PART I

FINAL REPORT

PROJECT E-20-620

MULTIDISCIPLINARY ACCIDENT INVESTIGATIONS PHASE 6

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Prepared for

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National Highway Traffic Safety Administration

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MULTIDISCIPLINARY ACCIDENT INVESTIGATIONS
PHASE 6

PART I FINAL REPORT

Prepared for the
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Georgia Tech Vehicular Collision Research Team
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16. Abstract

This report describes the results of Phase 6 of a continuing multidisciplinary accident investigation research program sponsored by the National Highway Traffic Safety Administration. It summarizes the results of a comprehensive and systematic study of twenty-two vehicular accidents which occurred in metropolitan Atlanta, Georgia, during the period October, 1971, to September, 1972. The research was a broadbased team effort which involved the participation of civil engineers, physicians, an automotive technician, a pathologist, social workers, and a secretary. Each accident investigation included a study of the factors which contributed to the crash as well as an in-depth study of the "second collision" to establish the kinematics of the occupants and to identify the agent(s) which caused the injuries and deaths.

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This research was truly a team effort, and each participant provided significant and important contributions to this report. The roles of the various members of the research team are given in Chapter II.

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Without the cooperation of various organizations, this research would have been difficult, and in certain cases, impossible to conduct. The research team acknowledges with appreciation the cooperation of the following organizations: The Atlanta Engineering Department, Atlanta Police Department, DeKalb County Police Department, Emory University Clinic, Fulton County Medical Examiner, Georgia Department of Public Safety, Georgia Department of Transportation, Georgia Safety Council, Grady Memorial Hospital, National Weather Service, South Fulton Hospital, Office of the Coordinator of Traffic Safety, Piedmont Hospital, and various physicians and insurance companies.

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ABSTRACT

This report summarizes the results of a comprehensive and systematic study of twenty-two vehicular accidents which occurred in metropolitan Atlanta, Georgia, during the period October, 1971, to September, 1972. The research was a broadbased team effort which involved the participation of civil engineers, physicians, an automotive technician, a pathologist, social workers, and a secretary. Each accident investigation included a study of the factors which contributed to the crash as well as an in-depth study of the "second collision" to establish the kinematics of the occupants and to identify the agent(s) which caused the injuries and deaths.

This report describes the results of Phase 6 of a continuing research program sponsored by the National Highway Traffic Safety Administration. Previous reports(1,2,3,4,5)* describe the research that was accomplished under earlier phases of this program. The first three reports included detailed case studies of 45 investigations made under these phases. This report includes case summaries of 22 investigations completed during a 12-month report period ending September 30, 1972. The full case reports for these investigations have been previously mailed to the sponsor, and are available for public inspection at the National Highway Traffic Safety Administration, 400 - 7th Street, S. W., Washington, D. C., 20590.

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* Numbers in parentheses designate references at end of report.

CHAPTER I

INTRODUCTION

In 1968, the federal government under the auspices of the National Highway Safety Bureau undertook a program to collect a scientifically valid body of information regarding vehicular collisions. The initial phase of this program involved the development of multidisciplinary medical-engineering research teams located in six U. S. cities: Atlanta, Boston, Houston, Rochester, Los Angeles, and New Orleans. Additional multidisciplinary teams have since been organized, and sixteen research teams are currently active. These teams have been given the following objectives:

1. to determine causes of traffic accidents,
2. to identify agents which produce injuries and deaths in these accidents,
3. to evaluate effectiveness of new safety features,
4. to provide early detection of vehicular and roadway design problems, and
5. to evaluate Federal Motor Vehicle Safety Standards and Federal Highway Safety Program Standards.

To date, one hundred and twenty-two crash investigations have been completed by the Atlanta research team. Five final reports (1,2,3,4,5) have been previously published by the Atlanta team describing the work that was accomplished under earlier phases of this program:

Phase	Number of Cases	Date of Report	Number of Pages
1	10	June, 1968	116
2	20	February, 1969	179
3	15	June, 1969	140
4	25	August, 1970	59
5	30	September, 1971	128

The first three reports included detailed case studies of the 45 investigations made under these phases of the program. Since July, 1969, when Phase 4 of the research program was initiated, case reports have been submitted to the sponsor singularly and immediately upon completion.

The present document summarizes the results of twenty-two accident investigations which were completed during the report period October 1, 1971, to September 30, 1972. The full case reports for these investigations have been previously mailed to the Accident Investigation Division, National Highway Traffic Safety Administration and are available for public inspection at 400 - 7th Street, S. W., Washington, D. C., 20590.

As a part of the research project, a special pilot study was made of the relationship between off-road fixed-object accident rates and roadway elements of urban highways. The results of this special study are given in a separate report(6).

