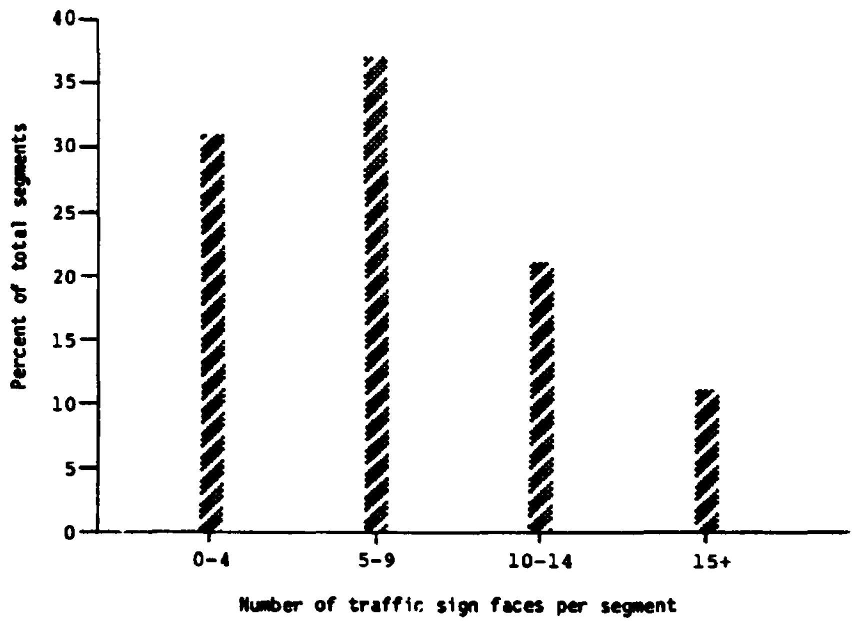


Figure 8. Distribution of roadway segments by number of traffic sign faces per segment.

Table 10. Frequency of roadway segments by number of traffic sign faces per segment.

Number of Signs	Number of Segments	Adjusted Frequency (Pct.)	Cumulative Frequency (Pct.)
0-4	2,675	30.8	30.8
5-9	3,179	36.6	67.4
10-14	1,856	21.4	88.8
15+	968	11.2	100.0
Total	8,678	100.0	

Table 11. Selected descriptive characteristics of the urban arterial segments.

Variable	Selected Category	Number Of Segments	Percent Of Total Segments	Range Containing 50 Percent Of The Total Segments
Lane width	12-foot	2,386	28.4	10 to 12 foot
Number of through lanes	2 lanes	3,786	43.6	2-3 lanes
Average shoulder width	3-foot	182	24.0	3 to 7 foot
Roadway classification	two-way, two-lane	3,459	39.9	two-way, two-lane and multilane undivided
Pavement surface	bituminous	6,828	78.8	bituminous
Median width	30-foot	175	11.0	15-60 ft. wide
Median curb	curbed	1,418	94.9	curbed
Median type	paved	514	96.6	paved
Curb type - right side	vertical	6,017	69.3	vertical
Curb type - left side	vertical	6,081	70.1	vertical
Percent guardrail	0 percent	8,332	96.0	0 percent
Land use	residential	4,194	49.4	residential & commercial
Number of signalized intersections	0	6,382	73.5	0
Number of non-signalized intersections	1	3,876	44.7	0-1
Number of bus stops	0	5,410	62.3	0

Note: A comprehensive summary of the roadway characteristics is included in Appendix E.
1 foot = 0.3 m

Table 11. Selected descriptive characteristics of the urban arterial segments (continued).

Variable	Selected Category	Number Of Segments	Percent Of Total Segments	Range Containing 50 Percent Of The Total Segments
Number of driveways	0	996	11.0	0 to 5
Curb lane usage	through traffic	4,499	51.8	through traffic
Parking lane - right side	none	5,008	57.5	none
Parking lane - left side	none	5,018	57.8	none
Right turn bays at intersection	0	8,082	93.1	0
Left turn bays at intersection	0	7,724	89.0	0
Horizontal alinement	tangent	7,572	87.6	tangent
Vertical alinement	level	5,094	58.9	level
Number of large obstacles	10	467	5.0	3 to 13
Number of small obstacles	0	3,524	41.0	0 to 1
Number of trees	0	5,588	64.0	0
Number of utility poles	5	970	11.0	3 to 7
Roadway lighting	yes	7,719	88.9	yes
City size	large	4,424	51.0	large
Average daily traffic	15,000	586	7.0	9900 to 20,000
Vehicle mix	10 percent commercial	3,647	53.0	10 percent commercial
Local buses per hour	5	2,811	80.2	5

Note: A comprehensive summary of the roadway characteristics is included in Appendix E.
1 foot = 0.3 m

Table 11. Selected descriptive characteristics of the urban arterial segments (continued).

Variable	Selected Category	Number Of Segments	Percent Of Total Segments	Range Containing 50 Percent Of The Total Segments
Posted speed limit	30 mph	3,427	39.5	30 to 35 mph
Operating speed	30 mph	3,027	35.0	30 to 35 mph
Number of traffic sign faces	4	683	8.0	3 to 9
Number of regulatory sign faces	0	1,019	12.0	0 to 4
Number of warning sign faces	0	6,074	70.0	0
Number of guide sign faces	2	2,285	26.0	0 to 2
Bus stop-curb	none	5,439	62.7	none
Bus stop-pullout	none	8,645	99.6	none
Right turn bays at midblock driveways	0	8,580	98.9	0
Bus stop near-side	0	6,678	77.0	0
Bus stop far-side	0	7,789	89.8	0
Bus stop midblock	0	7,804	89.9	0
Peak hour factor	0.95	6,169	90.0	0.95
Parking turnover rate	1.50	45	26.8	1.20-3.00
Average cycle length	60 sec.	1,867	67.2	60 sec.
Location factor	1.25	3,598	65.1	1.25
City population	485,000	1,125	13.0	372,000-649,000
Rainfall	32 inches	2,067	30.7	28 to 32 inches
Snowfall	32 inches	2,067	38.3	32 to 45 inches
Capacity	1,650 vph	3,648	42.0	1,650 to 4,950 vph

Note: A comprehensive summary of the roadway characteristics is included in Appendix E.
1 mph = 1.6 kph
1 inch = 2.5 cm

CHARACTERISTICS OF URBAN ARTERIAL ROADWAY ACCIDENTS

One primary objective of the study was to determine accident characteristics for urban arterial roadways. The analyses in the remaining sections of the report were conducted to identify specific accident problems and related countermeasures. In this section the general dimensions of the urban arterial accident problem are outlined.

The mean accident frequencies and rates for the 0.1-mile (0.16-km) arterial roadway segments included in the sample are given in Table 12. As shown in Table 12, multilane divided roadways have the highest annual accident frequency and the lowest accident rate. Two-lane, two-way streets had the lowest annual accident frequency while one-way streets had the highest accident rates.

Table 12. Mean accident frequencies and rates for the 0.1 mile (0.16-km) urban roadway segments.

Roadway Classification	Annual Accident Frequency*		Accident Rate**	
	Mean	Std. Dev.	Mean	Std. Dev.
One-way	3.71	5.11	10.06	11.49
Two-lane, two-way	2.50	3.98	8.06	10.93
Multilane divided	4.73	6.21	7.82	10.32
Multilane undivided	4.38	5.62	8.59	10.76
All segments	3.66	5.24	8.33	10.81

* Accidents per 0.1-mile (0.16-km) segment per year
** Accidents per million-vehicle miles
Note: 1 mile = 1.6 km

While total accident frequencies and rates can be used to describe general accident problems, an analysis of the data by severity and accident type is needed to identify specific causal factors and countermeasures. The distribution of accidents by severity and accident type is shown in Figures 9 and 10. The percentage of fatal accidents on arterial streets (0.24 percent) appears to be higher than the estimated 0.12 percent of fatal accidents that are annually reported in urban areas [4]. However, it should be noted that only 225 fatal accidents were reported in the 8,678 sample segments during the three-year accident period (1976 through 1978), thus the percentage of fatal accidents may be highly variable due to the small sample size.

In comparison to the findings of the other researchers, Mulinazzi and Michael [32] reported that 0.31 percent of the accidents reported in urban

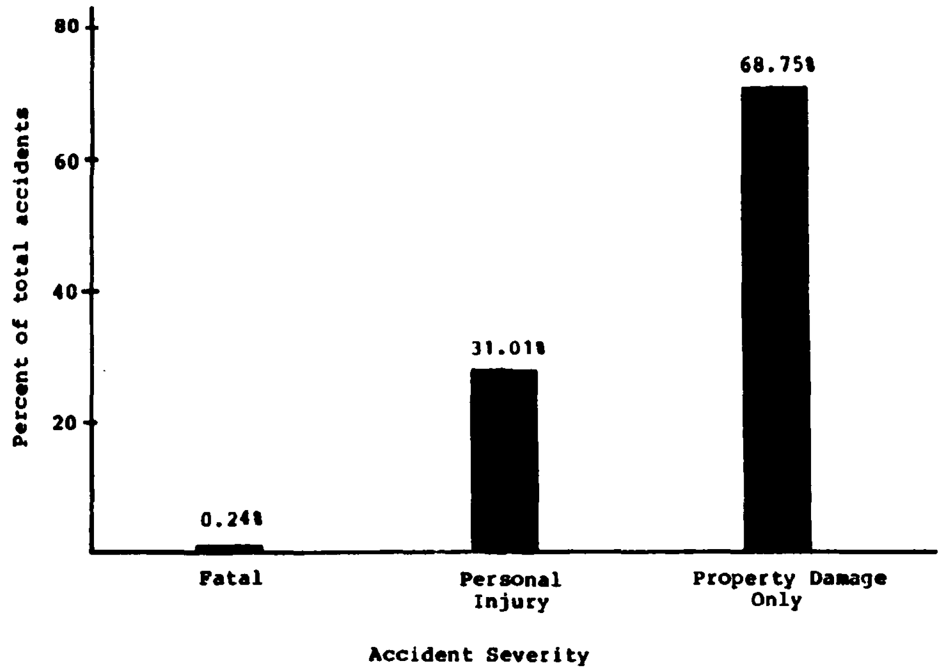


Figure 9. Distribution of accidents by severity.

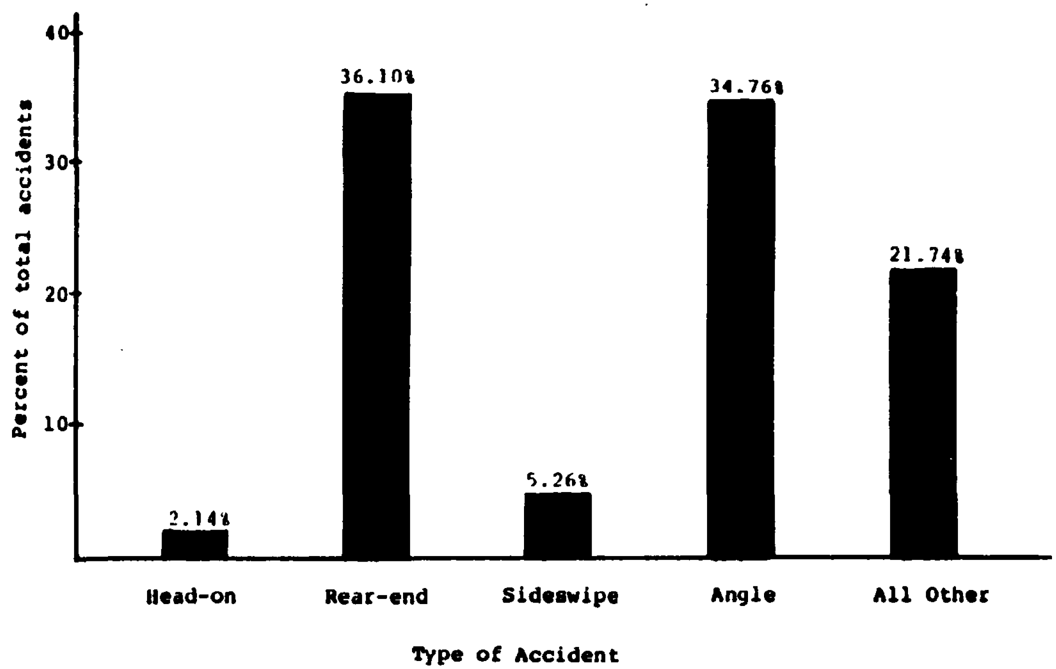


Figure 10. Distribution of accidents by accident type.

areas in Indiana during 1963, 1964, and 1965 were fatal collisions. Recently, Parker [22] noted that fatal accidents constituted 0.36 percent of the total accidents reported during the period 1975, 1976 and 1977 on multilane urban arterial streets in 30 cities in Virginia. These data also provide evidence that the percentage of fatal accidents on urban arterial roadways may be significantly higher than the percentage of fatal accidents on other urban facilities.

Parker [22] also conducted an analysis of the accident data by accident type and reported that the percentages of head-on, rear-end, sideswipe, and angle accidents are comparable to the percentages shown in Table 10 which were found in this study. It should be noted that accident type data are not provided in the computerized data base for the cities of Topeka, New Orleans, Milwaukee, and San Francisco. The computerized accident data files for these cities do not contain accident data by type and it was not possible to obtain these data within the research budget as the task would have required obtaining copies of the accident reports.

The distribution of accidents by severity and city is shown in Table 13. A review of Table 13 provides an indication of the problems in collecting a large sample of severity data for research purposes. First, several cities do not have severity or other accident data in a computerized format that can be easily reduced and reformatted. For example, repeated attempts were made to recode severity data for each study segment in San Francisco and Seattle, however, the process of assigning the severity data to specific roadway segments was found to be extremely time consuming and subject to considerable error. Thus, to improve the accuracy of the data base, severity data for Seattle and San Francisco do not appear in the computerized data base. Another problem is that fatal accidents are rare events in many cities. Four of the cities included in the sample did not have a reported fatality in the study segments during a three-year period.

While the sample of 225 fatal accidents is much less than the target sample size of 1,000 fatals, in retrospect it appears that the target value was unrealistic given the overall scope of the research. For example, taking into consideration the data transfer problems and the low number of fatals in urban areas, data would have to be collected on a minimum of 56,720 segments or 5,672 miles (9,132 km) of urban roadway to obtain a minimum of 1,000 fatal accidents. This is 6.5 times the number of segments currently included in the data base.

A summary of severity and accident type data stratified by functional roadway classification is given in Tables 14 and 15. As shown in Table 16, accident severity was also summarized by city size. Examination of the data reveals that there is little difference in the severity of accidents by roadway type with the exception that one-way streets appear to have a lower percentage of injury accidents as compared to the percentage of injury accidents reported on the other roadway types. As shown in

Table 13. Distribution of urban arterial accidents by city and accident severity.

City	Number Of 0.1-Mile (0.16-km) Segments	Three Year Accident History (1976-78)			
		Fatal Accidents	Personal Injury Accidents	Property Damage Accidents	Total Accidents
Big Rapids	135	0	185	607	792
Kalamazoo	489	3	1,284	4,442	5,729
Lansing	545	9	2,032	6,237	8,278
Saginaw	676	7	1,544	3,951	5,502
Birmingham	92	0	169	522	691
Farmington	49	1	176	400	577
Farmington Hills	72	0	105	182	287
Novi	162	7	251	485	743
Oak Park	10	0	24	58	82
Royal Oak	60	1	75	183	259
Southfield	281	4	900	1,095	1,999
Troy	318	7	1,019	1,916	2,942
Topeka	647	6	1,349	2,749	4,104
New Orleans	570	13	2,418	4,516	6,947
Milwaukee	875	9	3,215	9,239	13,463
San Francisco	774	38*	3,844*	7,843*	11,725
Fort Wayne	718	37	3,107	12,223	15,367
Seattle	1,125	34*	4,388*	6,025*	10,447
Minneapolis	1,080	49	3,434	2,763	6,246
Total	8,678	225*	29,519*	65,436*	95,180

* The severity data for these cities were taken from the data provided by city officials, however, these data do not appear in the computerized data base because coding anomalies prevented assigning severity type to specific 0.1-mile (0.16-km) roadway segments.

Table 14. Summary of severity by roadway classification.

Accident Severity	Roadway Classification			
	One-Way	Two-Way, Two-Lane	Multilane Divided	Multilane Undivided
Fatal	8 (0.1%)	56 (0.2%)	33 (0.2%)	56 (0.2%)
PI	1,630 (24.9%)	6,840 (29.9%)	6,198 (29.7%)	6,617 (29.3%)
PDO	4,920 (75.0%)	16,152 (69.9%)	14,618 (70.1%)	15,877 (70.5%)
Total	6,558 (100.0%)	23,048 (100.0%)	20,849 (100.0%)	22,550 (100.0%)

Table 15. Summary of accident type by roadway classification.

Accident Type	Roadway Classification			
	One-Way	Two-Way, Two-Lane	Multilane Divided	Multilane Undivided
Head-on	42 (0.6%)	490 (3.0%)	188 (1.7%)	491 (2.1%)
Rear-end	3,190 (48.9%)	4,692 (29.2%)	4,275 (38.5%)	8,382 (36.2%)
Sideswipe	306 (4.7%)	543 (3.4%)	700 (6.3%)	1,440 (6.2%)
Angle	2,038 (31.3%)	5,982 (37.2%)	3,672 (33.1%)	8,080 (34.9%)
All Other	942 (14.5%)	4,382 (27.2%)	2,271 (20.4%)	4,774 (20.6%)
Total	6,518 (100.0%)	16,089 (100.0%)	11,106 (100.0%)	23,617 (100.0%)

Table 16. Summary of severity by city size.

Accident Severity	City Size		
	Small	Medium	Large
Fatal	8 (0.3%)	74 (0.2%)	143 (0.3%)
PI	805 (27.9%)	11,415 (25.7%)	17,299 (36.2%)
PDO	2,072 (71.8%)	32,978 (74.1%)	30,386 (63.5%)
Total	2,885 (100.0%)	44,467 (100.0%)	47,828 (100.0%)

Table 16, the percentage of injury accident data for large size cities appears to be significantly higher than the percentage of injury accidents reported in smaller and medium size cities. However, a review of the accident reporting procedures in the large cities contained in the sample revealed that property damage accidents are not routinely investigated, thus, it is doubtful if there is a real difference in the percentage of injury accidents.

Further details and summaries of the urban arterial accident characteristics are provided in the preceeding sections of this report and in the Appendixes.

MACROSCOPIC ANALYSIS

This section presents the results of a series of tests conducted to identify specific roadway characteristics which are over or underrepresented in terms of accidents. Chi-square tests were used to determine if the frequency of accidents with regard to a specific variable and the frequency of roadway segments for that variable are significantly different. A contingency coefficient was used to identify the effects of sample size on the Chi-square statistic, while the Z-test was used to identify particular groups within the distribution that accounted for the over or under representation of accidents. In this section confounding factors such as traffic volume, land use, etc. are not accounted for.

A macroscopic analysis of the data was undertaken to determine if the data base provided evidence of a relationship between a single roadway feature and traffic accidents. A frequency table was constructed for each independent variable listing the range and categories of the independent variable in order to compare the number of segments within each category, and the frequency of accidents on those segments. For purposes of illustration, the frequency table for median width is shown in Table 17. Median widths for the 1,555 roadway segments with a median range from one foot (0.3 m) to 198 feet (60 m). Five categories were selected to summarize the data for analysis, e.g., 1 to 4 feet (0.3 to 1.2 m), 5 to 10 feet (1.5 to 3 m), 11 to 20 feet (3.3 to 6 m), etc. These categories were selected based upon a review by team members of the distribution of each independent variable. A total of 21,721 accidents were reported on the 1,555 segments with a median.

As shown in Table 17, 12.3 percent of the segments have medians 1 to 4 feet (0.3 to 1.2 m) wide, and 15.0 percent of the accidents occurred on these segments. Thus, it appears plausable that a higher proportion of accidents occur on roadways with narrow medians.

Operating under the hypothesis that the proportion of accidents is not influenced by the width of median, i.e., the null hypothesis, several statistical tests were conducted. The Chi-square test is used to determine if there is an association between two variables, e.g., accident frequency per segment of roadway and median width. In this nonparametric test, observed accident frequencies are compared with expected accident frequencies which would exist if the two variables were independent.

The computed Chi-square value is compared with the critical Chi-square value obtained from statistical tables at an assumed level of confidence. If the calculated value is greater than the critical value, the null hypothesis is rejected and it is concluded that there is a significant association between the variables. If the calculated value is less than the critical value, it is assumed that there is no association between the variables.

Table 17. Frequency distribution of roadway segments and accidents by median width.

Median Width (feet)	0.1-Mile (0.16-km) Segments		Number of Accidents	
	Number	Percent	Number	Percent
1-4	192	12.3	3,263	15.0
5-10	435	28.1	5,741	26.4
11-20	167	10.7	2,197	10.1
21-40	403	25.9	5,188	23.9
41+	358	23.0	5,332	24.6
Total	1,555	100.00	21,721	100.00

Note: 1 foot = 0.3 m

Because the Chi-square statistic is strongly affected by sample size and table size, especially when large data samples are taken, the contingency coefficient, c, was computed and used to determine if significance was attributable to sample size. The contingency coefficient ranges from 0 to 1, (depending upon table size - for example the maximum value for a 2 x 2 table is 0.707) with values close to 0 indicating that little relationship (association) exists between the variables even if the Chi-square value indicates the relationship is significant. However, for values of the coefficient close to 1, a strong relationship can be assumed between the variables.

As shown in Table 18, the calculated Chi-square value for median width is 12.73 which is significant at the 0.05 level of significance. However, as the contingency coefficient equals 0.023, median width may have an effect on accidents but most of the association is attributed to the large sample size, and the relationship is not considered strong.

When the Chi-square test indicated a significant association existed between roadway segments and accidents, the Z-test was used to identify category(s) that contributed to the relationship. The Z-test is used to determine if the proportion of accidents to total accidents for a category is significantly different from the proportion of segments to total segments in that category.