CHAPTER II

PROCEDURE

This research employed a multidisciplinary approach involving the participation of civil engineers, physicians, an automotive technician, a psychologist, a mechanical engineer, a pathologist, social workers, a secretary, and research assistants. The principal role of each participant is given by Table 1.

In each case, the research team was concerned, first of all, with identifying, isolating, and evaluating those human, vehicular, and environmental factors which contributed to the accident initiation. Secondly, the team concerned itself with the kinematics of the vehicle occupants during the at-crash phase, and the identification and description of accident trauma and the agent which caused each injury.

Twenty-two vehicular crash investigations were made during this report period, all of which occurred in metropolitan Atlanta, Georgia. A sketch of this study area is given as Figure 1.

Selection of Accidents for Investigation.

Selection of accidents for investigation was based on criteria stipulated by the sponsor:

1. That each investigation involve at least one vehicle of the last three model years.

2. That the studies consist of a reasonable and balanced distribution of fatal, injury-producing, and property damage collisions with the stipulation that in the latter case at least one vehicle had to be towed from the accident scene.

Sixteen of the 22 cases chosen for investigation were discovered by monitoring police radios and going to the scene of accidents to which an ambulance had been dispatched. Three accidents were discovered by happenstance, and one was witnessed by a member of the research team. A Georgia Tech student reported one crash to the team by telephone, and another accident was brought to the attention of the team by the Fulton County Medical Examiner.

Table 1. Principal Functions of Various Research Participants.

Participant	Principal Functions
Fleming L. Jolley, M. D. Neurological Surgeon and Norman E. McSwain, Jr., M. D. General Surgeon	Identified and described accident trauma; correlated injury patterns with agent(s) which produce injuries.
Paul H. Wright, Ph.D. Civil Engineer	Served as Administrative Director of Project; identified and evaluated factors which contribute to accident initiation; authored reports.
King-Kuen Mak, B.S., M.S.C.E. and J. S. Hassell, Jr., B.C.E.,M.S.C.E. Research Engineers	Made on-the-scene investigations; conducted engineering roadway studies and prepared maps; made photographs; conducted field studies; assisted with writing of reports.
Mr. Bruce Ivey Automotive Technician	Directed all mechanical aspects of the study including identification of pre-accident mechanical defects and evaluation of vehicle damage.
W. M. Williams, Ph.D. Mechanical Engineer	Assisted with accident analysis; provided expertise on automotive systems.
Robert R. Stivers, M. D. Pathologist	Served as consultant to provide autopsy reports.
E. Jo Baker, Ph.D. Psychologist	Directed psychological studies for certain drivers.
Miss Jo Stallings, A.C.S.W. Mrs. Elizabeth Stout, B.S. Mrs. Charlene Solomon, B.A. Social Workers	Assisted Dr. Baker by conducting psychological interviews.
Mrs. Laura Mack Secretary	Typed reports; handled numerous administrative details.

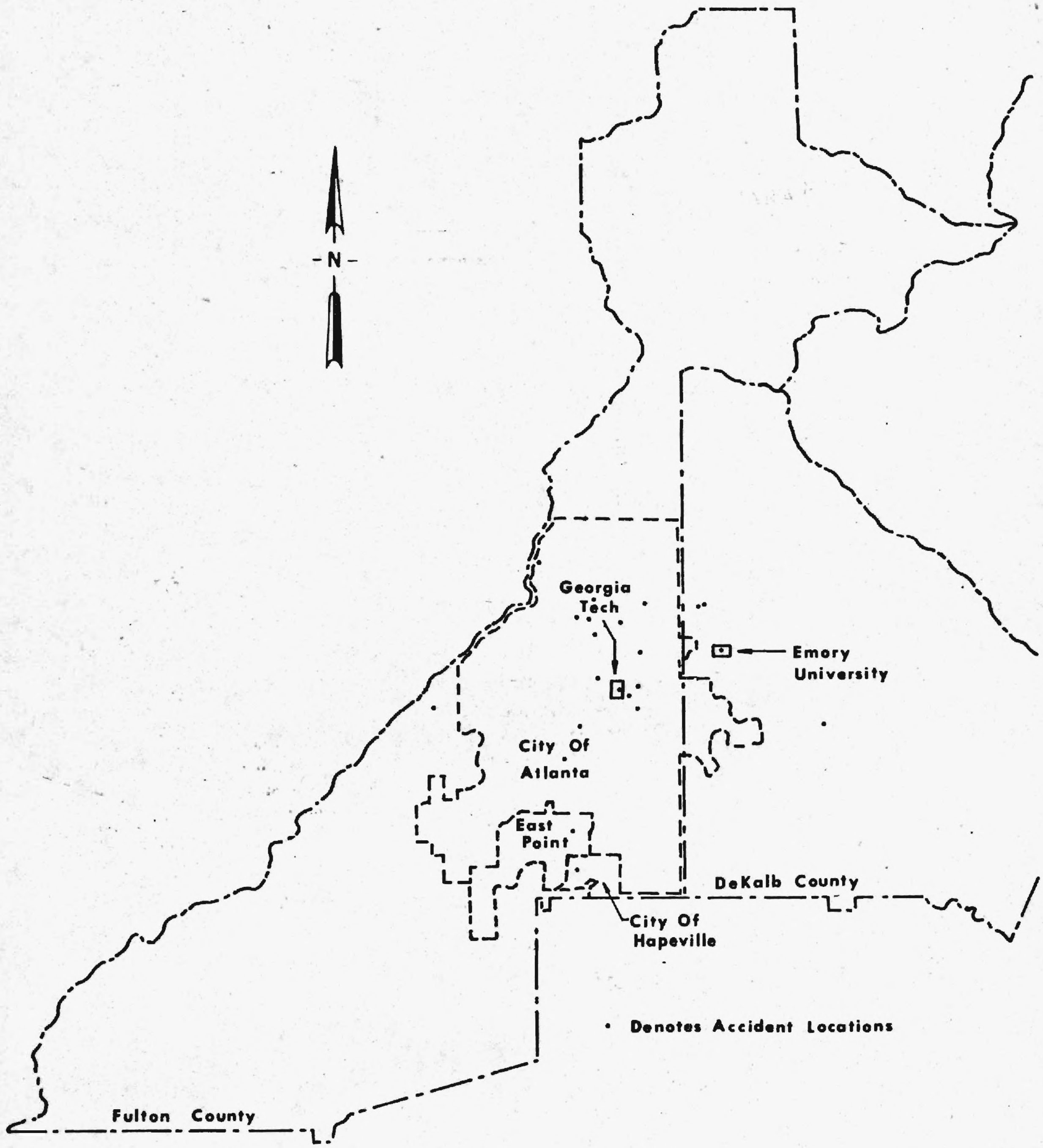


Figure 1. A Sketch of the Study Area.

On-Scene Investigation.

In 21 of the 22 cases, members of the research team were able to arrive at the accident scene before the vehicles had been removed, and often team members arrived before the ambulance. In these cases, photographs were taken, witnesses were interviewed, and skid marks and other physical evidence were measured and documented. On numerous other occasions, members of the team went to the scene of accidents which failed to meet the criteria for further investigation.

Roadway Studies.

Because of the observed tendency for certain physical crash evidence to deteriorate rapidly or disappear, roadway studies were undertaken at each accident scene as soon as practicable after learning of the accident. The roadway studies were conducted by two or three people and consisted of measuring or evaluating the following roadway factors: alignment and curvature, gradient, cross section dimensions, superelevation, sight distance, visibility, traffic control and warning devices, traffic volume at the time and day of week of the accident, and skid resistance of the pavement.

Estimates of pavement skid resistance were based on tests made with a Tapley decelerometer at a speed of twenty miles per hour.

Attempts were made to locate skid and gouge marks and other physical evidence to assist in determining the movement of the vehicle during the impact event.

Photographs of the roadway were made with a 35 mm. YASHICA TL-Super camera and a 35 mm. NIKON F camera.

Mechanical Analyses.

While it was sometimes possible to detect certain readily visible vehicular defects at the accident scene, it was necessary in each case to conduct an in-depth mechanical analysis after the vehicle had been removed to a more suitable location. The mechanical inspections were made at impound lots, salvage disposal lots, garages, vehicle owners' homes--in short, wherever the inspection could be conveniently performed. Generally, whenever a mechanical defect was suspected, the component was removed from the vehicle and transported to the team office or laboratory for further analyses. In one case, a consultant metallurgist was employed to make a study of the nature of a trailer hitch failure.

Results of the mechanical inspections were recorded on Collision Performance and Injury Report Forms (General Motors Report No. GM PG 2070) and Vehicle Inspection Data Forms. The damages and defects of each automobile were documented by means of color photograph slides and black and white photographs.

In order to make the results of the mechanical analysis more amenable to computer analysis, an alphanumeric vehicular deformation index(7) was used to describe vehicle damages. This index contains vectorial representation of impact direction, impact magnitude and a detailed description of vehicle impact location. The deformation index is composed of four components:

1. Direction of principal force at point of impact.
2. Vehicle deformation location.
3. General type of collision.
4. Damage scale.

A detailed description of the vehicle deformation index system is given by Figure 2.

Medical Reports on the Injured.

The pattern of injuries received by each accident victim was generally determined by reviewing the medical records of those injured, and/or by conversation with the attending physicians.

A number of the injured were examined with the attending physicians to gain additional insight to correlate the injury pattern with contacting agents within the vehicle. Such cooperation has permitted identifying for the attending physician certain additional facts as to symptomatology of injury received by his patient.