As shown in Table 19, the results of the Z-test for the median width categories revealed that a significantly higher percentage of accidents occur on roadway sections with narrow median widths ranging from 1 to 4 feet (0.3 to 1.2 m).

The results of the Z-test identify the specific categories of a variable which may have a significant over or underrepresentation of accidents. Such findings provide useful information that can be utilized to further investigate relationships between roadway features and accidents.

The Chi-square test, contingency coefficient, and Z-test were conducted for each of the geometric, environmental, and operational independent variables. The significant findings are reported in the following discussion. These results do not necessarily depict a cause-effect relationship, nor do they explain any possible interactional effects of various independent variables. However, the analyses do present a picture of the distribution of accidents relative to specific geometric, environmental, and operational variables. A complete set of results is shown in Appendix E.

The factors determined to have a significant deviation from the expected frequency (assuming the null hypothesis) are listed in Table 20. Median curb, horizontal alinement, and vertical alinement which are listed as having a probable relationship with accidents in Table 3, failed to demonstrate such a relationship with the study data. This finding may simply mean that the effect of these variables are masked by other variables distributed nonuniformly through the data base. The remaining tests

Table 18. Chi-square test results for median width.

Median Width (feet)	Number of 0.1-Mile (0.16-km) Segments	Number of Accidents	Total
1-4	192	3,263	3,455
5-10	435	5,741	6,176
11-20	167	2,197	2,364
21-40	403	5,188	5,591
41+	358	5,332	5,690
Total	1,555	21,721	23,276

Calculated Chi-square = 12.73 with 4 degrees of freedom.

Contingency coefficient, C = 0.023

Critical Chi-square for $\alpha = 0.05 = 9.49$ with 4 degrees of freedom.

Thus, as the calculated Chi-square is greater than the critical Chi-square, i.e., 12.73 > 9.49, the frequencies are significantly different.

Note: 1 foot = 0.3 m

Table 19. Z-test results for median width.

Median Width (feet)	0.1-Mile (0.16-km) Segments		Number of Accidents		Calculated Z-Value	Significance* α =0.05
	Number	Percent	Number	Percent		
1-4	192	12.3	3,263	15.0	2.87	Yes
5-10	435	28.1	5,741	26.4	1.33	No
11-20	167	10.7	2,197	10.1	0.79	No
21-40	403	25.9	5,188	23.9	1.81	No
41+	358	23.0	5,332	24.6	1.35	No
Total	1,555	100.00	21,721	100.00		

Note: 1 foot = 0.3 m

* Critical Z-Value = 1.96 at α = 0.05

Table 20. Summary of accident relationships for urban arterial streets based on the macroscopic analysis.

Roadway Feature	Type of Relationship: Possible	Type of Relationship: None
<u>Geometric Factors</u>		
Lane width	•	
Number of through lanes	•	
Average shoulder width	•	
Roadway classification	•	
Pavement surface	•	
Median width	•	
Median curb		•
Median type	•	
Curb type-right side	•	
Curb type-left side	•	
Percent guardrail	•	
Number of signalized intersections per segment	•	
Number of nonsignalized intersections per segment	•	
Number of bus stops per segment	•	
Bus stop type-curb	•	
Bus stop type-pullout		•
Number of near side bus stops per segment	•	
Number of far side bus stops per segment	•	
Number of midblock bus stops per segment	•	
Number of driveways per segment	•	
Curb lane usage	•	
Parking lane-right side	•	
Parking lane-left side	•	
Number of right turn bays at intersections	•	
Number of left turn bays at intersections	•	
Number of right turn bays at midblock driveways		•
Vertical alinement		•
Horizontal alinement		•
Number of large obstacles per segment	•	
Number of small obstacles per segment	•	
Number of trees per segment	•	
Number of utility poles per segment	•	
Type of land use	•	
Midblock right turn lanes		•
<u>Environmental Factors</u>		
Roadway lighting	•	
City size	•	
Amount of rainfall	•	
Amount of snowfall	•	
<u>Operational Factors</u>		
Average daily traffic	•	
Roadway capacity	•	
Location factor	•	
Peak hour factor	•	
Vehicle mix-percent commercial	•	
Vehicle mix-percent cars	•	
Parking turnover rate	•	
Number of local buses per hour	•	
Average cycle length	•	
Posted speed limit	•	
Operating speed	•	
Number of traffic sign faces per segment	•	
Number of regulatory sign faces per segment	•	
Number of warning sign faces per segment		•
Number of guide sign faces per segment	•	

were conducted to determine if combinations of these variables display a significant relationship with urban arterial accident frequencies or rates.

A brief description of some of the variables with a significant difference is given below. The statistics for each variable are provided in Appendix E.

Analyses of Selected Variables

Average Shoulder Width

An association between average shoulder width and accident frequency was found, with the percent of accidents less than expected for roadway segments with 7- to 9-foot (2.1 to 2.7 m) shoulders, and greater than expected for shoulders greater than 10 feet (3 m) wide.

Traffic Sign Faces

As previously noted, four independent variables were developed from the sign inventory: total number of traffic sign faces; number of regulatory sign faces; number of warning sign faces; and number of guide sign faces. Three of these independent variables exhibit a significant relationship with accident frequency; total number of traffic sign faces as shown in Figure 11, number of regulatory sign faces, and number of guide sign faces. In each case there are significantly more accidents than expected where the sign densities exceed certain limits. For each of these independent variables the critical densities are listed below.

- Total number of traffic sign faces - 10 sign faces per segment
- Number of regulatory sign faces - 4 sign faces per segment
- Number of guide sign faces - 3 sign faces per segment

Obstacles

Obstacles were classified into four categories: large; small; trees; and utility poles. Each category was examined separately. The analysis revealed that each of these variables exhibited a relationship with accident frequency. For those segments with 10 or more large obstacles there were more total accidents than expected as shown in Figure 12, while the same result was found where there were 0 and 1 small obstacles per segment, 0 trees per segment, and 8 or more utility poles per segment. While

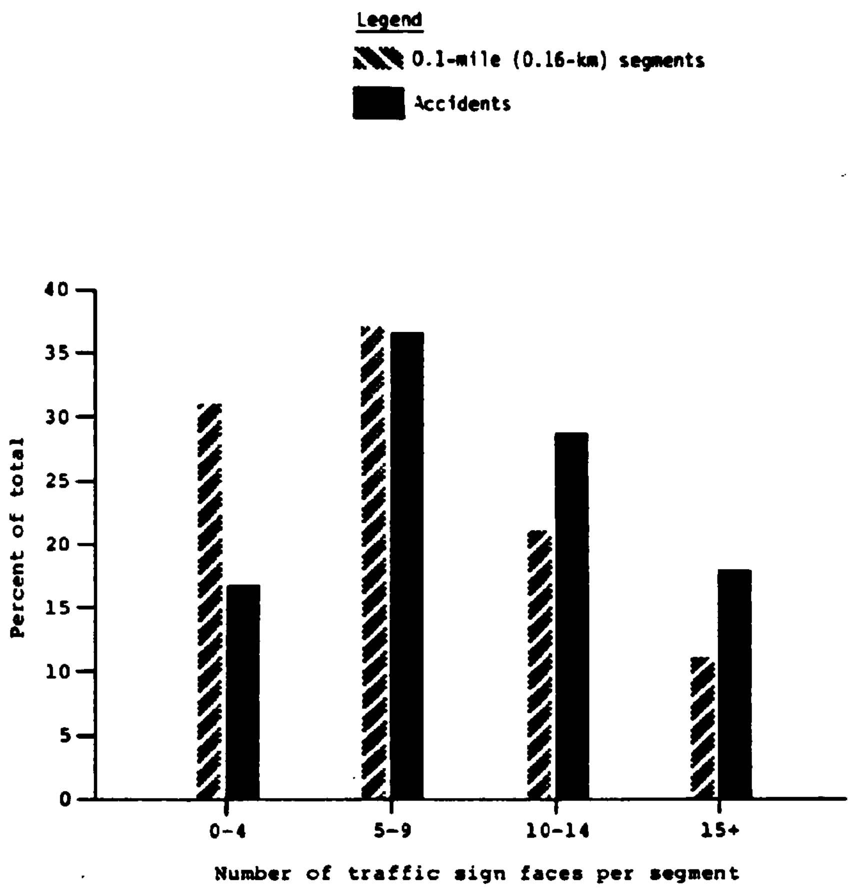


Figure 11. Distribution of roadway segments and accidents by number of traffic sign faces per segment.

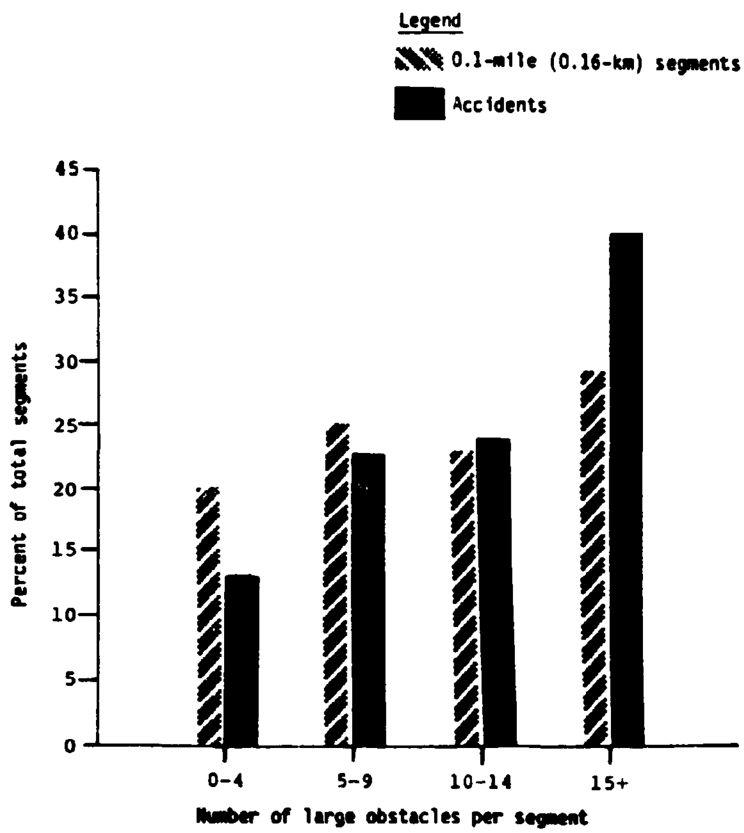


Figure 12. Distribution of roadway segments and accidents by number of large obstacles per segment.

the relationship for the number of small obstacles and trees per segment may be influenced by other variables, the magnitude of the statistics for large obstacles and utility poles indicates that these variables strongly are associated with urban arterial accidents and should receive further examination.

Land Use

When the four land use categories of commercial, residential, vacant, and other were analyzed, it was found that segments with commercial land use have a higher than expected number of accidents, while segments classified as residential and vacant have correspondingly lower than expected accident frequencies. This finding is illustrated in Figure 13.

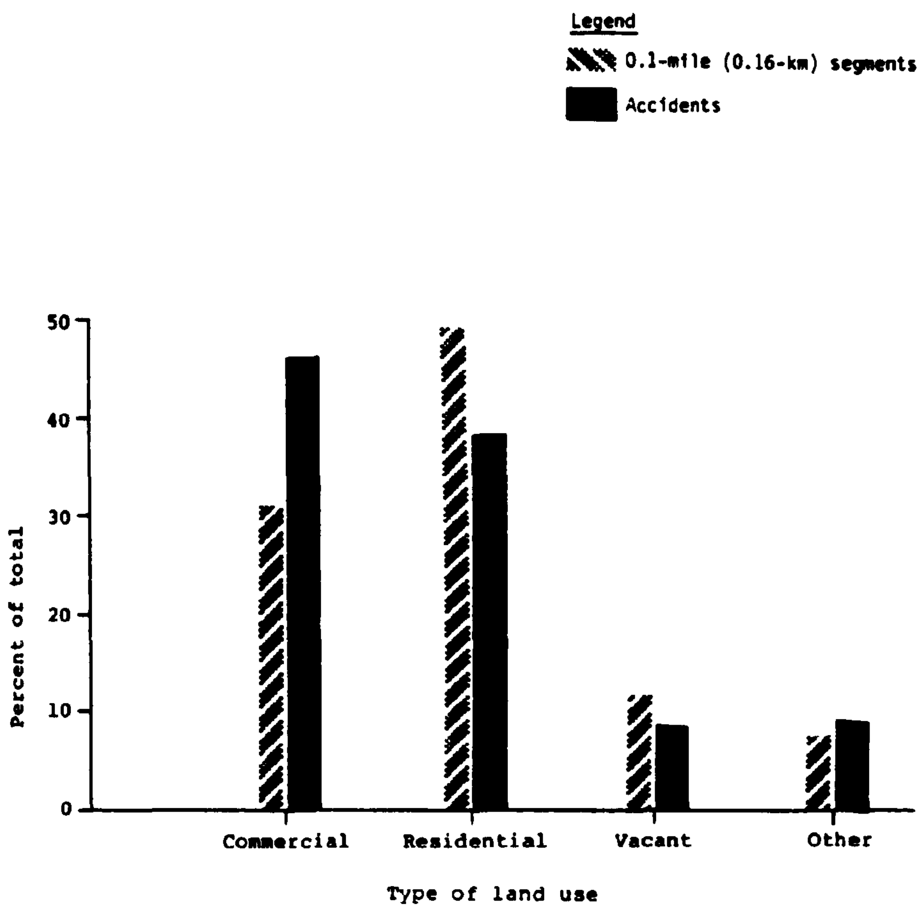


Figure 13. Distribution of roadway segments and accidents by type of land use.

BRANCHING ANALYSIS

Branching analysis was used to identify the independent variables that explain the variation in accident rates and frequencies and to establish an inter-relational framework among the variables. The branching program selected the independent variables that account for the highest amount of explained variation. This process provided guidelines for later analysis work, including the selection of independent variables for inclusion in regression analysis, the analysis of variance and the partitioning of the data file to identify key classification variables. The branching results also were used to identify possible accident causal factors and to select appropriate countermeasures.

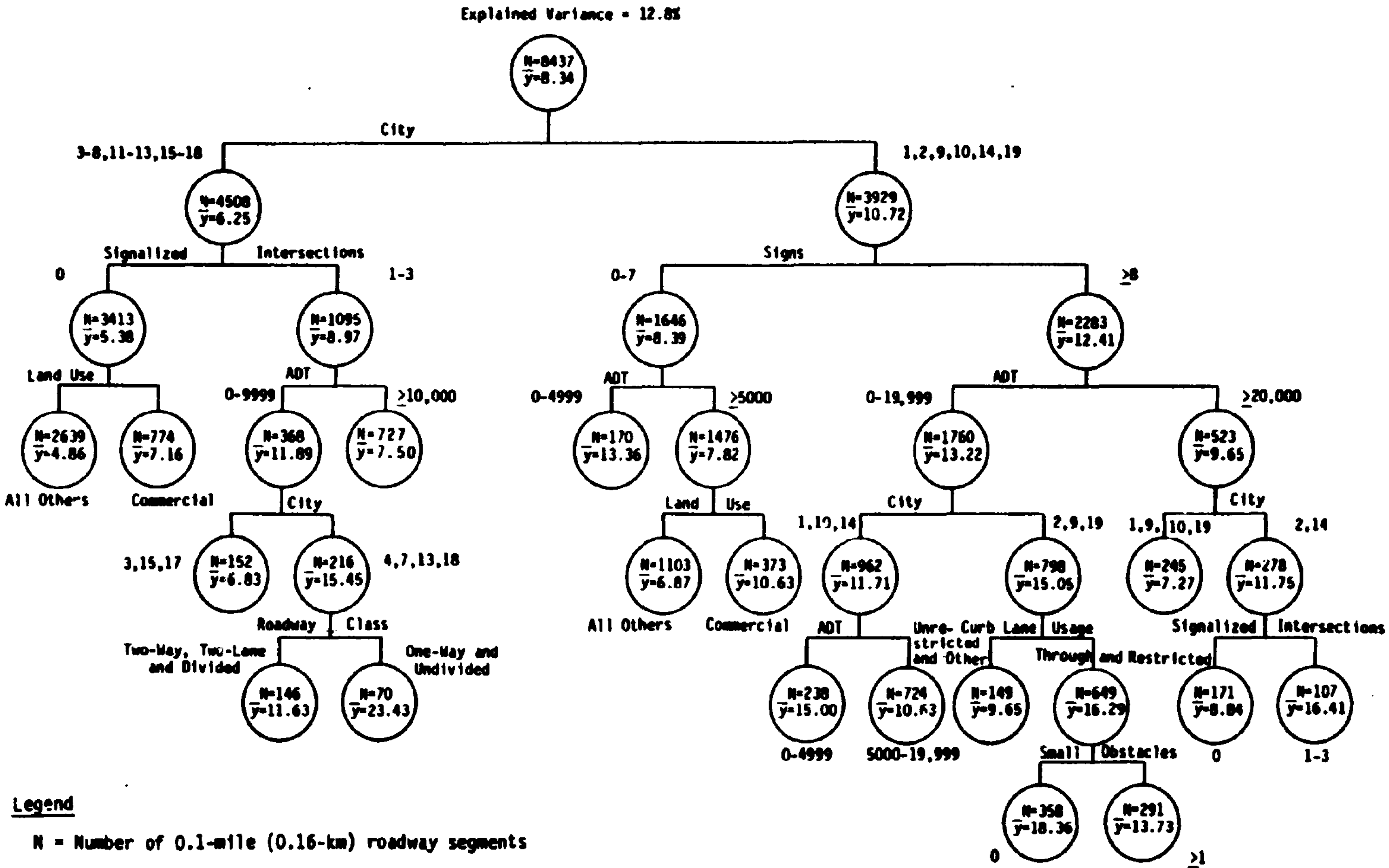
The results reported in the previous sections were developed from the total accident data file, and there was no effort to identify the interactive affects of such factors as city size, traffic volume, or road type. This phase of analysis, therefore, initiated the investigation of relationships among variables and how they may affect accident rates and frequencies.

As an initial attempt to identify these inter-relationships, the entire accident file and all independent variables were entered into the branching program. The resulting stratification for accident rate is shown in Figure 14. The branching diagram using annual accident frequency as a dependent variable is given in Figure 15. As shown in Figures 14 and 15, the following variables contributed significantly to the explanation of accidents on urban arterial roadways when all roadway segments were considered in the analysis.

- City
- Number of signalized intersections
- Number of traffic sign faces
- Land use
- Average daily traffic
- Functional roadway classification
- Curb lane usage
- Number of small obstacles

The branch for accident rate, presented in Figure 14, was initiated by a split based on the city from which the data were obtained. In other words, this result suggests that a major variable which explains the variation in accident rate is a function of the city where the sample is taken. A list of cities and respective codes that are used on the branching diagrams are given below.

City		Code
San Francisco	-	1
Fort Wayne	-	2
Topeka	-	3

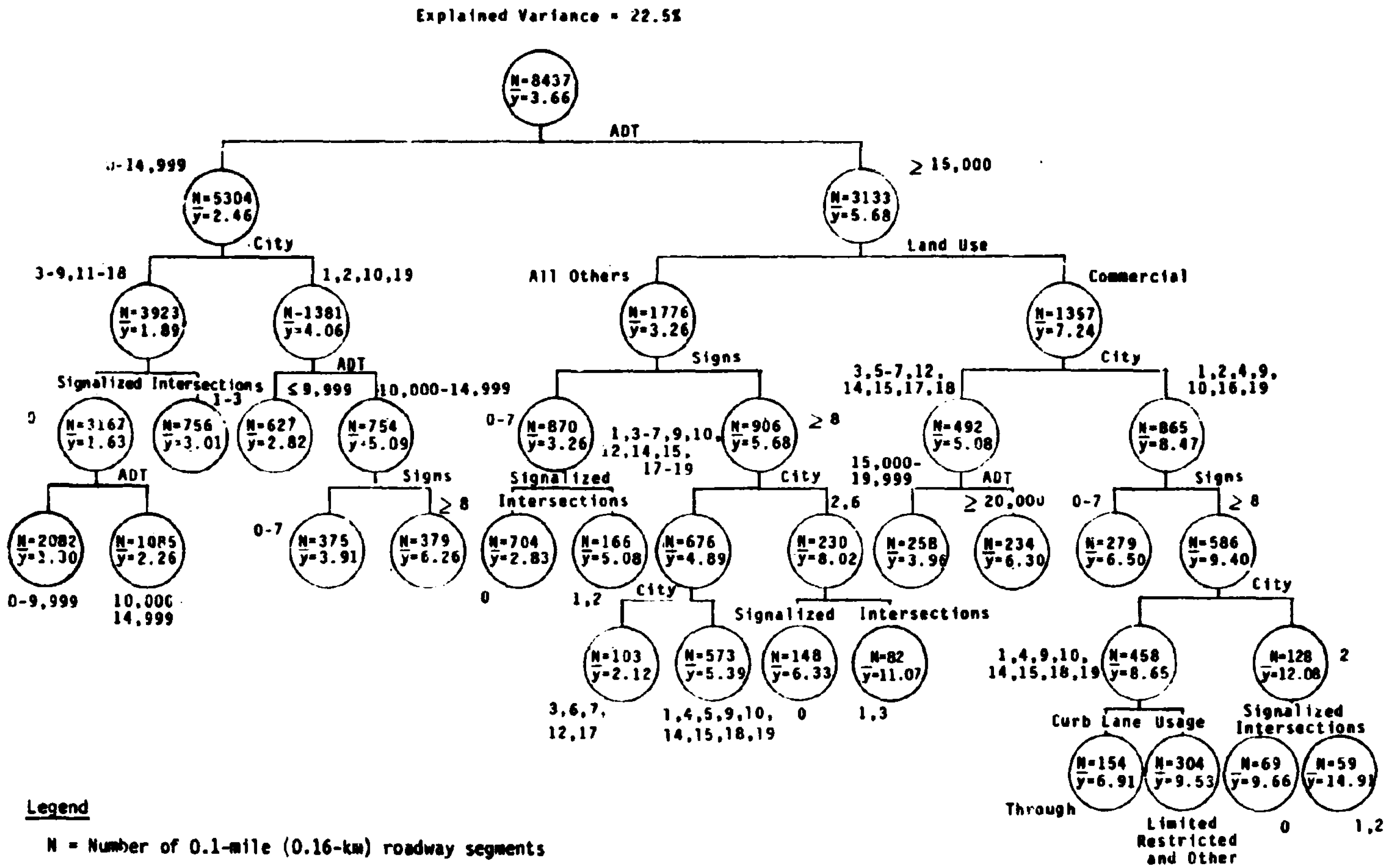


Legend

N = Number of 0.1-mile (0.16-km) roadway segments

$\bar{y}$ = Accident rate per million vehicle miles

Figure 14. Branching diagram for accident rate using all roadway segments.



Legend

N = Number of 0.1-mile (0.16-km) roadway segments

$\overline{y}$ = Annual accident frequency

Figure 15. Branching diagram for annual accident frequency using all roadway segments.

City		Code
New Orleans	-	4
Big Rapids	-	5
Birmingham	-	6
Farmington	-	7
Farmington Hills	-	8
Kalamazoo	-	9
Lansing	-	10
Novi	-	11
Oak Park	-	12
Royal Oak	-	13
Saginaw	-	14
Southfield	-	15
Troy	-	16
Minneapolis	-	17
Seattle	-	18
Milwaukee	-	19

A number of confounding factors may account for this result. Some of these factors are differences in accident reporting practices in the cities, differences in levels of law enforcement, safety programs, etc.

For 13 of the 19 cities, a significant accident rate difference is indicated between segments with signalized intersections and those without signalized intersections. Again this result is expected as the influence of traffic signals on vehicle accidents has been extensively investigated. This group is divided further by the independent variables average daily traffic and land use. The presence of average daily traffic emphasizes the important part played by traffic volume. For 6 of the 13 cities, segments with less than 8 traffic sign faces per segment had a significantly lower accident rate than segments with more than 8 traffic sign faces per segment. Traffic sign faces presents a rather unexpected result as the use of this variable in traffic accident research has not been extensive [56]. It is possible that the number of traffic sign faces is a surrogate for another variable such as traffic volume. For this group of cities, the accident rate is also influenced by average daily traffic, land use, number of signalized intersections, and curb lane usage.

When all roadway segments were included in the analysis, the segments with the highest accident rate were located in the cities of Fort Wayne, Indiana, and Saginaw, Michigan, and these segments had greater than 20,000 vehicles per day with one or more signalized intersections per segment. In contrast, the segments with the lowest accident rate had no signalized intersections and residential, vacant, or other type of land use.

The branching diagram for annual accident frequency for all segments is given in Figure 15. The following variables contribute significantly to the accident frequency on urban arterial roadway segments.

- Average daily traffic
- City
- Number of signalized intersections
- Number of traffic sign faces
- Land use
- Curb lane usage
- Functional roadway classification

Because the functional class of highway is a significant factor in traffic operations and many countermeasures are applicable to only one class of roadway (i.e., adding medians, etc.), this stratification was chosen as a forced branch and the branching analysis program re-run for each of the four functional classes. The final results of these branching analyses are shown in Figures 16 through 23. A brief discussion of each analysis follows.

Two-Lane, Two-Way Segments

The branching results for two-lane roadways are given in Figures 16 and 17. The major variables influencing accident rate on two-lane, two-way roadways are city, volume, traffic sign faces, and curb lane usage. The major factors influencing the annual accident frequency are city and average daily traffic with a split at the 10,000 average daily traffic level. The second level branching is characterized by splits on the number of signalized intersections per segment and the number of traffic sign faces. The third level branching contains major components of curb lane usage and further splits in traffic volume.

One-Way Segments

Branching analyses for one-way segments are presented in Figures 18 and 19. The major variables that influence accident rate are city and number of traffic sign faces per segment. At the second level a division was made for vertical alinement. The major factors that influence the annual accident frequency on one-way streets are average daily traffic, city, and curb lane usage.

Multilane Divided Segments

The branching diagrams for accident rate and frequency for multilane divided segments are presented in Figures 20 and 21. Similar to the other functional roadway classes, the accident rate on divided highways was influenced by the city, land use, average daily traffic, and curb lane usage. The annual accident frequency was influenced by traffic volume

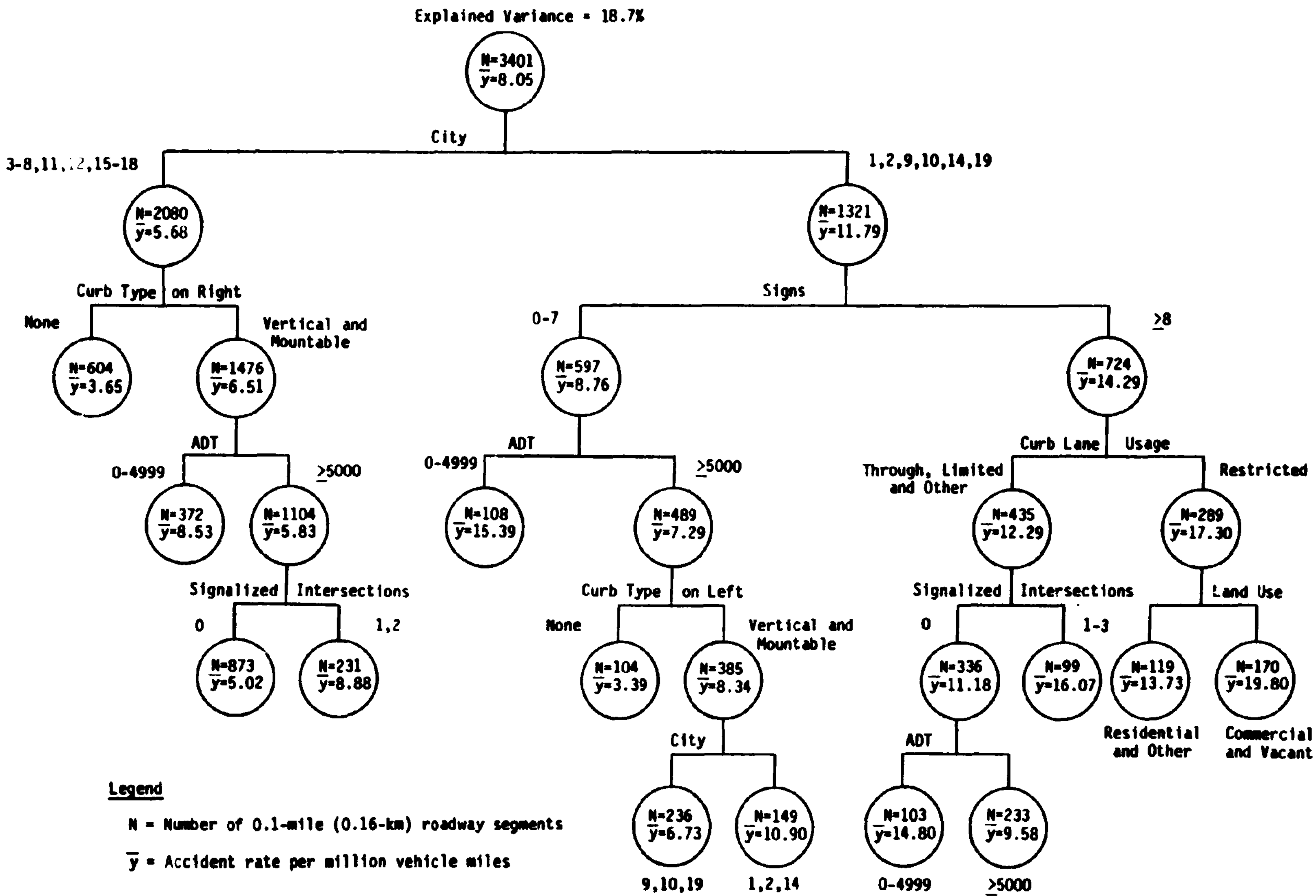


Figure 16. Branching diagram for accident rate using two-lane, two-way segments.

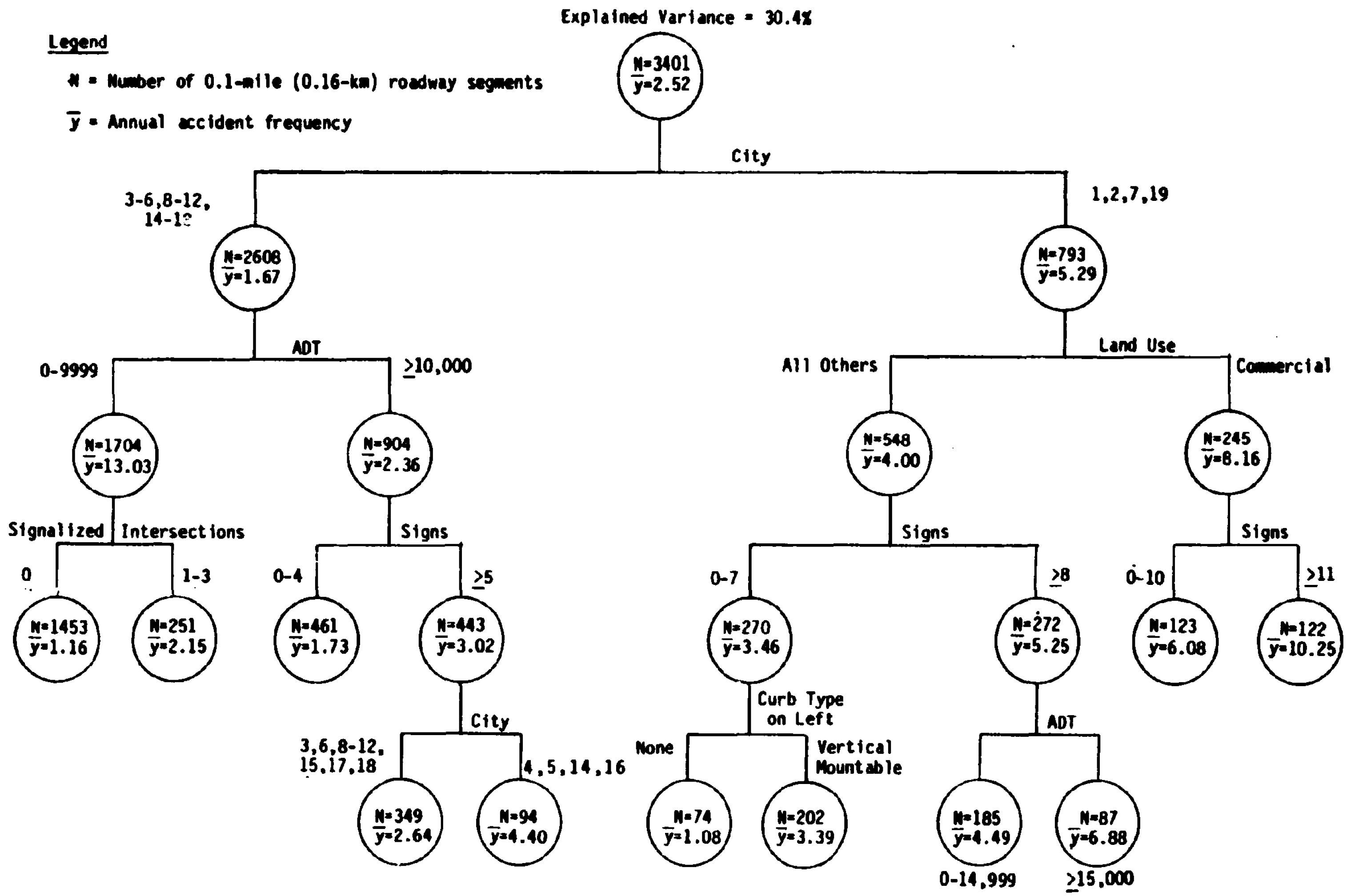


Figure 17. Branching diagram for annual accident frequency using two-lane, two-way segments.

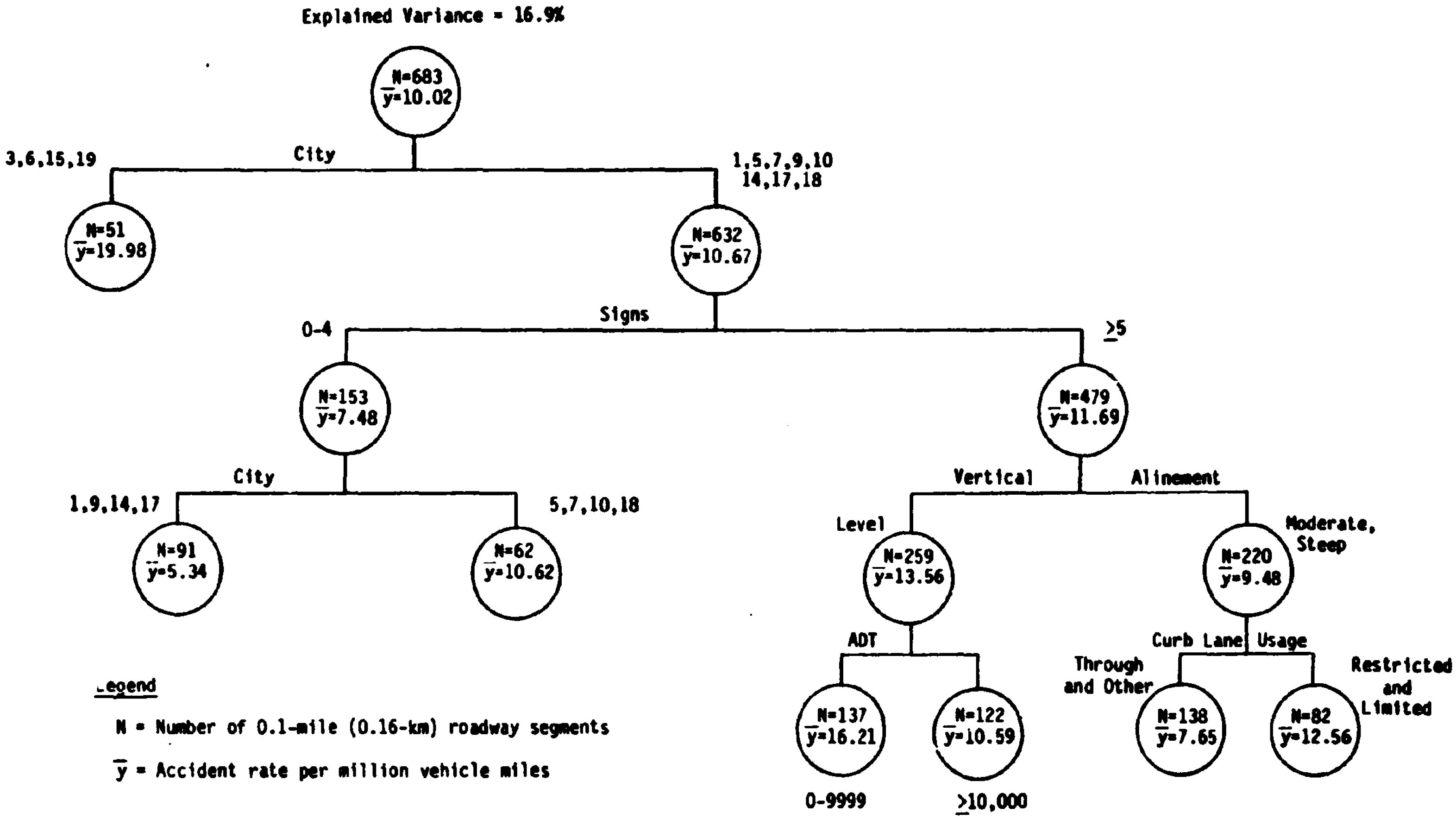


Figure 18. Branching diagram for accident rate using one-way segments.

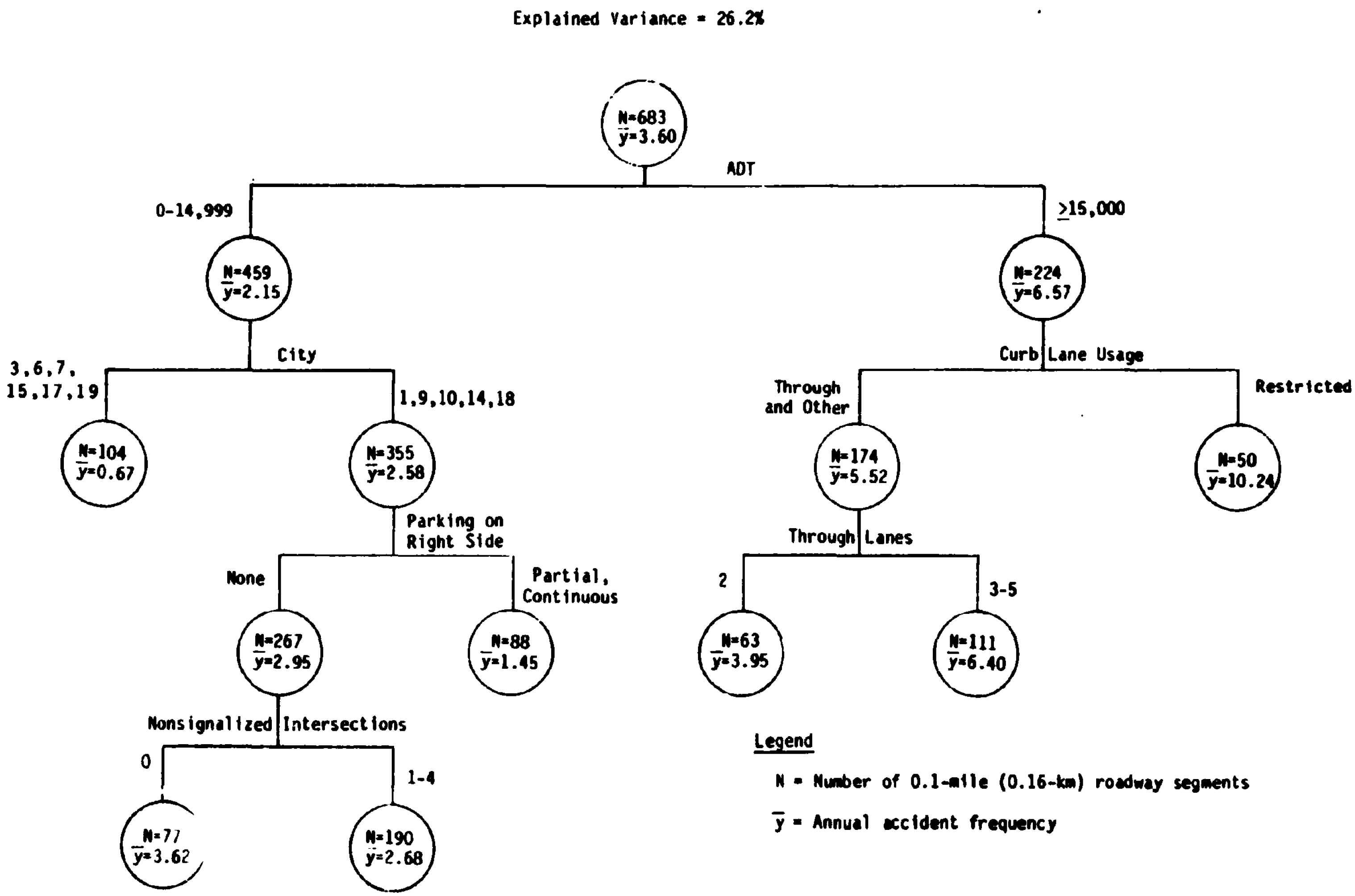


Figure 19. Branching diagram for annual accident frequency using one-way segments.

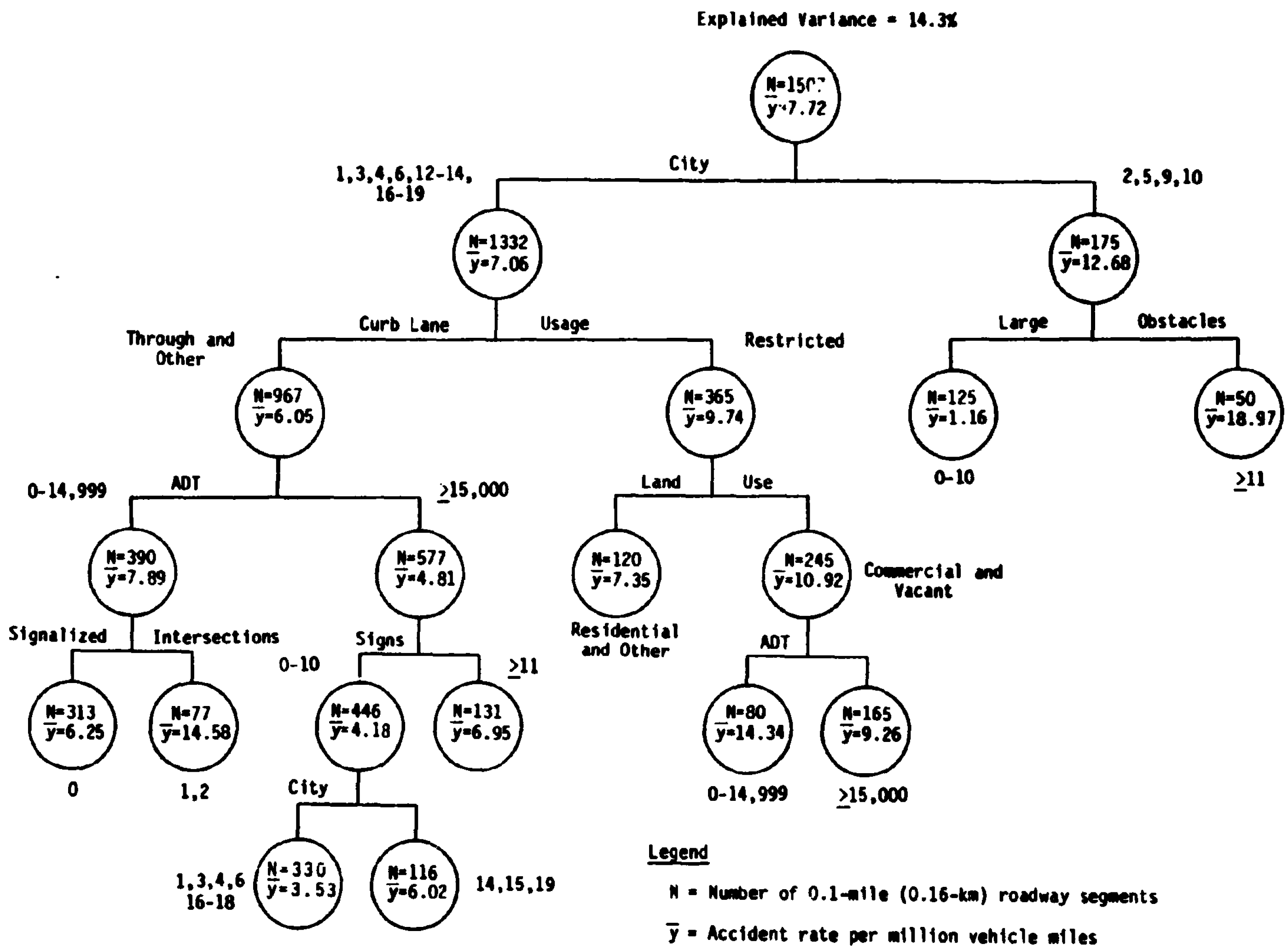


Figure 20. Branching diagram for accident rate using multilane divided segments.