Additional valuable information was gained in reviewing x-rays as well as other diagnostic studies performed.

Autopsies.

Four of the accidents investigated resulted in a total of seven fatalities, and autopsies were performed on all seven of the victims. The Medico-Legal Autopsy Report form developed by the Registry of Accident Pathology, Armed Forces Institute of Pathology was used for reporting the results of these autopsies.

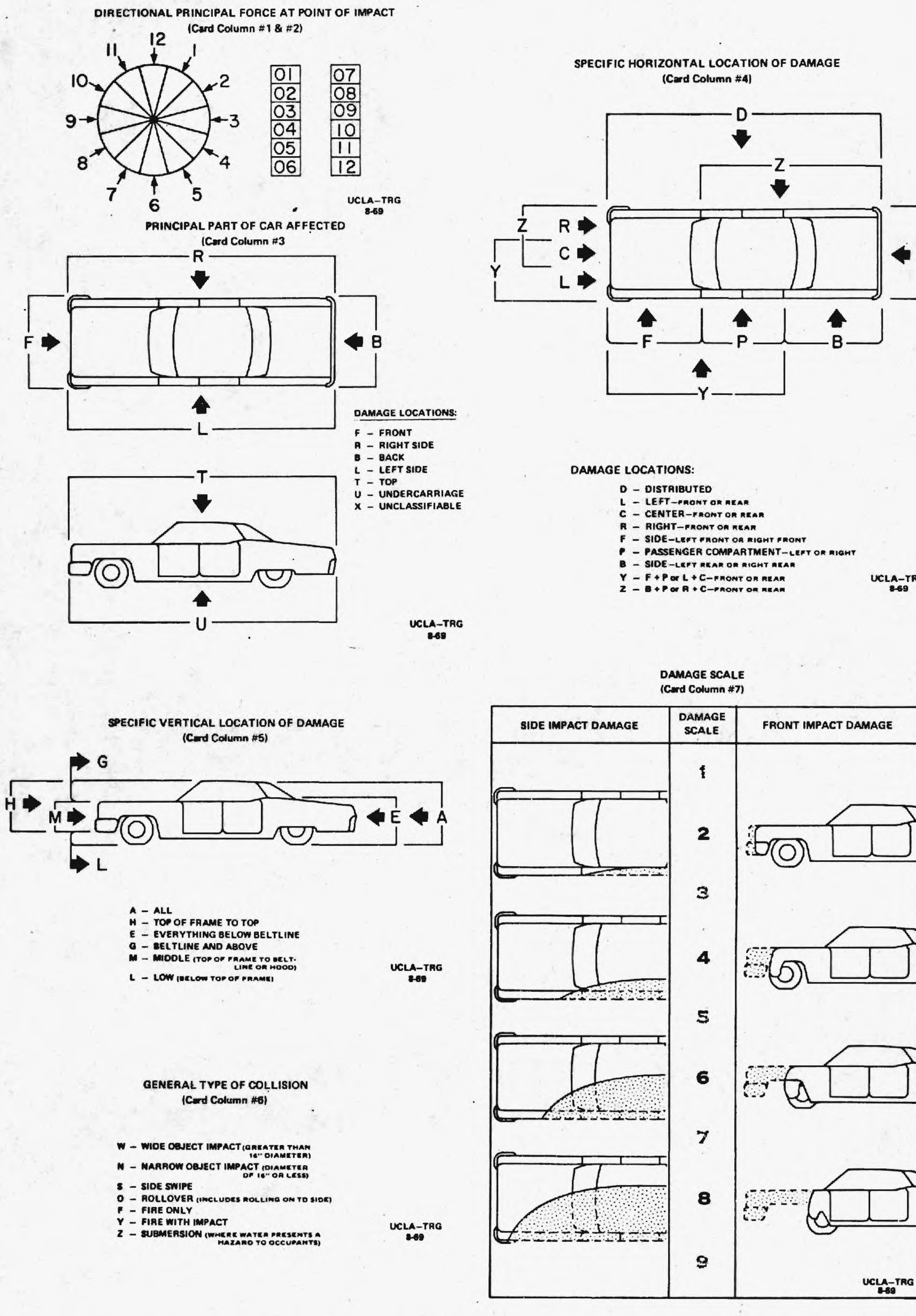


Figure 2. Vehicle Deformation Index System.

Post-Crash Interviews.

Drivers involved in case accidents were usually interviewed by staff personnel either on-scene or in the driver's home. In those cases in which there was suspicion of involvement of psychological factors, in-depth home interviews of drivers were conducted by a social worker under the direction of a psychologist. Interviews of passengers and witnesses were generally conducted by telephone.

Report of Previous Traffic Violations.