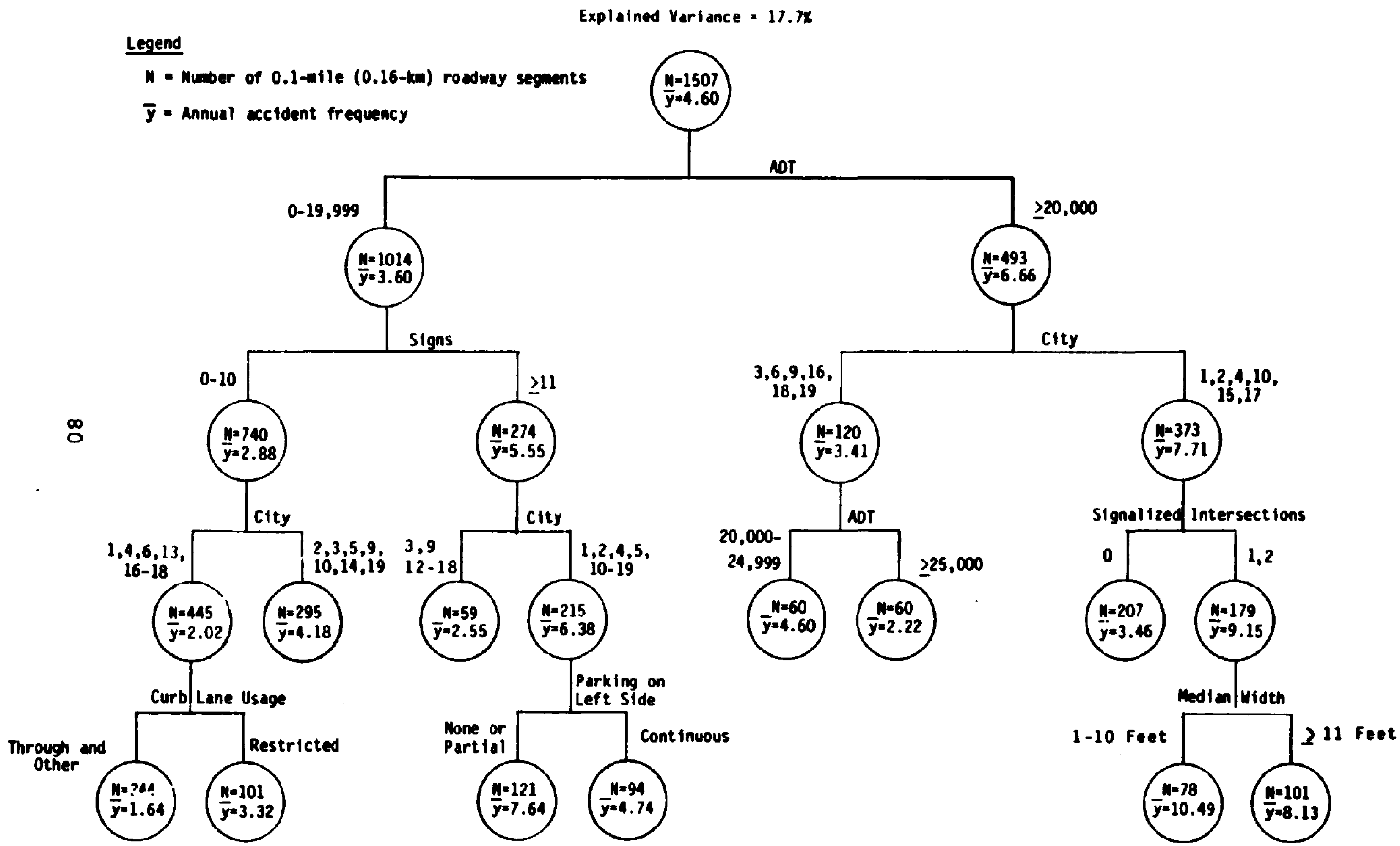


Figure 21. Branching diagram for annual accident frequency using multilane divided segments.

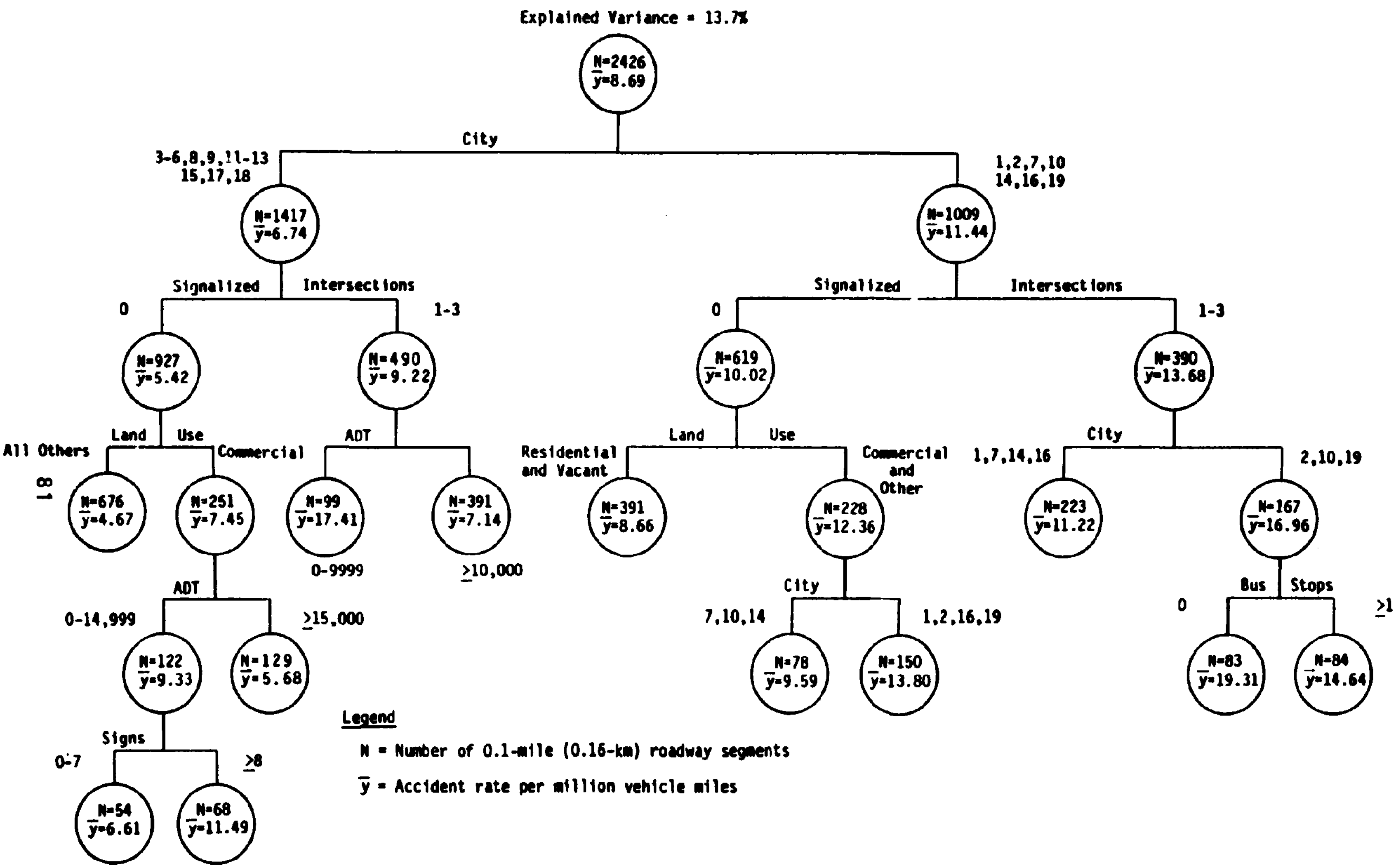


Figure 22. Branching diagram for accident rate using multilane undivided segments.

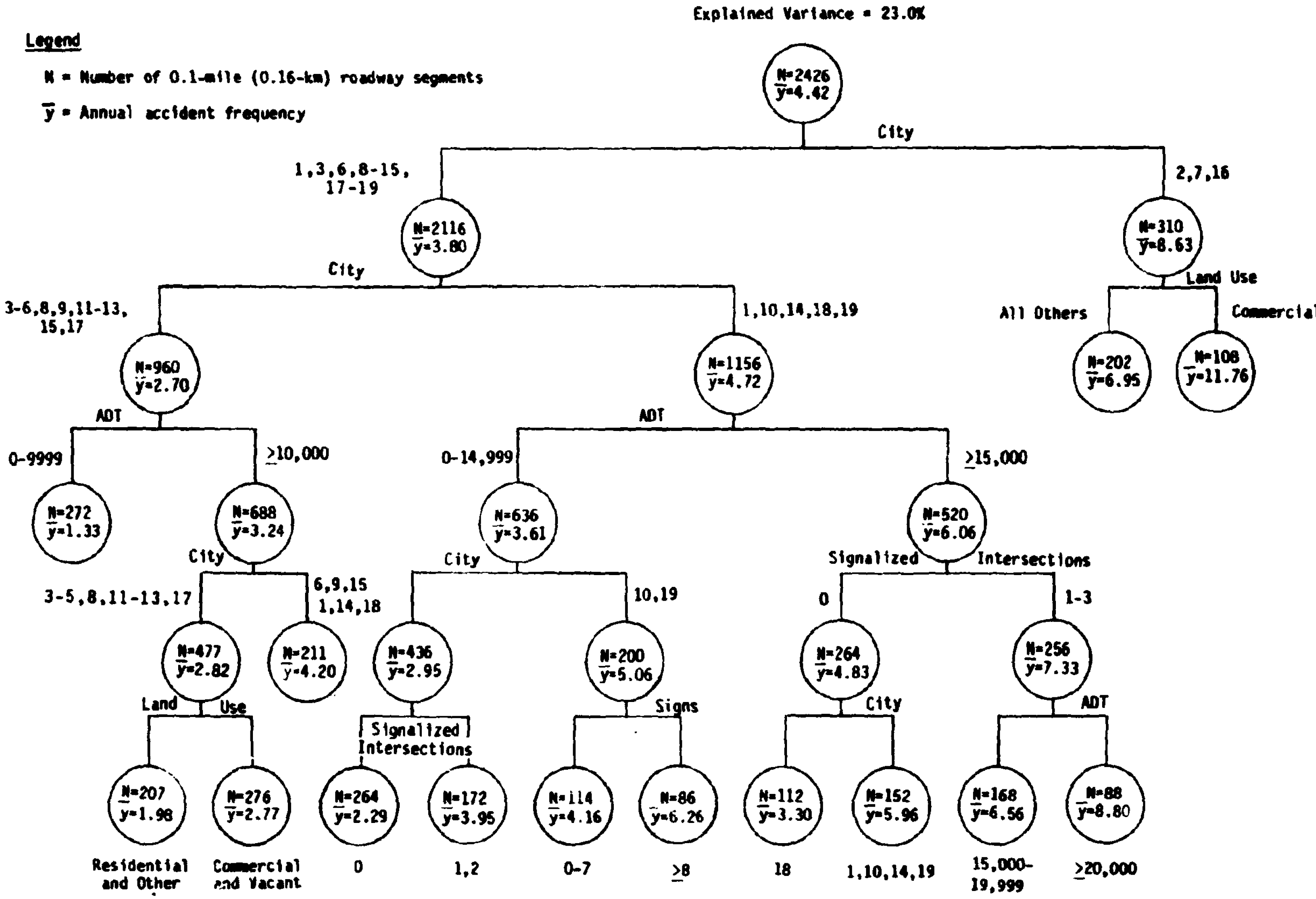


Figure 23. Branching diagram for annual accident frequency using multilane undivided segments.

which split at 20,000 vehicles per day, city, the number of traffic sign faces per segment, and the number of signalized intersections per segment.

Multilane Undivided Segments

The branching diagrams for the multilane undivided roadway segments are given in Figures 22 and 23. Again the rate is influenced by city, number of signalized intersections per segment, land use, and traffic volume. The annual accident frequency is influenced by city, traffic volume, land use, and number of signalized intersections per segment.

Summary

Using the results of the branching analysis, variables were selected for inclusion in the regression analysis, and the analysis of variance and covariance testing.

One important overall conclusion that appears from the branching results is that generally the independent variables do not explain a major percentage of the variation in accident rate or annual accident frequency. The highest explained variance ranged from 17.7 to 30.4 percent using annual accident frequency as a dependent variable. A number of hypotheses may be offered to explain this result. One hypothesis that was examined was the effect of the short 0.1-mile (0.16-km) segment length on the explained variance. The results of this investigation are reported in Recommended Research section of this report.

Branching analyses were also conducted using angle, rear-end, sideswipe, and head-on accidents as dependent variables. Separate branches were obtained for the four roadway groups available in the data base for these accident types and the results are given in Appendix F. Also, a branching analysis was conducted for the four roadway groups using only the segments in large cities, i.e., cities with a population exceeding 250,000 persons, and the results are presented in Appendix F.

REGRESSION ANALYSIS

Multiple linear regression analysis was utilized to identify relationships between variables that explained the greatest amount of accident variation in the accident frequency and rate for each functional roadway class. The selection of independent variables used for analysis input was based upon the literature review, the identification work performed in the macroscopic and branching analyses, and the experience of the research team members. From ten to twenty independent variables were included in each stepwise multiple regression test. A final selection of the most meaningful independent variables was made based upon the explained variance, i.e., R^2, the overall F statistic, the magnitude of the standard error, and the calculated t value for each regression coefficient.

Tables 21 and 22 summarize the relationships established using the regression analysis. Details of the regression analysis are given in Appendix G. The purpose of the regression analysis was not to develop equations for predicting accident rates or frequencies but to determine the part a particular variable had in explaining variations in accident rates and frequencies. The regression results were generally poor, as the standard error tended to be high, while the explained variance was low.

Table 21 presents the independent variables deemed to have a significant influence on annual accident frequencies for each roadway classification. Table 22 gives the regression results for accident rate. As can be observed, several independent variables appear repeatedly. For example, average daily traffic appears as a factor in both accident rate and frequency for al functional classes. Likewise, the number of signalized intersections per segment also appears in most cases. Based upon previous studies it is not surprising that these two factors appear. On the other hand, the number of traffic sign faces, number of utility poles, number of through lanes, and land use appear in only a few cases. Several of these factors were not expected based upon knowledge of the state-of-the-art, but they were supported by the results of the earlier analysis phases of this study.

Several other independent variables provide useful information by their presence or absence in the regression results. For example, the number of driveways is not present. Also it is somewhat unexpected that land use would not have a greater effect on accidents that is supported by the regression analyses.

Table 23 presents the independent variables that are identified as having a possible relationship with accidents. The table contains factors identified as a result of the literature review, macroscopic analyses, branching analyses, and multiple regression results.

Table 21. Independent variables identified by regression analysis with annual accident frequency as the dependent variable.

Roadway Classification			
One-Way	Two-Way, Two-Lane	Multilane Divided	Multilane Undivided
Average Daily Traffic	Average Daily Traffic	Average Daily Traffic	Average Daily Traffic
No. of Utility Poles	No. of Traffic Sign Faces	No. of Traffic Sign Faces	No. of Signalized Intersections
No. of Through Lanes	No. of Utility Poles	No. of Signalized Intersections	No. of Utility Poles
No. of Signalized Intersections			
$F = 51.89$ $R^2 = 0.22$	$F = 270.50$ $R^2 = 0.19$	$F = 91.76$ $R^2 = 0.12$	$F = 108.05$ $R^2 = 0.12$
Standard Error = 4.51	Standard Error = 3.58	Standard Error = 5.83	Standard Error = 5.29

Table 22. Independent variables identified by regression analysis with accident rate as the dependent variable.

Roadway Classification			
One-Way	Two-Way, Two-Lane	Multilane Divided	Multilane Undivided
No. of Utility Poles	No. of Traffic Sign Faces	No. of Signalized Intersections	No. of Utility Poles
Average Daily Traffic	Average Daily Traffic	Average Daily Traffic	No. of Signalized Intersections
Land Use	No. of Utility Poles	No. of Traffic Sign Faces	Average Daily Traffic
F = 10.99 R^2 = 0.05	F = 120.96 R^2 = 0.09	F = 36.63 R^2 = 0.07	F = 60.28 R^2 = 0.07
Standard Error = 11.27	Standard Error = 10.40	Standard Error = 10.35	Standard Error = 10.44

Table 23. Factors with a possible relationship to accidents.

Roadway Feature	Literature Review	Macroscopic Analysis	Branching Analysis	Regression Analysis
Geometric Factors				
Lane width	•	•		
Number of through lanes		•	•	•
Average shoulder width		•		
Roadway classification	•	•	•	
Pavement surface		•		
Median width	•	•	•	
Median type	•	•		
Curb type - right and left		•	•	
Percent guardrail		•		
Number of signalized intersections	•	•	•	•
Number of nonsignalized intersections	•	•	•	
Number of bus stops		•	•	
Type of bus stop		•		
Number of driveways	•	•		
Curb lane usage		•	•	
Parking	•	•	•	
Turn lanes at intersections	•	•		
Vertical alinement	•		•	
Horizontal alinement	•			
Number of obstacles	•	•	•	
Number of trees	•	•		
Number of utility poles	•	•		•
Type of land use	•	•	•	•
Environmental Factors				
Roadway lighting	•	•		
City size	•	•	•	
Amount of rainfall	•	•		
Amount of snowfall		•		
Operational Factors				
Average daily traffic	•	•	•	•
Roadway capacity	•	•		
Location factor		•		
Peak hour factor		•		
Vehicle mix		•		
Parking turnover rate	•	•		
Number of local buses per hour		•		
Average cycle length	•	•		
Posted speed limit	•	•		
Operating speed		•		
Number of traffic sign faces	•	•	•	•

The following factors are identified throughout the analyses as having a significant relationship with accidents.

- Type of land use
- Roadway classification
- City
- Number of signalized intersections per segment
- Average daily traffic
- Number of traffic sign faces per segment
- Number of through lanes

The following factors also appear to have an influence on urban arterial roadway accidents.

- Number of utility poles per segment
- Median width
- Number of nonsignalized intersections per segment
- Curb lane usage
- Parking
- Number of fixed-objects per segment

ANALYSIS OF VARIANCE AND COVARIANCE

These tests were used to identify differences in mean accident rates and frequencies for various independent variable groupings. In addition, the analysis was used to account for influencing factors, i.e., traffic volume, land use, etc. Factors tested as influencing factors were selected from the branching analysis results, the literature review, and experience of the research team. While an attempt was made to account for the influencing factors that can reasonably be expected to affect the accident rate and frequency, it must be recognized that an almost infinite number of influencing factor combinations are possible. This analysis includes the results of only a small number of combinations, but the data base developed in this study can be used for further research for any other combinations of variables and covariates.

Analysis of Variance

Analysis of variance is a method for dividing the variation observed in experimental data into different parts with each part assignable to a known source, cause, or factor. It is then possible to assess the relative magnitude of variation resulting from different sources and ascertain whether a particular part of the variation is greater than expected under the null hypothesis.

One-way analysis of variance is a statistical technique used to identify sources of variation in a dependent variable resulting from variations in the value of one independent variable. One-way analysis of variance was used to test for statistically significant differences between the mean accident rates and frequencies for categories of each independent variable.

Where there is more than one independent variable (as is most often the case in accident studies), the analysis of variance test can be used to determine the relationship between accidents and any two (or more) independent variables. One-way and two-way analysis of variance tests were conducted to identify variables or combinations of variables that aid in explaining the difference in mean accident rates or frequencies.

In the mathematical development of the analysis of variance a number of assumptions are made. One assumption is that the distribution of the dependent variable in the population from which the samples are drawn is normal. For large samples the normality of the distribution may be tested using a goodness of fit test. The effect of a departure from normality is to make the results appear somewhat more significant than they are. Consequently, where a fairly gross departure from normality occurs, a somewhat more rigorous than usual level of confidence should be employed. Another assumption in the application of analysis of variance is that the variances in the population from which the samples are drawn are equal. A third assumption is that the effects of various factors on the total variation are additive.

The assumptions underlying the analysis of variance are usually only roughly satisfied. Fortunately, however, reasonable departures from the assumptions of normality and homogeneity may occur without seriously affecting the validity of the inferences drawn from the data.

The Statistical Package for the Social Sciences (SPSS) ONE-WAY subprogram permits testing pairs of group means with several different test procedures. The posteriori test that was selected to compare all possible pairs of group means was the least significant difference (LSD) test. The LSD test is basically a student's t-test which is used to determine the significance of the difference between group means. The level of significance used was 0.01.

In addition to analyzing the total number of accidents per segment, the difference in mean accident frequencies for each accident type i.e., head-on, rear-end, etc., was examined for all roadway segments. A summary of the significant findings is presented below for several of the major roadway variables. The one-way analysis of variance tables for land use are given in Appendix H.

Land Use

Significant differences were found in the mean accident frequency, accident rate and the other accident types for commercial land use and the other land use categories when all roadway segments in the data base were examined.

Significantly fewer head-on accidents occur on segments with residential land use than other types of land use. The mean accident frequency, accident rate, and the number of rear-end, angle, and sideswipe accidents are significantly higher for commercial land use than for residential, other, and vacant land uses.

In summary, mean accident rates and frequencies are significantly higher (approximately two times higher) on segments with commercial development than on segments with other forms of land use.

Driveways

On the roadway segments, a statistically significant decrease was found in the annual accident frequency and rate for segments with fewer than 3 driveways compared to segments with more than 3 driveways. There were no differences in accident frequencies for head-on and sideswipe type accidents. The mean rear-end and angle accident frequency was significantly higher when the number of driveways was greater than 5 per segment.

The number of driveways is an important variable in explaining differences in the accident experience on each arterial highway type as well. Two-lane, two-way highway accident rates are significantly lower for segments with less than 3 driveways. Rear-end and angle rates are significantly lower for segments with less than 6 driveways, while head-on and sideswipe accident frequencies are not significantly different for all driveway categories.

On undivided multilane highways, the accident rate and the rear-end accident frequency for roadway segments with less than 3 driveways is significantly lower than segments with 3 or more driveways. The number of driveways does not explain differences in the head-on, angle, or sideswipe accident frequencies. Also, the number of driveways located on divided roadways does not appear to significantly affect the accident frequency or rate.

In summary, the accident frequency and rate on urban roadways appears to be influenced by the number of driveways.

Utility Poles

Street segments with more than 2 utility poles have a significantly higher mean accident frequency and rate than sections with 2 or fewer poles. However, no significant differences were found between the utility pole groups for head-on accidents. Segments with more than 2 utility poles have a significantly higher mean number of rear-end, angle, and sideswipe type accidents.

Two-lane, two-way roadways with more than 2 utility poles per segment have a significantly higher accident rate than segments with 2 or fewer poles. The mean frequencies for rear-end, sideswipe, and angle collisions are also significantly higher on segments with more than 2 utility poles.

The mean accident rates for undivided roadway segments with 2 or fewer utility poles are significantly lower than for segments with more than 2 poles. Rear-end, sideswipe, and angle accident frequencies are also significantly lower for segments with 2 or fewer poles.

A significant difference was found between the mean accident rate for segments with more than 2 utility poles on divided segments. The rear-end, sideswipe, and angle collision frequency was not significantly different for the pole groups. Thus, on divided highways it does not appear that an increase in the number of utility poles on a segment will result in an increase in accidents.

In summary, the number of accidents and accident rate on urban roadways appears to be influenced by the number of utility poles. Urban roadways with 2 or fewer utility poles per 0.1-mile (0.16 km) segment have significantly fewer accidents than segments with more than 2 poles.

Regulatory Sign Faces

On arterial street segments the mean accident rate and frequency is significantly lower on segments with fewer than 3 regulatory sign faces. The analysis also revealed that rear-end, sideswipe, and angle accidents are also significantly lower on streets that had fewer than 3 regulatory sign faces per 0.1-mile (0.16-km) segment.

In summary, accidents on urban roadway segments appear to be related to the number of regulatory sign faces on the segment. Generally, segments with fewer than 3 regulatory signs per 0.1-mile (0.16-km) segment have significantly lower accident rates than segments with 3 signs or more. The relationship between regulatory sign faces and accidents is the most significant finding (statistically) of this series of tests and suggests that it may be possible to use sign faces as a surrogate to describe the safety characteristics of urban streets. In fact, grouping urban arterials by number of regulatory sign faces may provide a more statistically significant classification scheme for describing safety than any other variable considered, including land use, number of driveways, average daily traffic.

Analysis of Covariance

Analysis of covariance was used to test for differences in means for several factors while the effects of other influencing variables were controlled. The study sampling strategy resulted in a sample with a wide range of values for characteristics which have been shown to affect highway safety. In testing the relationship between the accident rates for roadways with different numbers of signalized intersections, or numbers of traffic sign faces, for instance, it is desirable to control for the effect of average daily traffic. This is critical as segments of roadways with many signalized intersections or a larger number of sign faces may have high traffic volumes, and volume has been shown to be highly correlated with accidents.

An important feature of analysis of covariance is the ability to test for the significance of interactive effects among variables. Analysis of covariance conducted using the SPSS subprogram ANOVA analyzes interactions among factors but does not analyze factor-covariate interactions. Subprogram NEW REGRESSION, however, utilizes the multiple regression method to conduct an analysis of covariance which provides analysis of factor-covariate interactions.

Table 24 summarizes some of the variables examined by analysis of variance testing and identifies the significant interactions that were found. As can be observed in Table 24, average daily traffic has a significant interaction with nearly all of the factors tested. Given in Table 25 are the pairs of factors that had significant interactions when the effects of volume were removed from the analysis. Several combinations of variables were further examined in order to gain a better understanding of these interactions. Six specific cases of significant findings are discussed below. The analysis of covariance tables for these tests are given in Appendix H.

Signalized Intersections and Traffic Sign Faces on Two-Lane, Two-Way Segments

The branching analysis of the two-lane, two-way roadway segments indicated that signalized intersections and the number of traffic sign faces contributed significantly to the explained variance in accidents. Based on other studies, it was decided that the effects of average daily traffic should be controlled in testing the effects of these two variables on accidents. After removing the effects of volume, there are still significant differences in the mean accident frequency for the various groups of number of signalized intersections and traffic sign faces. Using the F test, it was determined that the interaction effect between signalized intersections and traffic sign faces is significant. Thus, on two-way streets, the accident frequency will be affected by the number of traffic signals and the number of traffic sign faces on the segment, and these two factors tend to explain the same variance.

Small Obstacles and Traffic Sign Faces On Two-Lane, Two-Way Segments

The one-way analysis of variance test indicated that the accident frequency increases as the number of small obstacles on a segment increases. A similar trend was found for the number of traffic sign faces. After removing the effects of volume, the difference in mean accident frequency is still significant for the various groups of small obstacles and for the different categories of traffic sign faces. However, it was found that there is a significant interaction effect between small obstacles and traffic sign faces, i.e, both variables tend to explain the same variance in the accident frequency.

Table 24. List of significant interactions by roadway classification.

Roadway Classification	Variables	Level of Significance
One-way	• Average daily traffic and number of through lanes	0.012
	• Number of through lanes and number of signalized intersections	0.010
	• Average daily traffic and number of utility poles	0.050
Two-lane, two-way	• Average daily traffic and number of traffic sign faces	0.000
	• Average daily traffic and number of utility poles	0.000
	• Average daily traffice and number of signalized intersections	0.000
	• Number of traffic sign faces and number of signalized intersections	0.004
	• Number of traffic sign faces and number of driveways	0.020
Multilane divided	• Average daily traffic and number of signalized intersections	0.033
Multilane undivided	• Average daily traffic and number of signalized intersections	0.000

Table 25. List of significant interactions using average daily traffic as a covariate by roadway classification.

One-Way Segments
• Number of through lanes and number of signalized intersections
Two-Lane, Two-Way Segments
• Number of traffic sign faces and number of signalized intersections • Number of traffic sign faces and number of driveways • Number of small obstacles and number of traffic sign faces
Multilane Divided Segments
• Median type - curb and median width
Multilane Undivided Segments
• No significant interactions identified
All Segments
• Roadway classification and city size

Roadway Classification and Land Use on all Urban Segments

Previous analysis of the data indicated that significant differences in the mean accident rate and frequency existed for various urban roadway classes, i.e., one-way, two-lane, two-way, multilane divided, and multilane undivided, and for various land uses. It is reasonable to assume that these variables may also be affected by the traffic volume using the facility. After removing the effects of average daily traffic, it was found that the mean accident frequencies and rates are significantly different for roadway classification and land use. The adjusted means revealed that two-lane roads had the lowest accident frequency (3.47 accidents per segment per year), compared to one-way facilities which had the highest frequency (4.02 accidents per year). Also, roadways in the commercial land use group experienced the highest accident frequency (4.99 accidents per segment per year) and segments with vacant land use had the lowest accident frequency (2.55 accidents per segment per year). Based on these data, the effects of land use on urban accidents is clearly evident. No significant interaction effect was found between land use and roadway classification.

Roadway Classification and City Size on all Urban Segments

One of the basic assumptions made prior to data collection for this study was that roadway classification and city size were appropriate variables that could be used to classify urban arterial streets in terms of safety characteristics. The analysis of variance results suggested that the assumption was correct as significant differences were found in the mean accident frequency and rate for both variables. However, it has been demonstrated by several safety researchers that volume also affects accidents on urban roadways. After removing the effects of volume, it was found that significant differences in the mean accident frequency and rate occur for the various roadway types and city sizes. Two-lane highways had the lowest accident rate (7.58 accidents per million vehicle miles) while one-way segments had the highest rate (9.42). Small cities had the lowest accident rate (5.71), while medium cities had the highest rate (9.13). The interaction effect between roadway classification and city size was significant. This analysis indicates that classifying urban sections for safety in terms of roadway type and city size is an appropriate practice, i.e., there appears to be real differences in safety between these variables.

Median Curb and Median Width on Multilane Divided Segments

On multilane divided highways, several safety researchers have found that medians with curbs and median width affect safety. However, other variables such as volume may affect accidents on multilane divided facilities. After removing the effects of volume, it was found that no significant differences exist in the mean accident frequency for curbed and uncurbed median sections. Also, no significant differences were found in the mean accident frequencies for the various median width groupings. The interaction effect between median type and width was significant. It can be concluded that median curbs and median width do not appear to influence accident frequency on multilane divided segments.

Lane Width and Number of Driveways on Multilane Undivided Segments

Previous one-way analysis of variance results revealed that various classes by lane width and the number of driveways had significantly different mean accident frequencies and rates. In urban areas, it is reasonable to assume that volume also significantly affects the accident experience. To test this hypothesis, an analysis of covariance was conducted. After the effects of volume were removed, it was found that significant differences existed in the accident frequencies and rates for the various lane width groupings, however, the differences in the driveway categories were not significant. The interaction effect was not significant. This analysis suggests that lane width may be an appropriate variable to categorize safety characteristics for urban arterial highways.

PRIMARY ACCIDENT RELATIONSHIPS

During the study the research team identified primary accident causal factors based upon the results of the various analyses. Several of the significant findings are presented below in two subsections. The first section deals with continuous variables and their identified relationships, and the second with discrete situations such as accident experience for parking and no parking conditions.

Continuous Variables

One of the primary objectives of this study was to determine those factors that significantly affect accident frequency and rate on the urban arterial street network; in particular, the objective was to determine factors that would result in fewer accidents if controlled during design or by the traffic operations engineer. Using the results of the literature review and the previous analyses, the research team prepared a list of significant factors shown in Table 26. The following discussions summarize the more significant findings of this phase of the study.

Traffic Volume

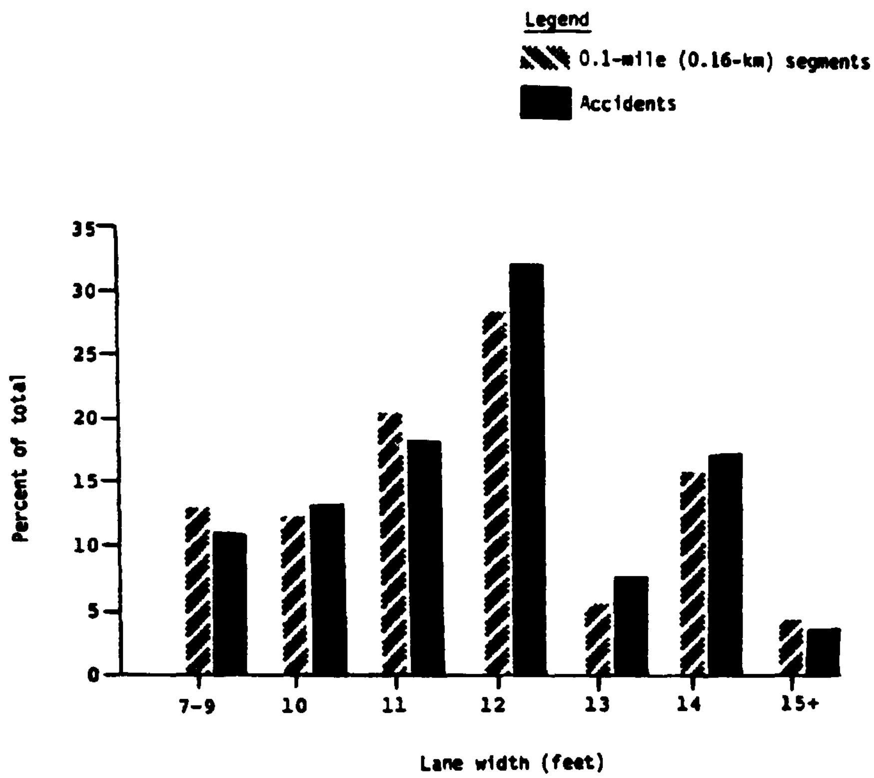
One general consensus expressed among traffic engineers is that traffic volume has a significant influence on accident rates and frequencies. Analysis of the urban arterial data set verified this influence. Traffic volume, in the form of an average daily traffic, was a significant factor in all analyses. In addition, average daily traffic is the only independent variable to appear in both rate and frequency regression equations for all roadway classifications.

Lane Width

Lane width is a traditional matter of interest for traffic engineers, and the subject has been extensively studied through the years. The sample of urban arterial roadways for which data were collected in this study include a wide range of lane widths, with the predominant lane width being 12 feet (3.6 m) as shown in Figure 24. Analysis of the distribution of accidents indicates that width alone does not seem to explain the variation in accident experience as there is no particular range of widths for which there is a significant overrepresentation of accidents.

Table 26. Summary of roadway factors significantly affecting accident rates and frequencies on urban arterial segments.

Factors	Roadway Classification			
	One-Way	Two-Way, Two-Lane	Multilane Divided	Multilane Undivided
<u>Geometric Factors</u>				
Number of through lanes	•			
Number of small obstacles		•		
Number of signalized intersections	•	•		•
Number of utility poles	•	•	•	•
Number of driveways		•		
<u>Operational Factors</u>				
Average daily traffic	•	•	•	•
Number of traffic sign faces		•	•	



Note: 1 foot = 0.3 m

Figure 24. Distribution of roadway segments and accidents by lane width.

Number of Through Lanes

A potential response to congestion and safety problems on urban arterials is the addition of travel lanes to an existing facility. The relationship between the number of through lanes and accidents is not clearly established with an analysis of this data base. Even when the effect of volume is controlled by employing the analysis of covariance, the accident rate is only found to be significantly higher on three-lane roads. This probably reflects the odd geometric and traffic situations the laneage presents for two-way traffic.

There is no substantial support for the practice of considering increasing laneage as a first level solution to accident problems. More cost-effective and less environmentally disruptive solutions should be considered first.

Shoulder Width

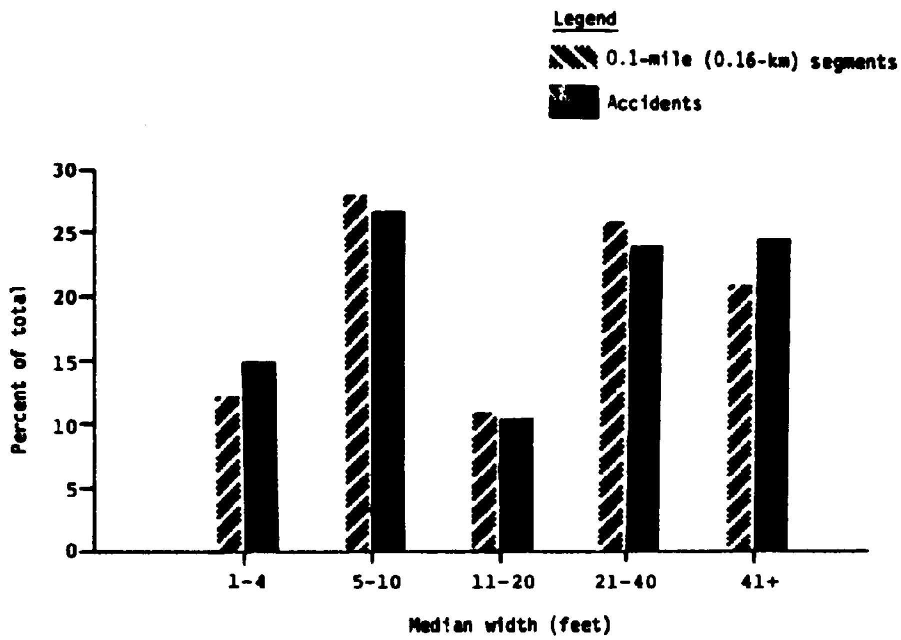
Shoulder width has also been studied extensively (although most studies have been in rural areas), with the general consensus that the wider the shoulder the safer the facility. The study results tend to agree with those findings as shoulder width appears as a significant factor in explaining two-lane, two-way roadway accident frequency. When traffic volume is controlled for, accident rates are significantly lower with wider shoulders.

Median Width

A major issue during the design of any divided highway is the median width, as this is a major contributor to right-of-way requirements and directly affects the operation of vehicles through median openings. Figure 25 illustrates the fact that there is an overrepresentation of accidents on segments with medians less than 4 feet (1.2 m) wide. Analysis shows a significantly higher accident frequency for medians less than 4 feet (1.2 m) wide as opposed to medians greater than 4 feet (1.2 m) wide.

Land Use

For many years land use has been considered a possible surrogate for side friction or driver burden. The results of this analysis support this conclusion, with both accident frequency and accident rate increasing with increased land use intensity (i.e., vacant to residential to commercial). In addition, when such factors as average daily traffic, posted speed limit, and population are accounted for, the same significant relationship exists. In addition, land use is a significant factor in both the two-lane, two-way category and the multilane divided category regression models.



Note: 1 foot = 0.3 m

Figure 25. Distribution of roadway segments and accidents by median width.

Unfortunately, land use is not generally a factor that can easily be modified by the designer or through the efforts of the traffic operations engineer.

Number of Signalized Intersections

The analyses used in this study show a strong relationship between increasing the number of traffic signals and increasing accident rate and frequency. Tables 27 and 28 present the final regression equations derived for each roadway classification for accident frequency and rate.

The analysis findings agree with the generally held belief that the more traffic signals on a roadway segment, the larger the accident problem. Figure 26 shows the effect of increasing accidents with an increased number of signals. This relationship is most pronounced in the large city category. Figure 27 shows that there is little effect of increasing nonsignalized intersections on accidents.

Because of the rather short sample length used in this study (0.1 mile or 0.16 km), it is possible that the number of signalized intersections simply reflects the influence of intersections, and thus conclusions drawn on the basis of these samples might be incorrect. Therefore, additional analyses were conducted utilizing a segment length of one-half mile (0.8 km). This analysis confirms that the number of signalized intersections remains a significant factor regardless of the segment length. In addition, analysis of segments with and without traffic signals indicates that for all segment road types and accident types where a significant difference is noted, segments without signals have significantly lower accident rates than segments with signals. After controlling for traffic volume in the analysis of covariance, the same relationship (increasing rate with increasing signalized intersections) was found.

Obstacles

Many studies found in the literature describe a strong relationship between roadside obstacle density and traffic accidents. Therefore, as part of this study an in-depth look was taken at a variety of roadside obstacles. Obstacles were first classified into the categories; large obstacles, small obstacles, trees, and utility poles.

Large obstacles include such items as large sign supports, utility poles, and fire hydrants. The analysis showed a trend of increasing accident rate and frequency with an increased number of large obstacles. For both the accident rate and accident frequency there is a significant difference (increase) when four or more large obstacles are present.

Table 27. Regression analysis summary for annual accident frequency by roadway classification for 0.1-mile (0.16-km) segments.

One-Way

Variables	Coefficient
Average daily traffic	0.00024
No. of utility poles	0.25491
No. of through lanes	0.67070
No. of signalized intersections	0.58059
Constant	-1.72743

The four variables explain 22.40 % of the variance
F=51.89
Mean accident frequency = 3.72 acc./segment/yr.
Standard error = 4.51

Two-Way, Two-Lane

Variables	Coefficient
Average daily traffic	0.00021
No. of traffic sign faces	0.17766
No. of utility poles	0.16018
Constant	-1.18240

The three variables explain 19.02% of the variance
F=270.50
Mean accident frequency = 2.50 acc./segment/yr.
Standard error = 3.58

Multilane Divided

Variables	Coefficient
Average daily traffic	0.00015
No. of traffic sign faces	0.20040
No. of signalized intersections	1.36156
Constant	-0.15483

The three variables explain 12.14% of the variance
F=91.76
Mean accident frequency = 4.73 acc./segment/yr.
Standard error = 5.83

Multilane Undivided

Variables	Coefficient
Average daily traffic	0.00017
No. of signalized intersections	1.47243
No. of utility poles	0.24177
Constant	-0.16226

The three variables explain 11.51% of the variance
F=108.05
Mean accident frequency = 4.38 acc./segment/yr.
Standard error = 5.29

Table 28. Regression analysis summary for accident rate by roadway classification for 0.1-mile (0.16-km) segments.