With the cooperation of the Georgia Department of Public Safety, a check was made of each driver's previous traffic violations, and this information was made a part of the respective case reports. In five cases involving out-of-state drivers, traffic violation information was obtained from the driver's respective state Department of Public Safety. In four of these cases, the information was requested through another multidisciplinary team.

Roadway Accident History.

In each case, a study was made of the accident history of the roadway and an evaluation of the roadway from this viewpoint was made a part of the case report.

Police Officer's Report.

Periodic visits were made to the Atlanta Police Station and the DeKalb County Police Department to learn of accidents that had occurred. Copies of police reports were obtained for those accidents chosen for investigation to provide personal and biographical data and supplemental information on how the accident occurred.

Case Review and Analysis.

Each case was analyzed within the framework of a nine-cell matrix(8) recommended by the sponsor. This matrix is employed in order to: 1) conveniently categorize causal factors, findings, conclusions, and recommendations of researchers; 2) to facilitate the location of findings relating to the specific interests of users; and, 3) to permit tallying frequencies of occurrence of significant factors in common cells, thus providing a gross indication of where the problem areas and trends are emerging.

The matrix, shown by Figure 3, is comprised of three groups of factors: human, vehicular, and environmental; and three phases of the accident event: pre-crash, at-crash, and post-crash. The pre-crash phase is concerned with accident avoidance, the at-crash with injury prevention, and the post-crash phase with the reduction of the severity of the accident.

In an attempt to describe and evaluate the various factors which contributed to the initiation and consequences of the accidents investigated, the research team defined the following terms:

1. Principal Contributing Factors. This factor, acting alone, was sufficient to explain the occurrence of the accident. Without this single factor, the accident, in the investigators' opinion, would not have occurred.
2. Joint Principal Contributing Factors. These factors are defined as two or more factors acting jointly which were sufficient to explain the occurrence of the accident. Without the combined presence of these factors, the accident, in the investigators' opinion, would not have occurred.
3. Modifying Factors. Absence of these factors would not have prevented the accident from occurring. However, these factors, in the investigators' opinion, compounded the consequences of the crash and increased the magnitude of the damages to property and injuries to those involved in the accident.

Preparation of Case Reports.

After the various source reports and studies were assembled, a rough draft of the narrative of the case report was made and distributed to members of the research team. Periodic meetings of the research team were held to review case studies. After suitable discussion and review, the case reports were revised and prepared for mailing to the sponsor.

A typical case report was 50 to 60 pages in length, and it included a one-to-three page summary, a narrative description of the investigation, a roadway sketch, black and white photographs, a police report, a color slide index, the GM Collision Performance and Injury Report Form, vehicle inspection data, and, in fatal cases, the Medico-Legal Autopsy Report. A selection of 35 mm. color photographic slides were submitted with the written report.