One-Way

Variables	Coefficient
No. of utility poles	0.59153
Average daily traffic	-0.00024
Land use	-1.55282
Constant	12.63213

The three variables explain 4.51% of the variance
F=10.99
Mean accident rate = 10.03 acc./MVM
Standard error = 11.27

Two-Way, Two-Lane

Variables	Coefficient
No. of traffic sign faces	0.50055
Average daily traffic	-0.00027
No. of utility poles	0.46159
Constant	5.33399

The three variables explain 9.51% of the variance
F=120.96
Mean accident rate = 8.06 acc./MVM
Standard error = 10.40

Multilane Divided

Variables	Coefficient
No. of signalized intersections	2.83003
Average daily traffic	-0.00015
No. of traffic sign faces	0.27031
Constant	7.14023

The three variables explain 6.61% of the variance
F=36.63
Mean accident rate = 7.83 acc./MVM
Standard error = 10.35

Multilane Undivided

Variables	Coefficient
No. of utility poles	0.51825
No. of signalized intersections	2.65908
Average daily traffic	-0.00020
Constant	7.38401

The three variables explain 6.89% of the variance
F=60.28
Mean accident rate = 8.63 acc./MVM
Standard error = 10.44

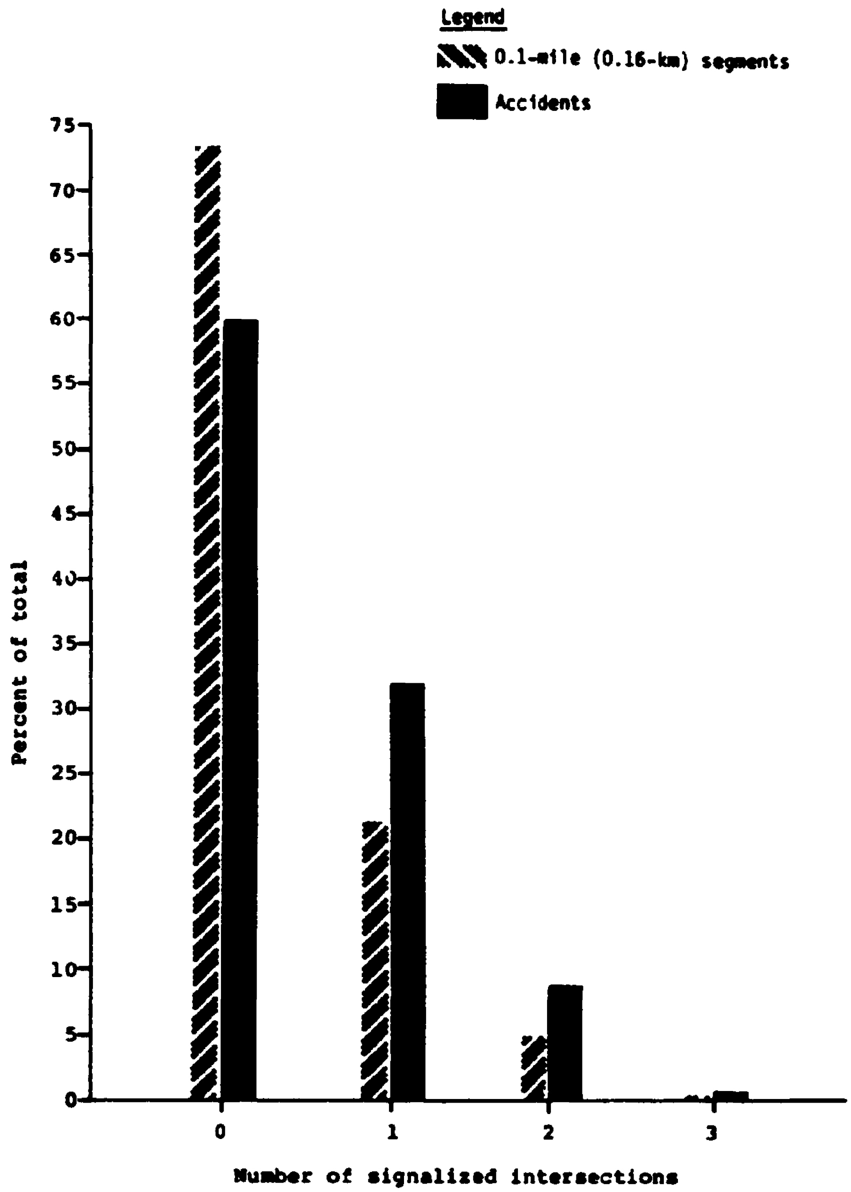


Figure 26. Distribution of roadway segments and accidents by number of signalized intersections per segment.

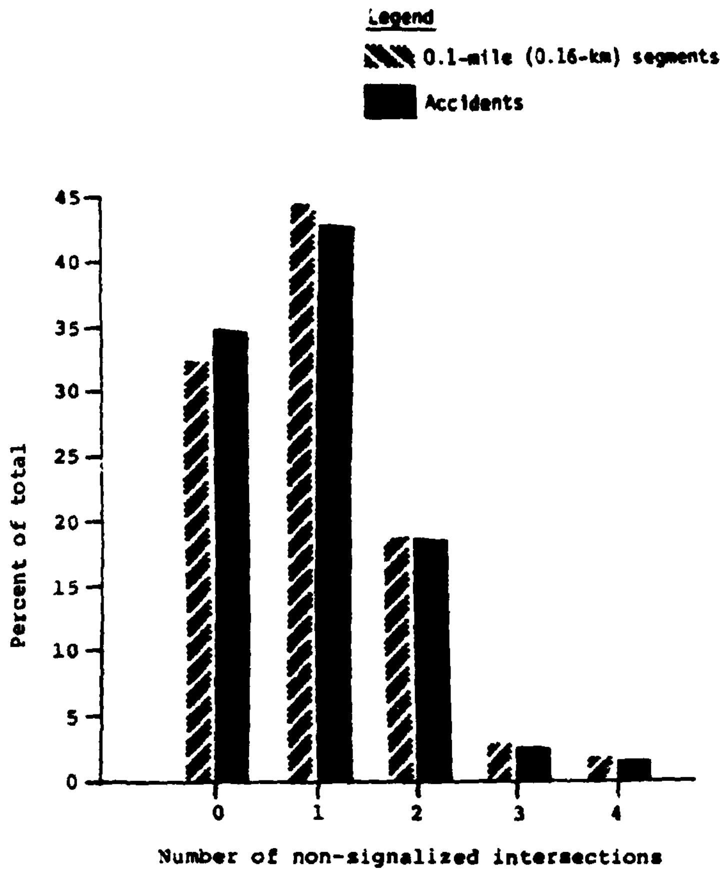


Figure 27. Distribution of roadway segments and accidents by number of non-signalized intersections per segment.

The number of utility poles in general caused a significant change in accident rate. Segments with densities of 4 to 7 poles appeared to be the main cut-off point, with locations having 8 to 11 poles in particular have significantly higher accident frequencies.

Number of Traffic Sign Faces

This variable appears as a significant factor during analyses for all roadway classes. The analysis shows an increasing trend between accidents and the number of traffic sign faces, in particular where the sign count is 10 or more per segment. In addition to total sign faces, regulatory, and guide signs are also significant variables for selected road classes. As with the total sign count, regulatory and guide signs exhibit a positive relationship with accident statistics. Warning signs do not appear as a significant factor, probably because the use of warning signs is very limited in the urban environment.

Discrete Variables

In addition to investigating the effect of continuous variables on accident rates, a specific analysis was conducted on a few selected discrete variables that are generally controllable by the operations engineer or designer.

This analysis utilized the basic functional roadway classification as a starting point, and subdivided the file further by specific factors such as bus stop location, special lanes, and parking. Accident rates and frequencies were developed for each accident category and a student's t-test used to determine if significant differences exist between cells.

Bus Stop Location

A number of recurring questions occur in conjunction with the presence and/or location of bus stops on arterial roadways. Analysis reveals that the presence of a bus stop on a segment of arterial street results in a significantly higher accident rate for that segment. This relationship was found to be valid for all functional classes of roads.

Comparison of segments containing bus stops with different locations indicates that segments with near-side or midblock stops have in general lower accident rates than those segments containing far-side stops. Also, segments containing near-side stops have significantly lower accident rates than those with midblock stops, except for one-way streets where segments with midblock stops exhibit the lowest accident rate.

A comparison between curb bus stops and bus pullouts was also conducted and yielded mixed results. Segments with pullouts have significantly lower rear-end and angle accident frequencies than those with curbside stops. However, there are several cases, mainly on one-way and two-lane, two-way streets, where other accident categories exhibit a lower accident frequency with curbside stops.

Special Auxiliary Lanes

Several design alternatives can be used to facilitate turning vehicles, including:

- right-turn bays;
- left-turn bays;
- one direction, median left-turn lanes; and
- two direction, median left-turn lanes.

In general, segments with one-direction, center, left-turn median lanes have significantly lower accident frequencies than segments with other types of left-turn facilities. Segments with two-direction, center, left-turn median lanes have significantly lower accident frequencies than segments with left-turn bays. Conversely, segments with left-turn bays have significantly higher accident frequencies than segments with no special turn facilities.

Since the segments tested were 0.1 mile (0.16 km) in length, the presence of intersections might have a disproportionate influence on the accident frequency. Therefore, segments were aggregated to one-half mile (0.8 km) lengths and an analysis conducted of the relationship between accidents and the presence of a left-turn bay versus no special turn facilities. Segments with left-turn bays exhibited a significantly higher accident frequency than segments with no special turn facilities.

Parking

In general, segments with no parking have significantly lower accident frequencies than segments with full or part-time parking. One notable exception is one-way streets where segments with parking have significantly lower total accident frequencies as well as lower rear-end and angle accident occurrences.

CAUSAL FACTORS

Based upon the results of the various tests, conclusions were drawn concerning relationships between the independent variables and accident rates and frequencies. Independent variables with a previously defined relationship were specifically reviewed to determine if the data base supports causal factor relationships with urban arterial accidents.

It is important that the nature and purpose of the summaries and analyses described in this study be recognized. Any given traffic accident involves an interactive set of several geometric, environmental, and operational circumstances. Therefore, it is difficult to describe the contribution of any single factor on any single accident, and even more difficult to describe the contribution of a single factor on the total accident experience (even categorized by accident type) for a segment of roadway 0.1 mile (0.16 km) in length. However, while the cause-effect relationship may be difficult to quantify, it is also clear that the accidents are influenced by certain geometric, environmental, and operational characteristics. The data base accumulated for this study will be useful in determining the likely causes of certain types of accidents on roadway type, but only if the influence of several other critical variables are identified and controlled in the investigation. Knowledge of these causes will be useful in the selection of effective countermeasures.

In many instances, there will be factors which cannot be addressed directly with a countermeasure available to the traffic engineer (e.g., a traffic signal at a high-volume intersection may be positively related to certain types of accidents, but removal of the signal is not a realistic countermeasure).

The analyses in the previous chapters are helpful in identifying the critical variables which should be controlled in the assessment of specific problems and potential countermeasures on urban arterial roads and streets. The results of these analyses are not intended for use in determining accident causation factors nor assessing countermeasure effectiveness directly. For example, the analysis indicates that the rear-end accident frequency for segments containing bus stops is nearly twice that for segments without bus stops. While this result indicates it might be advisable to control for the presence of bus stops in investigating rear-end accident problems, it does not imply bus stops cause rear-end accidents, nor that prohibition of bus stops will necessarily reduce the rear-end accident experience at a specific site. It may well be that the number of rear-end accidents is higher for these segments simply because these segments are usually located within intersections, and accidents related to the bus stop cannot be separated from other accidents in the segment.

Similarly, nearly all the analyses which involve accident experience and a single geometric, environmental, or operational factor are subject to multiple interpretations, and can lead to several possible countermeasures. Hence, conclusions regarding causal relationships or countermeasure effectiveness should not be based solely on these single factor analyses. The primary value of the results reported in the preceding chapters is in identifying the particular variables that should be controlled in multi-factor analyses.

Since there are data available for a large number of factors, as shown in Table 1, the number of possible combinations of two or more factors is very large. There is no realistic way to "summarize" the data base in a conventional report format. This report can only describe the data base and provide an indication of the types of analyses that can be conducted. An example of the use of the data base in selecting potential countermeasures is provided in the following chapters.

On the other hand, some general statements regarding the influence of certain factors in characterizing the urban arterial street accident picture are warranted. For instance, a few factors emerge as significantly related to accident experience in a number of the characterization tests described in the preceding chapter and are listed below.

- Turn lanes (at intersections and/or continuous)
- Median presence
- Intersection versus non-intersection segments
- Signalized versus non-signalized intersection
- Roadway classification
- Presence of fixed-objects
- Parking versus no parking
- Land use
- Traffic volume
- Lane width
- Driveway density
- Density of traffic sign faces

These factors must be considered in causal factor and/or countermeasure effectiveness analyses. While it is essential that the critical confounding variable be identified and used for stratifying the data base if valid conclusions regarding the effectiveness of practical countermeasures are to be reached, it is also important that the number of variables included in the analysis be kept to a minimum. Each time a stratification is made, a significant reduction in the data base results.

Observations from the Data Tabulations

The following observations are products of the accident characterization conducted within this study. As mentioned earlier in this chapter, cause-effect relationships should not be inferred.

- Segments with medians narrower than 4 feet (1.2 m) have higher accident frequencies (i.e., accidents per segment) than those with wider medians.

- Segments bounded by commercial development have higher accident frequencies than those bounded by other types of land use.

- Accident frequency increases as the number of large obstacles in the segment increases. Accident frequency seems to be independent of the number of small obstacles in the segment.

- Accident frequencies are higher in segments where there are 3 or more utility poles.

- Accident frequency increases as the number of traffic sign faces increases.

- Accident frequency, i.e., the annual number of accidents per segment, increases with traffic volume (as would be expected) but accident rates, i.e., accidents per million vehicle-miles, are lower on those segments with higher traffic volumes -- with the exception of one-way streets, where the rate increases with increasing volume.

- Segments containing signalized intersections have higher accident frequencies and rates than segments without signalized intersections.

- Segments where left-turn and/or right-turn bays are present have higher accident rates than those where there are no auxiliary lanes.

- Segments where parking is not allowed have lower accident frequencies than those segments where full or part-time parking is permitted.

Most of these observations are consistent with what might be expected. It is clear, however, that a number of confounding variables must be accounted for before cause-effect relationships can be inferred. The fact that the cited pseudo-relationships are readily observable indicates that these factors should be addressed when making use of the data base.

Examples illustrating the use of the data base for future urban arterial accident studies are provided in a subsequent section of this report.

COUNTERMEASURES

Potential countermeasures for reducing urban arterial accidents were selected based on the literature review and the results of the data analysis. As discussed earlier, the literature review provided a comprehensive list of geometric, environmental, and operational variables which have been previously found to be associated with accidents on urban arterial streets.

The second source of countermeasure development was the results of a series of branching analyses conducted for each of the four functional roadway classifications. For each of these roadway types, a separate branching analysis was made for rear-end accidents, angle accidents, sideswipe accidents, and head-on accidents. These analyses were used to determine which variables, or combination of variables were associated with a significantly larger number of accidents for a particular roadway type and accident type.

The use of the branching analysis can be illustrated, as shown in Figure 28, for angle accidents on multilane undivided streets. The overall accident mean is 4.51 accidents per segment per three-year period. The first split is made at a traffic volume of 20,000 vehicles per day. Segments with a volume of 20,000 or more vehicles per day have an overall mean of 7.54 accidents per three years. Within that subgroup, sections with one or more signalized intersections have a combined accident experience of 11.23 accidents per three years. For the volume group less than 20,000 vehicles per day, the higher accident experience also occurs for sections with one or more signalized intersections (an overall mean of 5.10 accidents per segment).

The above analysis provides evidence that certain combinations of high volume and the presence of signalized intersections are associated with a higher number of angle accidents on multilane undivided roadways. Similar findings have been reported in the literature. Based on this information, possible accident causes are listed below.

- Absence of signal progression
- Inadequate signal timing
- Restricted sight distance to the signal or to cross street traffic

For each of these possible accident causes, one or more candidate countermeasures was developed. For example, the countermeasures for inadequate signal timing are listed below.

- Adjust the amber interval
- Include all red phase
- Retime the signals to meet current traffic demands on the major and minor streets

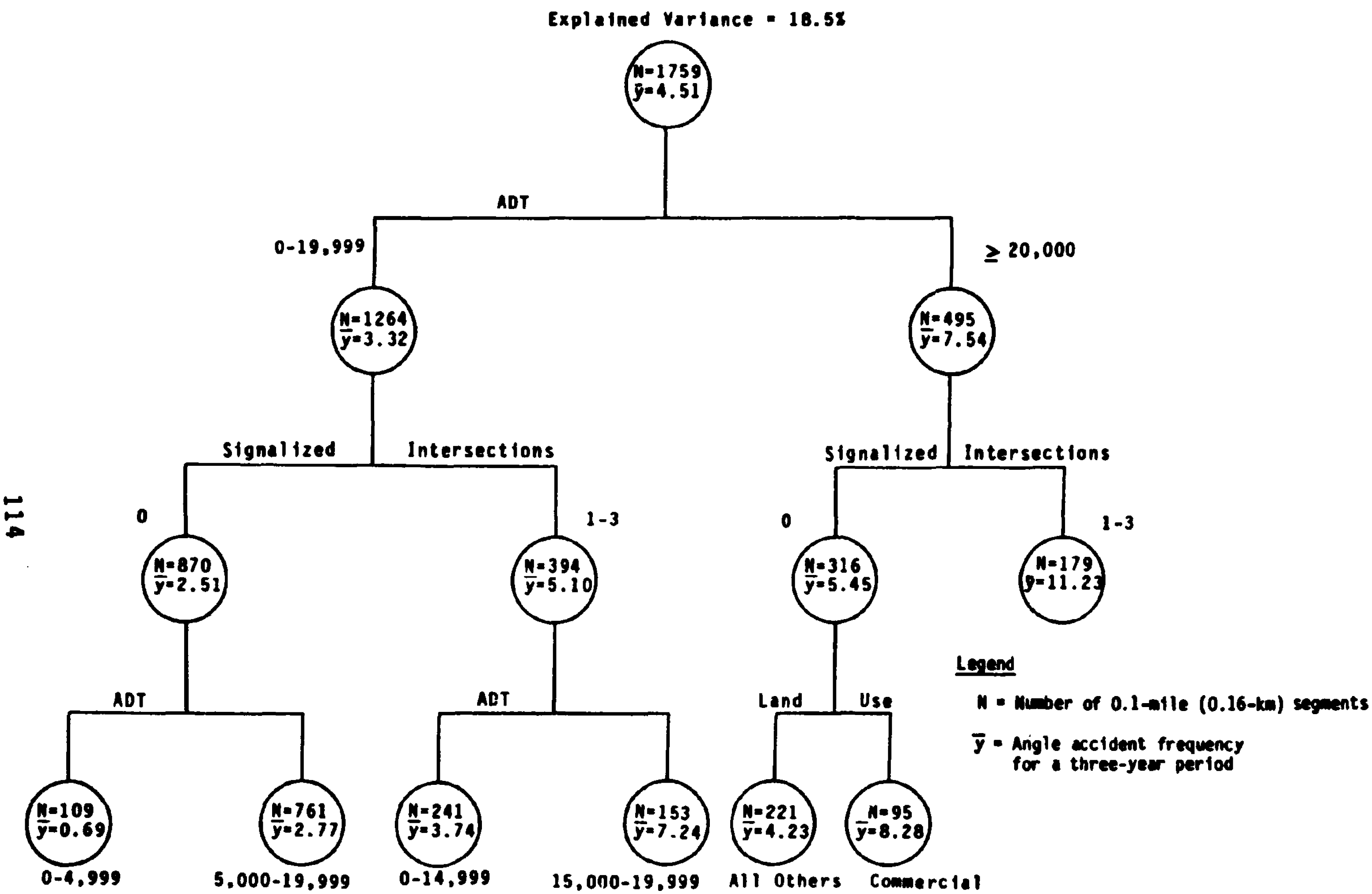


Figure 28. Branching diagram for angle accident frequency using multilane undivided segments.

- Install signal actuation
- Install a multidial controller

Similar efforts were also used to develop other possible causes and countermeasures for each roadway classification. It should be noted that many of the countermeasures would be applicable to any or all of the roadway types. Some countermeasures, however, would only apply to one of the roadway classifications.

Using the literature results and the branching analyses described above, countermeasures were developed for each accident type as shown in Tables 29 through 32. For each possible accident cause, an L denotes that the information was based on the literature results and an A denotes that analysis of the study data was used to determine the possible accident cause. In many cases, the accident cause was based on input from both the literature review and the data analysis.

Tables 29 through 32 can be used by safety engineers to select countermeasures for any of the four specific accident types for the four roadway classifications. These are general countermeasures and are intended to be a guide for selection of the most appropriate countermeasure for a given accident problem on an urban arterial road or street.

Table 29. Countermeasures for angle accidents.

Possible Accident Cause	Possible Countermeasures	Applicable Roadway Classification
1. Lack of progressive movement (L,A)	1. Provide signal progression	All classes
2. Restricted sight distance to traffic on intersecting streets or signals (due to horizontal alinement, roadside sight obstructions, or parked vehicles) (L,A)	1. Remove sight obstructions 2. Restrict parking near intersections 3. Install or improve advance warning signs 4. Install 12 inch signal lenses	All classes (particularly two-lane, two-way)
3. Inadequate signal timing (L,A)	1. Adjust amber time 2. Provide all-red clearance 3. Retime signals 4. Install signal actuation 5. Add multidial controller	All classes
4. Inadequate gaps in traffic (L,A)	1. Install traffic signals (if warranted by MUTCD)	All classes
5. Excessive speed on arterial (L)	1. Reduce speed limit and initiate speed enforcement	All classes
6. Excessive commercial driveways combined with traffic volume of 10,000 to 15,000 (increased level of commercial development) (A,L)	1. Consolidate driveways 2. Prohibit left-turns into and out of driveways	Multilane undivided, and two-lane, two-way
7. High intersection street traffic volumes at unsignalized intersections (i.e., minor cross streets, commercial driveways, and high density residential driveways.	1. Consolidate commercial driveways 2. Prohibit left-turns from driveways 3. Install traffic signals (if warranted by MUTCD)	All classes

Note: L denotes that the cause is based on the results of the literature review.
A denotes that the cause is based on the results of the data analysis.
1 inch = 2.5 cm

Table 30. Countermeasures for rear-end accidents.

Possible Accident Cause	Possible Countermeasures	Applicable Roadway Classification
1. Poor signal visibility or sight distance (L,A)	1. Relocate or add additional signal heads 2. Install or improve advance warning signs 3. Install 12 inch signal lenses 4. Reduce speed limit on approaches and initiated speed enforcement	All classes
2. Slippery pavement surface (L)	1. Overlay pavement with skid resistant surface treatment 2. Improve drainage 3. Reduce speed limit and initiate speed enforcement	All classes
3. Inadequate storage area for vehicles turning into driveways (L)	1. Construct separate left-turn and/or right-turn lanes 2. Install a continuous median left-turn lane 3. Increase turning radii at driveways or intersections	Two-lane, two-way and multilane undivided
4. Inadequate signal timing (L,A)	1. Adjust amber time 2. Provide all-red clearance 3. Provide signal progression 4. Retime signals	All classes
5. Unnecessary signals (L,A)	1. Remove unwarranted signals (as per MUTCD)	All classes
6. Restrictions to through traffic due to on-street parking (combined with moderate to high traffic volume) (L)	1. Restrict or prohibit on-street parking 2. Widen roadway	All classes

Note: L denotes that the cause is based on the results of the literature review.
A denotes that the cause is based on the results of the data analysis.
1 inch = 2.5 cm

Table 30. Countermeasures for rear-end accidents (continued).

Possible Accident Cause	Possible Countermeasures	Applicable Roadway Classification
7. Congested traffic flow due to inadequate roadway capacity (L)	1. Convert to one-way street network	Two-lane, two-way, multilane and undivided
8. Excessive commercial driveways combined with high ADT's (about 15,000 for multilane roads and 10,000 to 15,000 for two-lane roads) due to increased commercial development (L,A)	1. Consolidate driveways 2. Prohibit left-turns into and out of driveways 3. Provide continuous left-turn median lane	Two-lane, two-way Multilane undivided and multilane divided

Note: L denotes that the cause is based on the results of the literature review.
A denotes that the cause is based on the results of the data analysis.

Table 31. Countermeasures for sideswipe accidents.

Possible Accident Cause	Possible Countermeasures	Applicable Roadway Classification
1. Restricted and/or congested traffic flow due to inadequate roadway capacity (ADT of $\leq$25,000 for multilane divided, and ADT of $\geq$15,000 for other roadway classes) (L,A)	1. Convert to one-way street network 2. Widen street	All classes
2. Narrow lanes or surface width (L)	1. Widen lanes 2. Install channelization at intersections 3. Create a network of one-way streets 4. Install median divider	All classes
3. On-street parking and/or bus stops allowed on curb lane (L,A)	1. Restrict or remove on-street parking 2. Modify near-side bus stops to far-side	All classes
4. Restricted horizontal curvature (L,A)	1. Reconstruct section to modify horizontal alinement	All classes

Note: L denotes that the cause is based on the results of the literature review.
A denotes that the cause is based on the results of the data analysis.

Table 32. Countermeasures for head-on accidents.

Possible Accident Cause	Possible Countermeasures	Applicable Roadway Classification
1. Narrow lanes or surface width (L,A)	1. Install median divider 2. Widen pavement surface 3. Provide improved roadway delineation	Two-lane, two-way Multilane undivided
2. Poor roadway design (offset lanes or restrictive horizontal or vertical alinement (A,L)	1. Reconstruct roadway to improve alinement 2. Provide improved roadway delineation	All classes
3. Inadequate information regarding one-way street designation	1. Improve location of ONE-WAY signs and/or increase the number or size of signs 2. Channelize and/or stripe side street approaches to more clearly indicate a one-way street	One-way streets only

Note: L denotes that the cause is based on the results of the literature review.
A denotes that the cause is based on the results of the data analysis.

RESEARCH RESULTS

The data base collected for this study and the extensive testing conducted on individual variables and combinations of variables have produced a valuable resource for design and traffic operations engineers. While it is not possible to display all possible combinations of dependent and indepenent variables, this section presents several useful safety engineering products for the operations engineer.

During the analysis of urban arterial accidents, various combinations of the roadway variables and accident variables were examined. Several useful figures have been developed from these analyses, including branching diagrams. Figures 17 and 19 can be used to illustrate the relationship between annual accident frequency and several independent variables that account for significant accident variation on two-way, two-lane and one-way streets. These diagrams can be used to compare the expected accident frequencies for a roadway segment under different operating policies. Thus, it is feasible to estimate the possible effectiveness of different alternatives available to the traffic engineer.

For example, suppose that a two-lane, two-way roadway segment had the characteristics listed below.

- Length - 0.1 mile (0.16 km)
- Average daily traffic - 8,000 vehicles per day
- Lane width - 10 feet (3.0 m)
- Number of signalized intersections - 0
- Number of driveways - 5
- Posted speed - 30 mph (48 km/hr)
- Number of small obstacles - 2
- Total number of traffic sign faces - 7

By tracing the path through the two-way, two-lane branch for these parameters, see Figure 17, we find an average accident frequency of 1.16 accidents per year. If the street were changed to one-way operation, the trace through the branching diagram (Figure 19) for one-way streets using the same criteria would be 2.15 accidents per year. Thus, this change in the operation would result in an average increase of about one accident per year. Thus, the change from two-lane, two-way to one-way operation would not be desirable in this case.

Utilizing the branching diagrams, a number of similar comparisons can be made. In the utilization of these diagrams, only those factors that contribute to a significant explanation of accident rate or frequency variation are used. Thus, while other factors may be available for a particular site, it is necessary to use only the factors given in the diagram to estimate the mean accident experience at a site.

Based on the data collected in this study, several diagrams relating volume, accident rates, accident frequency, and other factors have been developed that provide an indication of the variability in accidents. For example, Figures 29 and 30 illustrate the effect of parking on sideswipe and angle accidents. In addition to these examples, numerous other relationships can be developed by proper partitioning of the data file.

The scope and magnitude of the data files compiled in this project allows for a variety of safety related analyses. Examples of the types of analyses which can be conducted with these data are described in the following sections. It should be noted that at least those critical factors (identified in this study) used to characterize the arterial segments be used in anay tyupe of future analysis. Other factors included in the data base can be added at the discretion of the analyst.

Comparative Analysis

The data base can be employed to compare the accident experience in terms of frequency, rate, or accident type of a given segment, or segments of an urban arterial to the accident experience of like segments contained in the data file. This comparison which determines whether or not the segment under investigation has an abnormal accident experience, is useful in prioritizing arterial segments for safety improvements.

To illustrate this type of analysis, assume that a signalized intersection on a multilane divided arterial is suspected of having a higher than normal frequency of rear-end accidents. Control factors, identified by the various analysis techniques and other factors considered to be important bvecause of the nature of the expected problem, are taken from the list of variables shown in Table 1. Not all factors identified as important earlier in the study must be included, as several, such as presence of fixed objects, shoulder width and type, etc., do not significantly affect rear-end accidents at signalized intersections.

Variable	Field Data
Number of through lanes	4
Median width	15-feet (4.5-m)
Land use	Commercial
Number of signalized intersections per 0.1 mile (0.16 km)	1
Vertical alignment	Level
Average daily traffic	22,500
Total number of traffic signs faces per 0.1 mile (0.16 km)	12

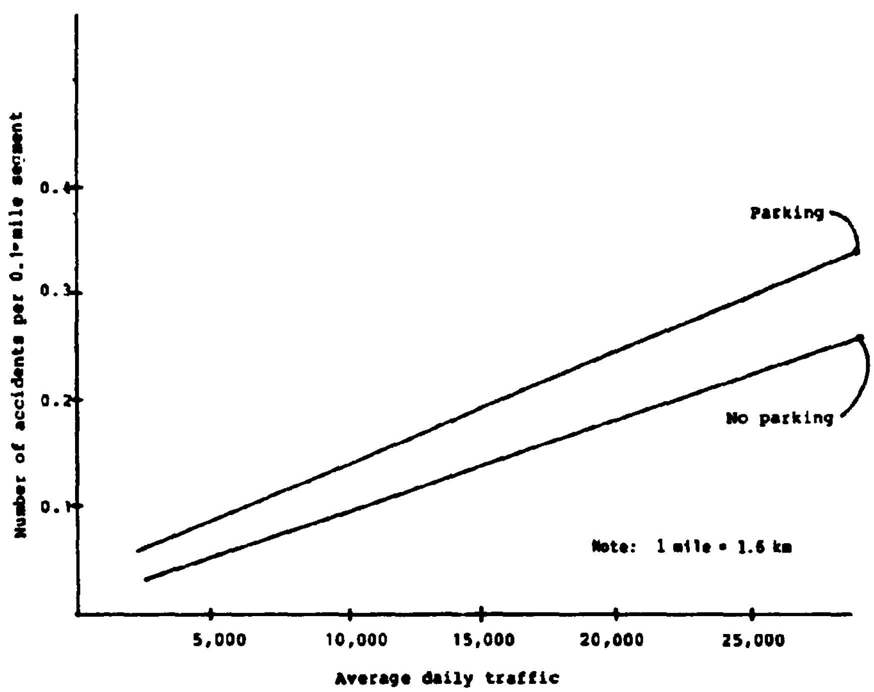


Figure 29. Number of sideswipe accidents during a three-year period as a function of average daily traffic and parking conditions.

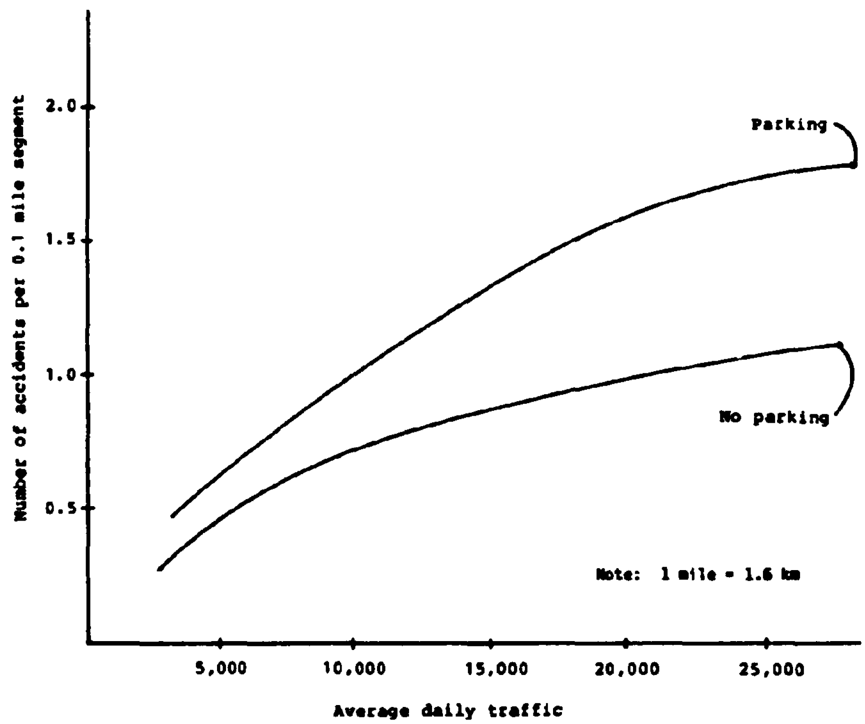


Figure 30. Number of angle accidents during a three-year period as a function of average daily traffic and parking conditions.

Parking conditions	Parking allowed
Surface type	Bituminous
Special auxiliary lanes	None
Operating speed	35 mph (56 kph)

The data base is then employed to determine the average frequency of angle accidents on similar segments. For some of the variable such as median width, average daily traffic, and total number of traffic sign faces, a range will have to be specified to insure an adequate sample size. For example, the following ranges may be specified.

Variable	Range
• Median width	15 to 20 feet (4.5 to 6.0 m)
• Average daily traffic	20,000 to 25,000
• Total number of traffic sign faces	10 to 15
• Operating speed	30 to 40 mph (48 to 64 kph)

If the sample size is still too small it may be necessary to eliminate one or more of the control variables. For this example surface type and/or vertical alinement may have to be eliminated. However, care must be taken to insure that the least important control variable is eliminated. In order to obtain a sample of a size suitable for testing, several of the original variables had to be eliminated. The following variables are left for further analysis.

- Road classification
- Number of signalized intersections
- Average daily traffic
- Number of through lanes
- Land use
- Parking conditions

The comparative examination between parking and no parking conditions revealed significantly higher rear-end and sideswipe accident frequencies where parking exists.

Evaluating Proposed Design and Operational Improvements

For those segments identified as having abnormal accident experience, the data can also be used to estimate the effect of proposed improvements. It should be noted that this type of analysis is limited to those improvements (variables) included in the data files.

For example, assume the frequency of rear-end accidents in the previous situation is higher than expected, and that some type of safety improvement is warranted. The analyst can then alter one or more variables (improvements) and estimate the effect of this change on rear-end accidents. For example, one possible improvement might be to eliminate on-street parking. For this type of analysis the average rear-end accident frequency for those segments which are similar to the existing segment, but without on-street parking, is determined from the data file. The difference in the two rear-end accident frequencies (segments with parking and segments without parking) indicates the expected effect of removing on-street parking.

Other improvements or combinations of improvements can be investigated to determine a "best" set of conditions. For example, the analyst may also want to investigate the effect on angle accidents of adding a left-turn bay (either with or without on-street parking).

Evaluating Proposed Changes to an Arterial Street System

The data base can also be used to evaluate proposed design and/or operational changes to a system of urban arterial streets. For example, two parallel arterials can be compared to determine which street would be least affected (in terms of accidents) by a proposed bus route. For this analysis the accident experience for each arterial being investigated is determined from the data file, first without the bus route and then with the bus route using variables such as local buses per hour, number of bus stops per segment, etc.

Summary

The examples in this section represent only a fraction of the possible uses of the data base. The impact of changing roadside development (adding driveways, changing land use, etc.) or changes in traffic volume can also be projected and used to evaluate policy and/or design changes.

RECOMMENDED RESEARCH

One of the objectives of this research was to develop a comprehensive urban accident and roadway data base. In addition, an analysis of these data was conducted utilizing the branching technique, analysis of variance and covariance, and regression as outlined in the methodology section of this report. However, detailed analyses were conducted only on the variables that maximized the explained variance in the mean accident frequency or rate. For example, if the presence of roadway lighting did not explain a significant portion of the variance in the accident frequency or rate, no further analysis was conducted for lighting.

Even though a variable did not explain a significant part of the variance in the accident data set, it can not be concluded that the variable has no influence on accidents or that there is no interactive effect between that variable and other variables. Where such interactions were considered likely, analysis of covariance tests were conducted to determine the extent of these interactions. However, only a limited number of variable combinations are included in this study. The complete analysis of interactions, comparison of individual group differences, and future similar analyses is left for other researchers.

General Recommendations

It may also be hypothesized that much of the analysis, and especially the branching, may simply be a comparison of intersections and segments without intersections. Preliminary analysis of intersection and non-intersection segments indicates that this hypothesis is not entirely tenable but further study is encouraged.

Another factor worth consideration is the effect of the segment length used for analysis. In the initial stages of the project, it was determined that data collection and analysis should be conducted based on 0.1-mile (0.16-km) roadway segments. Thus, all accident and roadway data were collected and analyzed for 0.1-mile (0.16-km) segments. One problem with using a short length for analysis is that the range of some variables (such as number of signalized intersections, driveways, etc.) is limited by these short lengths. For example, in a 0.1-mile (0.16-km) segment, the number of signalized intersections only ranged from 0 to 3. Other researchers have found that signal densities with a range from 0 to 10 per mile are related to accidents. Although this trend was also found in this study, the limitations on number of signals per segment resulted in testing relatively large discrete differences between 0,1,2, and 3 signals per segment. Using the variable number of signalized intersections per segment (and other similar variables) in a regression equation makes the explained variance appear smaller and the standard error of the estimate appear much larger than it is for longer segment lengths or for less discrete data sets.

Another problem with using 0.1-mile (0.16-km) segments is that in many cases it is not possible to accurately locate accidents within 0.1 mile (0.16 km). For this study, care was taken to place accidents in the nearest 0.1-mile (0.16-km) segment as indicated on the computer file. However, in such a short segment any difficulty in locating accidents accurately is magnified by the fact that the ratio of the end conditions to total segment length is high. To minimize this effect, analyses should be conducted on aggregated segment lengths.

Preliminary Analysis Using 0.5-Mile (0.8-km) Segment Lengths

To examine the effects of segment length on the research results, an analysis was conducted using 0.5-mile (0.8-km) segments of urban arterial roadway by linking five continuous 0.1-mile (0.16-km) segments together. A continuous 0.5-mile (0.8-km) section was defined using three variables; (1) city, (2) roadway type, and (3) street identification. A computer program was developed to search for five 0.1-mile (0.16-km) segments along a street of the same roadway type. In this process several roadway segments of the data base were eliminated. For example, if data were collected for 2.4 miles (3.84 km) of a roadway, at least 0.4 miles (0.64 km) of the street would be eliminated making four 0.5-mile (0.8-km) segments. In addition if the roadway type changed, additional portions of the roadway would be eliminated. As a result, 1,313 half-mile (0.8-km) segments were created from the 0.1-mile (0.16-km) data base totaling 656.5 miles (1,050.4 km) of urban arterial roadway.

In processing the data for the 0.5-mile (0.8-km) segments, most of the data items were additive such as the number of accidents, obstacles, utility poles, driveways, intersections, etc. Variables such as volume, median width, and shoulder width were averaged together although it is not expected that these would not vary to any great extent along a 0.5-mile (0.8-km) segment of roadway. Variables such as land use, and number of lanes were selected by finding a match in at least three of the five 0.1 mile (0.16-km) segments which make up the 0.5-mile (0.8-km) segment. Since roadway type was a controlling factor, major changes in these variables were not expected within a 0.5-mile (0.8-km) segment. Variables such as vertical and horizontal alinement were specified by identifying the most severe (greatest percent of grade or largest degree of curvature) 0.1-mile (0.16-km) segment within the 0.5-mile (0.8-km) segment.

After the data were aggregated into 0.5-mile (0.8-km) segments, branching analyses were conducted for all roadway segments as well as for the segments contained in each of the four functional roadway classes.

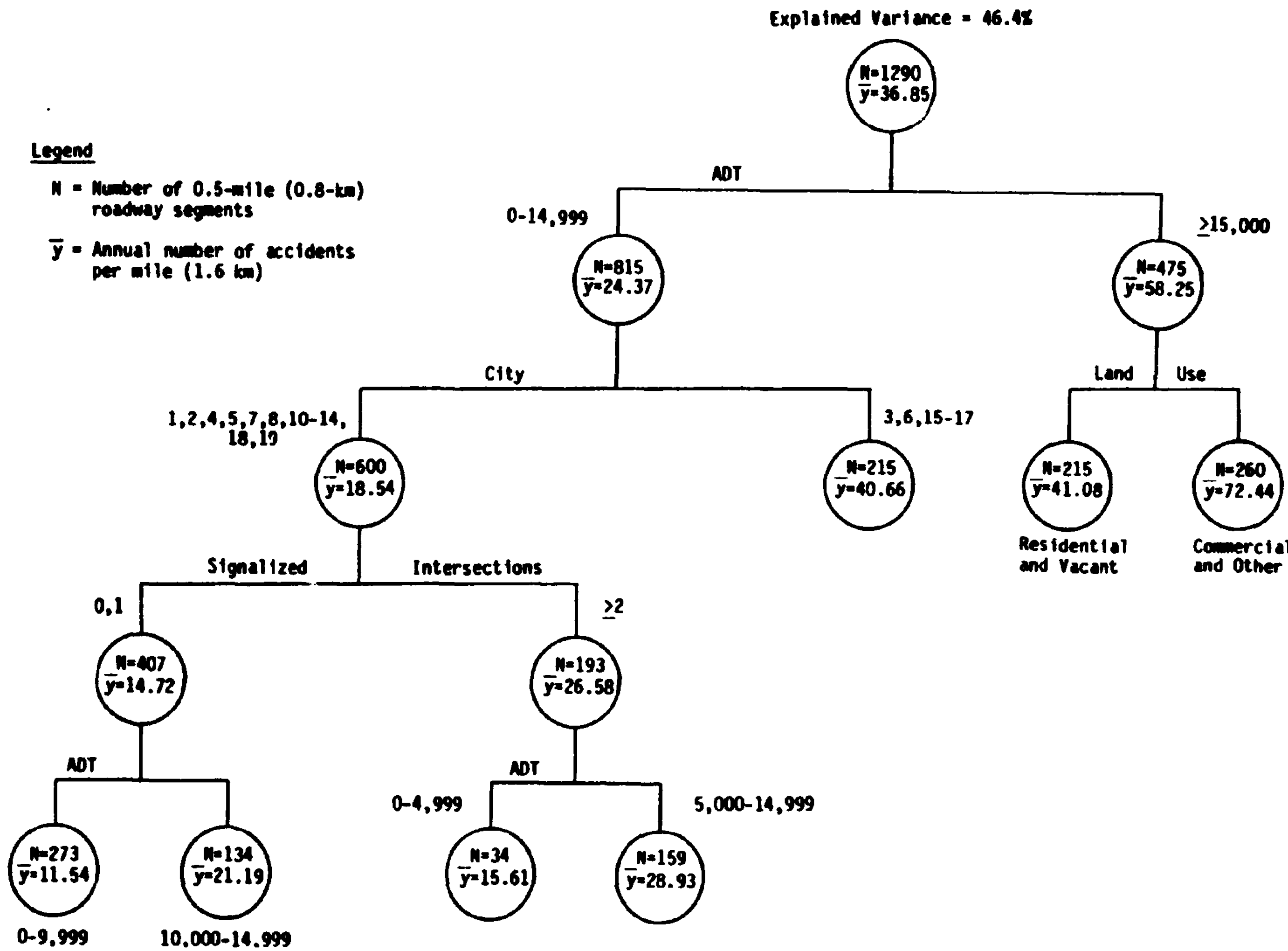


Figure 31. Branching diagram for annual number of accidents per mile using 0.5-mile (0.8-km) roadway segments.