PROGRAM MATRIX FOR HIGHWAY SAFETY RESEARCH

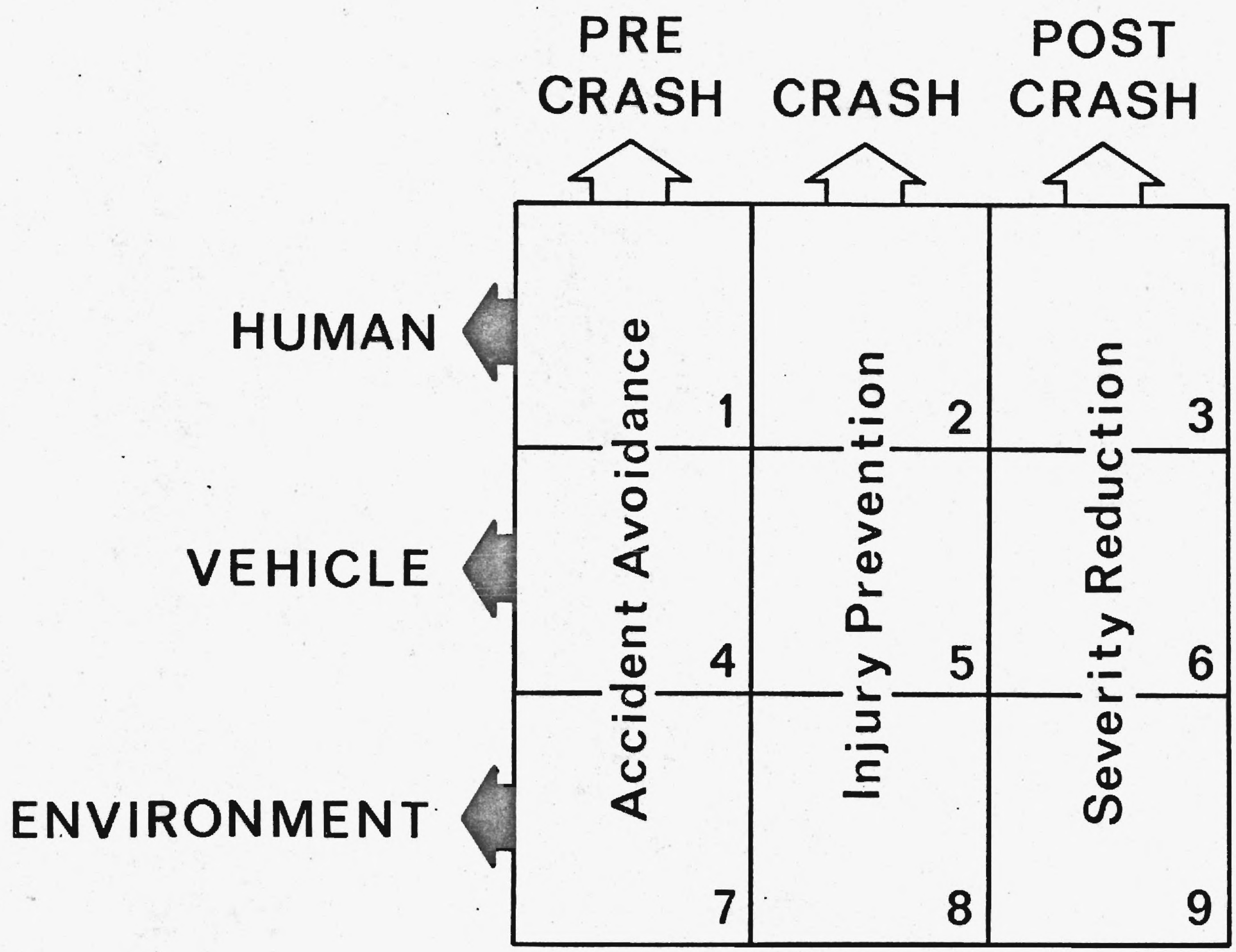


Figure 3.

CHAPTER III

DISCUSSION OF RESULTS

In the paragraphs which follow, a brief account is given of the sampled accident population, describing in a general way the characteristics of the drivers, vehicles, and roadway locations studied during this report period.

A subsequent section of this chapter will describe the various human, vehicular, and environmental factors which contributed to or modified the results of the 22 crashes. Finally, a brief discussion will be given of the evaluations of the Highway Safety Program Standards and Federal Motor Vehicle Safety Standards which were presented in the case reports.

Case summaries for the 22 crashes are given in the appendix.

The Accident Population.

The accidents investigated during this report period involved 42 drivers with ages ranging from 17 to 86. A breakdown of the drivers into age groups and sex is given in Figure 4. The average driver age was 35 and the median age was 29.5. About 26 percent of the drivers were females.

Previous traffic violations were held by 18 of the drivers. One driver, a taxi cab driver, had a record of 15 previous traffic violations while another driver had six violations. Eleven of the drivers revealed that they had driver's education.

Seven fatalities were investigated during this phase. However, approximately 73 percent of people involved in the accidents received either minor injuries or no injuries. Figure 5 shows the distribution of injury severity involved in this phase.

A wide distribution of damaged vehicles were studied during this report period. This is shown by Table 2 which classifies the 42 vehicles according to the damage scale of the vehicular deformation index.

Table 3 shows the vehicle year and make and estimated property damages for each accident. It is noted that the 22 crashes resulted in property damage amounting to a total of $66,589.