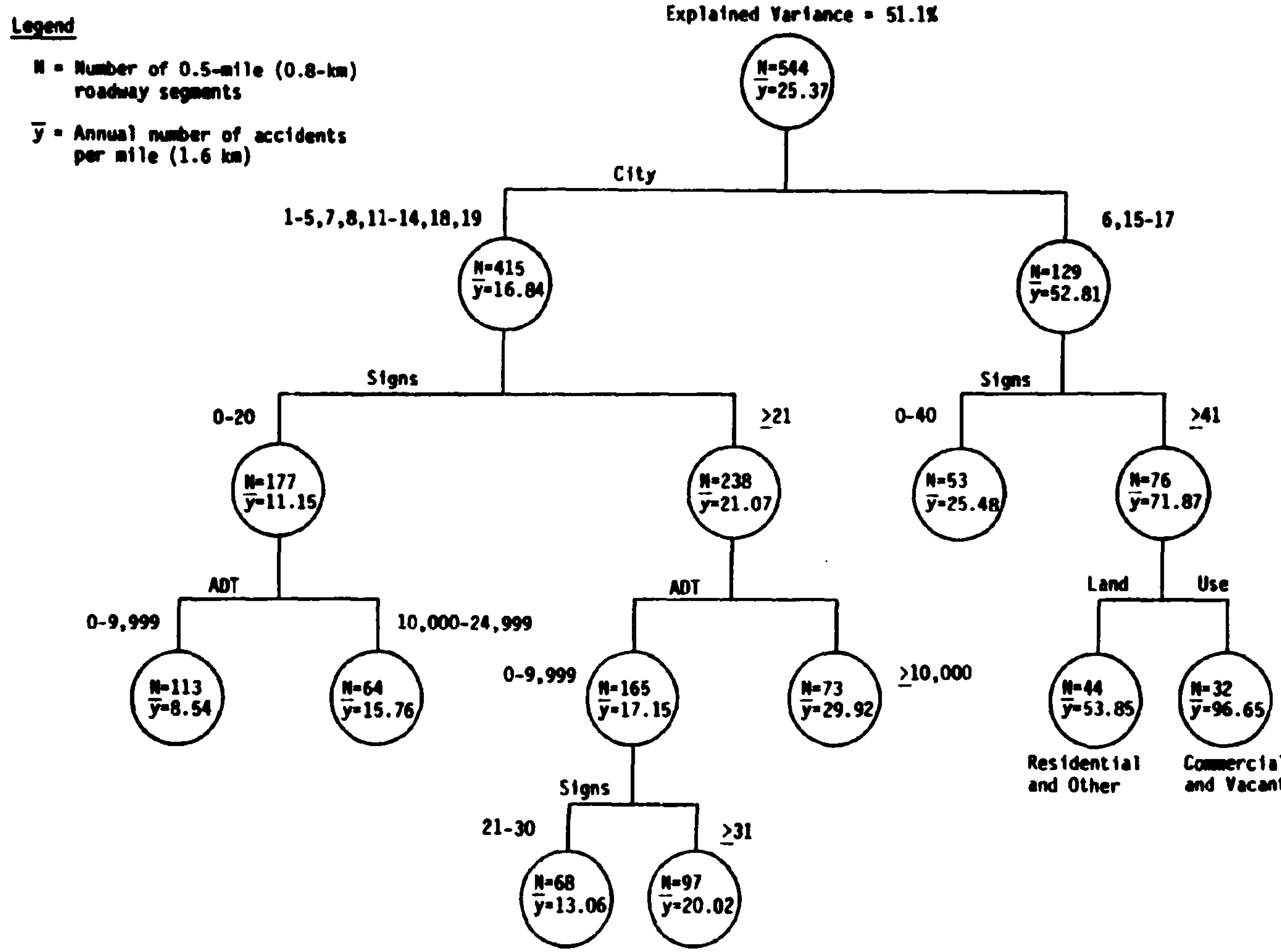


Figure 32. Branching diagram for annual number of accidents per mile using 0.5-mile (0.8-km) two-lane, two-way segments.

For illustrative purposes, the branching diagrams for the annual number of accidents per mile for all 0.5-mile (0.8-km) roadway segments and for the two-lane, two-way 0.5-mile (0.8-km) segments are given in Figures 31 and 32.

The effects of segment length on the analyses results can be examined by comparing the branching results for 0.1-mile (0.16-km) segments with the 0.5-mile (0.8-km) segments. For example, as shown in Figure 15, the explained variance for 0.1-mile (0.16-km) segments is 22.5 percent. As shown in Figure 31, the explained variance increased to 46.4 percent when 0.5-mile (0.8-km) segment lengths were used. It is important to note that the same independent variables, i.e., city, volume, land use, etc. were selected by the program in both cases. This finding suggests that the significant variables identified in the 0.1 mile (0.16 km) analyses are valid and not greatly affected by segment length. For the two-lane, two-way segments the explained variance increased from 30.4 percent for 0.1-mile (0.16-km) segment lengths to 51.1 percent for 0.5-mile (0.8-km) segment lengths as shown in Figure 32.

Multiple regression analyses were conducted for the 0.5-mile (0.8-km) segments using annual accident frequency per mile and accident rate as dependent variables. Separate analyses were conducted for each of the four functional roadway classes. A summary of the findings is presented in Tables 33 and 34. These data were compared to the results obtained for the analysis of 0.1-mile (0.16-km) segment lengths which was summarized in Tables 27 and 28. A comparison of the independent variables that were identified for annual accident frequency for the two segment lengths is presented in Table 35.

A review of Table 35 reveals that most of the independent variables selected for 0.1-mile (0.16-km) segments were also identified when the data were analyzed for 0.5-mile (0.8-km) segments. However, the influence of section length on the regression statistics is evident by comparing the data in Tables 27 and 28 with the data in Tables 33 and 34. For example, using annual accident frequency as a dependent variable, and selecting the two-way, two-lane roadway segments, the regression equation developed for 0.1-mile (0.16-km) segments yields an overall F value of 270.50, and R^2 (explained variance) value of 0.19, and a standard error of 3.58. The mean number of accidents per year was 2.50. Due to the small explained variance and the large standard error, the regression equation clearly would produce poor results if it were used for predictive purposes. For 0.5-mile (0.8-km) segments, the F value is 106.64, the explained variance is 0.37, and the standard error is 24.12, however, the mean annual accident frequency is 25.37. Thus by aggregating the data in 0.5-mile (0.8-km) segments, the explained variance is increased and the standard error is greatly decreased in comparison to the mean. Details of the preliminary analysis of the 0.5-mile (0.8-km) segments is provided in Appendix I.

Table 33. Regression analysis summary for annual accident frequency by roadway classification for 0.5-mile (0.8-km) segments.

One-Way

Variables	Coefficient
Average daily traffic	0.00301
No. of signalized intersections	6.13068
Constant	-5.81179

The two variables explain 39.01% of the variance
F=34.22
Mean accident frequency = 41.67 acc./mile/yr.
Standard error = 33.4

Two-Way, Two-Lane

Variables	Coefficient
No. of traffic sign faces	0.59351
Average daily traffic	0.00187
No. of signalized intersections	3.28222
Constant	-13.19390

The three variables explain 37.21% of the variance
F=106.64
Mean accident frequency = 25.37 acc./mile/yr.
Standard error = 24.12

Multilane Divided

Variables	Coefficient
No. of traffic sign faces	0.81129
Average daily traffic	0.00139
No. of signalized intersections	-2.00088
Land use	-4.69775
Constant	6.72988

The three variables explain 33.58% of the variance
F=36.14
Mean accident frequency = 47.46 acc./mile/yr.
Standard error = 34.89

Multilane Undivided

Variables	Coefficient
Average daily traffic	0.00140
No. of utility poles	0.72974
No. of signs	0.28324
No. of nonsignalized intersections	-1.83079
Constant	-2.06672

The four variables explain 21.51% of the variance
F=23.77
Mean accident frequency = 44.85 acc./mile/yr.
Standard error = 34.55

Table 34. Regression analysis summary for accident rate by roadway classification for 0.5-mile (0.8-km) segments.

One-Way

Variables	Coefficient
No. of traffic sign faces	0.06800
Constant	7.20640

The variable explains 6.38% of the variance
F=7.36
Mean accident rate = 10.77 acc./MVM
Standard error = 7.56

Two-Way, Two-Lane

Variables	Coefficient
No. of traffic sign faces	0.16859
Average daily traffic	-0.00340
No. of signalized intersections	0.94999
Constant	5.02577

The variable explain 25.31% of the variance
F=61.014
Mean accident rate = 8.17 acc./MVM
Standard error = 6.71

Multilane Divided

Variables	Coefficient
No. of traffic sign faces	0.09234
Average daily traffic	-0.00156
No. of signalized intersections	0.46097
Constant	5.82070

The three variables explain 14.94% of the variance
F=16.81
Mean accident rate = 7.61 acc./MVM
Standard error = 5.94

Multilane Undivided

Variables	Coefficient
No. of utility poles	0.16221
Average daily traffic	-0.00209
No. of traffic sign faces	0.04541
Constant	4.86729

The three variables explain 13.63% of the variance
F=18.32
Mean accident rate = 8.63 acc./MVM
Standard error = 6.79

Table 35. Comparison of significant independent variables using accident frequency for 0.1-mile (0.16-km) and 0.5-mile (0.8-km) segment lengths.

Roadway Classification	0.1-mile (0.16-km) Segments	0.5-mile (0.8-km) Segments
One-way	• Average daily traffic • Number of utility poles • Number of through lanes • Number of signalized intersections	• Average daily traffic • Number of signalized intersections
Two-lane, two-way	• Average daily traffic • Number of traffic sign faces • Number of utility poles	• Number of traffic sign faces • Average daily traffic • Number of signalized intersections
Multilane divided	• Average daily traffic • Number of traffic sign faces • Number of signalized intersections	• Number of traffic sign faces • Average daily traffic • Number of signalized intersections • Land use
Multilane undivided	• Average daily traffic • Number of signalized intersections • Number of utility poles	• Average daily traffic • Number of utility poles • Number of traffic sign faces • Number of nonsignalized intersections

A general improvement in the regression statistics were noted for the other roadway classifications. This example provides evidence that segment lengths greater than 0.1 mile (0.16 km) should be used for data collection and analyses in future urban arterial accident studies.

Summary

It is appropriate to note that future study into the urban arterial accident problem can utilize these results as a springboard for more in-depth controlled analyses. Controlled experiments using such techniques as before and after accident studies can be designed utilizing these results to define critical variables. The results of such experiments can aid in the further definition of accident causal factors and their corresponding countermeasures.

REFERENCES

1. Kihlberg, J.K. and K.J. Tharp, "Accident Rates as Related to Design Elements of Rural Highways", National Cooperative Highway Research Program Report 47, Highway Research Board, Washington, D.C., 1968.

2. Wright, P.H. and K.M. King, "Relationships Between Off-Road Fixed-Object Accident Rates and Roadway Elements of Urban Highways", DOT-HS-166-2-260, National Highway Traffic Safety Administration, Washington, D.C., September, 1972.

3. Head, J.A., "Predicting Traffic Accidents From Roadway Elements on Urban Extensions of State Highways", Bulletin 208, Highway Research Board, Washington, D.C., 1959.

4. National Safety Council, "Accident Facts - 1975 Edition", Statistics Division, Chicago, Illinois, 1975.

5. Sonquist, John A., Elizabeth L. Baker, and James N. Morgan, "Searching for Structure", University of Michigan, Ann Arbor, Michigan, 1973.

6. Nie, Norman H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent, "Statistical Package for the Social Sciences", Second Edition, McGraw Hill Book Company, New York, 1975.

7. Box, Paul C. and Associates, "Driveways," Chapter 5, Traffic Control & Roadway Elements, Highway Users Federation for Safety and Mobility, Washington, D.C., 1970.

8. Azzeh, J.A., B.A. Thorson, J.J. Valenta, J.C. Glennon, and C.J. Wilton, "Evaluation of Techniques for the Control of Direct Access to Arterial Highways," Final Report, FHWA-RD-76-85 prepared for Federal Highway Administration, Washington, D.C., August, 1975.

9. Ricci, Leda, "National Crash Severity Study Statistics", DOT-HS-805-227, prepared by Highway Safety Research Institute for the National Highway Traffic Safety Administration, Washington, D.C., October, 1979.

10. Zegeer, Charles V., "Identification of Hazardous Locations on City Streets," Research Report 436, Bureau of Highways, Division of Research, Lexington, Kentucky, November, 1975.

11. Frick, Warren A., "The Effect of Major Physical Improvements on Capacity and Safety," Traffic Engineering, Institute of Traffic Engineers, Arlington, Virginia, December, 1968.

REFERENCES (Continued)

12. Box, Paul C. and Associates, "Intersections," Chapter 4, Traffic Control & Roadway Elements, Highway Users Federation for Safety and Mobility, Washington, D.C., 1970.

13. Shaw, Robert B. and Harold L. Michael, "Evaluation of Delays and Accidents at Intersections to Warrant Construction of a Median Lane," Highway Research Record 257, Highway Research Board, Washington, D.C., 1968.

14. Terry, D.S. and Arthur L. Kassan, "Effects of Point Channelization on Accidents," Traffic Engineering, Institute of Traffic Engineers, Washington, D.C., December, 1968.

15. Cribbins, P.D., J.W. Horn, F.V. Beeson, and R.D. Taylor, "Median Openings on Divided Highways: Their Effect on Accident Rates and Level of Service," Highway Research Record 188, Highway Research Board, Washington, D.C., 1967.

16. Thomas, Richard C., "Continuous Left-Turn Channelization and Accidents," Traffic Engineering, Vol. 37, No. 3, Institute of Traffic Engineers, Washington, D.C., December, 1966.

17. David, N.A., and J.R. Norman, "Motor Vehicle Accidents in Relation to Geometric and Traffic Features of Highway Intersections: Volume II - Research Report," prepared for Federal Highway Administration and the National Highway Traffic Safety Administration, Washington, D.C., June, 1975.

18. Foley, J.L., Jr., "Major Route Improvements," Special Report 93, Highway Research Board, Washington, D.C., 1967.

19. Box, Paul C., "Access Control and Accident Reductions," Municipal Signal Engineer, May - June 1965.

20. Leong, H.J.W., "Effect of Curbed Median Strips on Accident Rates on Urban Roads," Proceedings of the Fifth Conference, Vol. 5, Part 3, Australian Road Research Board, Victoria, Australia, 1970.

21. Babcock, W.F. and Robert Foyle, "Urban Street Design For Traffic and Land Service," Highway Research Program, North Carolina State University, Raleigh, North Carolina, March, 1978.

22. Parker, Martin R., Jr., "Guidelines For Selecting Median Treatments For Urban Areas," Compendium of Technical Papers, 49th Annual Meeting of Institute of Transportation Engineers, Toronto, Canada, September 1979.

REFERENCES (Continued)

23. Sawhill, Roy B. and Dennis R. Neuzil, "Accidents and Operational Characteristics on Arterial Streets with Two-Way Median Left-Turn Lanes," Highway Research Record 31, Highway Research Board, Washington, D.C., 1963.

24. Hoffman, Max R., "Two-Way, Left-Turn Lanes Work!," Traffic Engineering, Vol. 44, No. 11, Institute of Traffic Engineers, Arlington, Virginia, August, 1974.

25. Burritt, Benjamin E., and Eugene E. Coppola, "Accident Reductions Associated With Continuous Two-Way Left-Turn Channelization," Arizona Department of Transportation, Phoenix, Arizona, July 31, 1978.

26. May, A.D., Jr., "Economics of Operation on Limited-Access Highways," Highway Research Bulletin 107. Highway Research Board, Washington, D.C., 1955.

27. May, Adolf D., Jr., "A Friction Concept of Traffic Flow," Vol. 38 Proceedings, 38th Annual Meeting, Highway Research Board, Washington, D.C., 1959.

28. Cribbins, P.D., J.M. Arey, and J.K. Donaldson, "Effects of Selected Roadway and Operational Characteristics on Accidents on Multilane Highways," Highway Research Record 188, Highway Research Board, Washington, D.C., 1967.

29. Head, J.A., "Predicting Traffic Accidents from Roadway Elements on Urban Extensions of State Highways", Highway Research Bulletin 208, Highway Research Board, Washington, D.C., 1959.

30. McGuirk, William W. and Gilbert T. Satterly, Jr., "Evaluation of Factors Influencing Driveway Accidents," Transportation Research Record 601, Transportation Research Board, Washington, D.C., 1976.

31. Walton, C. Michael and Randy B. Machemehl, "Continuous Two-Way Left-Turn Median Lanes: An Effective TSM Option," Compendium of Technical Papers, 49th Annual Meeting, Institute of Transportation Engineers, Toronto, Canada, September 1979.

32. Mulinazzi, T.E. and H.L. Michael, "Correlation of Design Characteristics and Operational Controls with Accident Rates on Urban Arterials," Joint Highway Research Project, Purdue University, Lafayette, Indiana, December, 1967.

33. Chapman, R.G., "Accidents on Urban Arterial Roads," TRRL Laboratory Report 838, Transport and Road Research Laboratory, Crowthorne, Berkshire, United Kingdom, 1978.

REFERENCES (Continued)

34. Webb, G.M., "The Relation Between Accidents and Traffic Volumes at Signalized Intersections," Proceedings, Institute of Traffic Engineers, Washington, D.C., 1955.

35. Olson, R.M., G.D. Weaver, H.E. Rarr, Jr., and E.R. Post, "Effect of Curb Geometry and Location on Vehicle Behavior," National Cooperative Highway Research Program Report 150, Transportation Research Board, Washington, D.C., 1974.

36. Gupta, R.C. and R. Jain, "Effect of Certain Geometric Design Characteristics of Higwhays on Accident Rates for Two-Lane, Two-Way Roads in Connecticut," University of Connecticut, Storrs, Connecticut, August, 1973.

37. Wright, Paul H. and King K. Mak, "Statistical Analysis of Single Vehicle Accident Relationships," Traffic Engineering, Vol. 46, No. 1, Institute of Transportation Engineers, Arlington, Virginia, January 1976.

38. Hanna, John T., Thomas E. Flynn, and Webb L. Tyler, "Characteristics of Intersection Accidents in Rural Municipalities," Transportation Research Record 601, Transportation Research Board, Washington, D.C., 1976.

39. King, G.F., and R.B. Goldblatt, "Relationship of Accident Patterns to Type of Intersection Control," Transportation Research Record 540, Transportation Research Board, Washington, D.C., 1975.

40. Moore, William L., Jr., and Jack B. Humphreys, "Sight Distance Obstructions on Private Property at Urban Intersections," Transportation Research Record 541, Transportation Research Board, Washington, D.C., 1975.

41. Glennon, John C. and Cathy J. Wilton, "Roadside Encroachment Parameters for Non-Freeway Facilities", Transportation Research Record 601, Transportation Research Board, Washington, D.C., 1976.

42. Jones, Ian S. and A. Stephen Baum, "Analysis of the Problem of Urban Utility-Pole Accidents," Transportation Research Record 681, Transportation Research Board, Washington, D.C., 1978.

43. Humphreys, Jack B., Donald J. Wheeler, Paul C. Box, and T. Darcey Sullivan, "Safety Considerations in the Use on On-Street Parking," Transportation Research Record 722, Transportation Research Board, Washington, D.C., 1979.

REFERENCES (Continued)

44. Mayer, Peter A., One-Way Streets," Chapter 10, Traffic Control & Roadway Elements, Highway Users Federation for Safety and Mobility, Washington, D.C., 1971.

45. Blackburn, R.R., D.W. Harwood, A.D. St. John, and M.C. Sharp, "Effectiveness of Alternative Skid Reduction Measures, Volume 1. Evaluation of Accident Rate-Skid Number Relationships", Report No. FHWA-RD-79-22, prepared for the Federal Highway Administration, Washington, D.C., November 1978.

46. Holbrook, L.F., "Prediction of Wet Surface Intersection Accidents From Weather and Skid Test Data," Transportation Research Record 623, Transportation Research Board, Washington, D.C., 1976.

47. Christie, A.W., "Street Lighting and Roadway Safety," Traffic Engineering and Control, Vol. 8, No. 4, Printerhall Limited, London, England, August 1966.

48. Stark, Richard E., "Studies of Traffic Safety Benefits of Roadway Lighting," Highway Research Record 440, Highway Research Board, Washington, D.C., 1973.

49. Box, Paul C., "Effect of Lighting Reduction on an Urban Major Route," No. 10, Vol. 46, Traffic Engineering, Institute of Transportation Engineers, Arlington, Virginia, October 1976.

50. Box, Paul C., "Comparison of Accidents and Illumination," Highway Research Record 416, Highway Research Board, Washington, D.C., 1972.

51. Snyder, James C., "Environmental Determinants of Traffic Accidents: An Alternate Model," Transportation Research Record 486, Transportation Research Board, Washington, D.C., 1974.

52. Fielding, Roy H. and Thomas E. Young, "Analysis of Flow on an Urban Thorofare," Highway Research Bulletin 107, Highway Research Board, Washington, D.C., 1955.

53. Clayton, Mike E. and Robert C. Deen, "Evaluation of Urban Intersections Using Traffic Conflicts Measures," Division of Research, Kentucky Department of Transportation, Lexington, Kentucky, August, 1977.

54. Parker, Martin R., Jr., Robert F. Jordan, Jr., Jeffrey A. Spencer, Melvin D. Beale, and Larry M. Goodall, "Right-Turn-On-Red," Virginia Highway and Transportation Research Council, Charlottesville, Virginia, September, 1975.

REFERENCES (Continued)

55. Glauz, William D. and Donald J. Migletz, "Application of Traffic Conflict Analysis at Intersections," National Cooperative Highway Research Program Report 219, Transportation Research Board, Washington, D.C., February, 1980.

56. Holahan, C.J., M.D. Campbell, R.E. Culler, and C. Veselka, "Relation Between Roadside Signs and Traffic Accidents: Field Investigation", Transportation Research Record 683, Transportation Research Board, 1978.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.