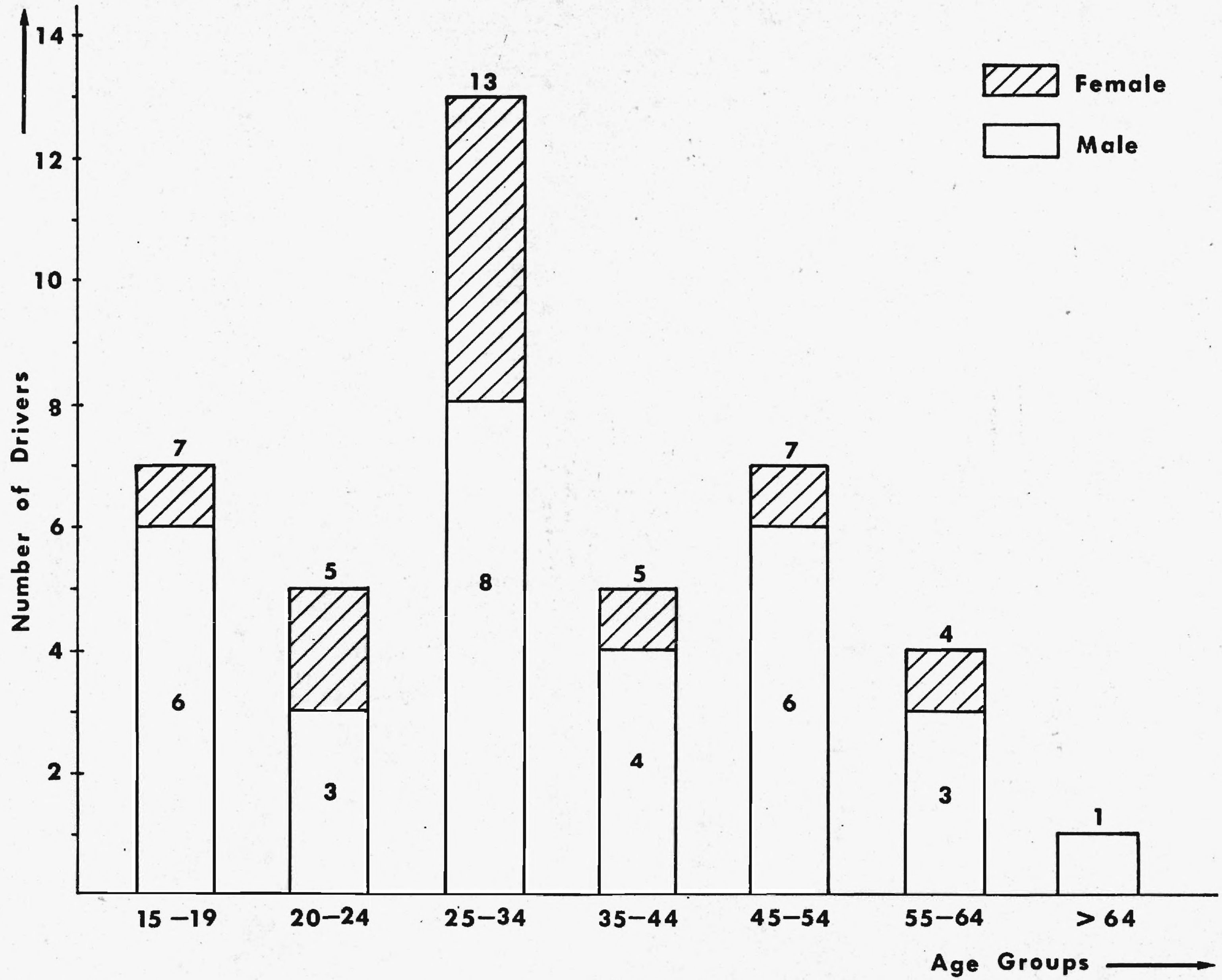


Figure 4. Research Sample Population Distribution by Age Group and Sex of Drivers, Phase 6.

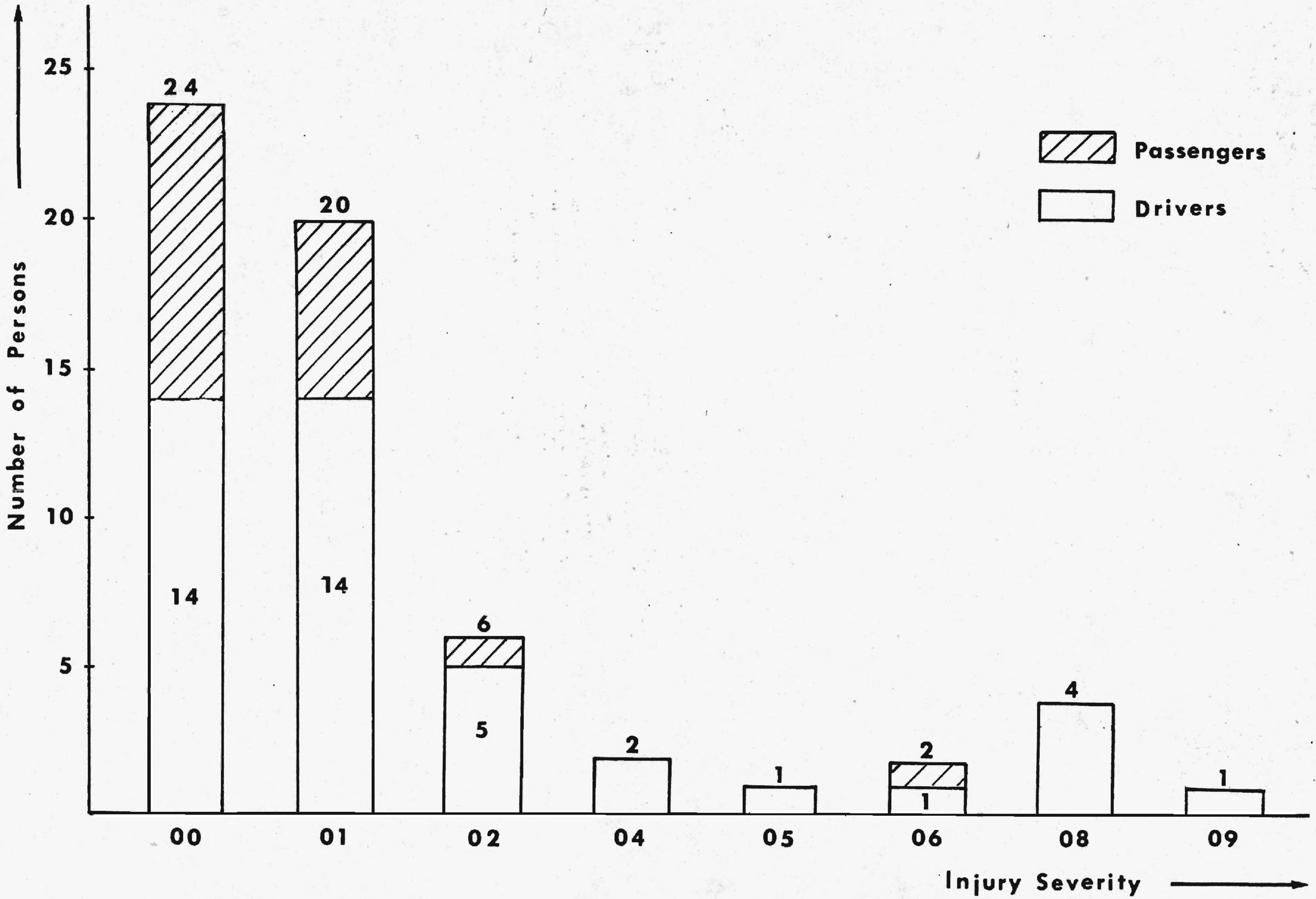


Figure 5. Injury Severity Distribution of Research Sample, Phase 6.

Table 2. Distribution of Research Sample Vehicle Damage Scales, Phase 6.

Damage Scale	Number of Occurrences
1	10
2	13
3	12
4	5
5	4
6	3
7	0
8	0
9	0
No Damages	2
Total	49

Table 3. Cost of Vehicle Repairs, Phase 6.

Accident Number	Vehicle Year and Make		Estimated Cost of Damages
101	1971	Plymouth Duster	$ 200.
	1971	Yamaha	350.
102	1970	Chevrolet Chevelle	1,140.
	1967	Opel Kadett	700.
103	1972	CJ5 Jeep	550.
104	1970	Volkswagen	1,100.
	1971	Pontiac	1,500.
	1970	Chevrolet	175.
105	1970	Toyota	1,700.
	1968	Chevrolet Chevelle	800.
106	1967	Mack R61T Tractor	600.
	1968	Oldsmobile	1,200.
	1971	Chevrolet Vega	2,200.
	1971	Toyota	250.
107	1971	Ford Torino	500.
	1967	Ford Galaxie	750.
	1971	Plymouth Fury	250.
108	1968	Chevrolet Corvette	2,500.
	1970	Ford Maverick	850.
109	1972	Toyota	3,200.
	1966	Chevrolet	750.
	1971	Buick Riviera	1,500.
110	1971	Pontiac Trans Am	4,800.
	1971	Chevrolet Caprice	4,300.
111	1971	Ford Station Wagon	4,200.
112	1972	Plymouth Valiant	3,200.
113	1969	Ford LTD	1,500.
114	1969	Buick LeSabre	924.
115	1970	Plymouth Satellite	450.
116	1971	Chevrolet	3,800.

Table 3 (Continued). Cost of Vehicle Repairs, Phase 6.

Accident Number		Vehicle Year and Make	Estimated Cost of Damages
117	1972	Mercury Comet	$ 2,800.
	1968	Pontiac Catalina	1,200.
118	1971	Toyota Corolla	-----
	1971	Plymouth Fury II	1,350.
	1962	Chevrolet Chevy II	-----
119	1972	Ford Maverick	2,600.
120	1970	Plymouth Duster	650.
121	1970	Ford Light Truck	250.
	1972	MG	3,200.
122	1971	Chevrolet Kingswood Station Wagon	3,800.
	1972	Chevrolet Chevelle	1,800.
	1971	Ford Maverick	3,000.
		Total	$66,589.

The 22 crashes investigated in this phase involved a total of 42 vehicles including two trucks, one Jeep, one motorcycle, six foreign and 32 domestic automobiles. All of the crashes involved at least one 1969, 1970, or 1971 vehicle. A classification of the vehicles studied according to year of manufacture is given by Table 4. This table should not be interpreted to indicate that late model vehicles are more frequently involved in accidents than older vehicles. The table simply indicates that the team was able to conform to the requirement of the sponsor that only accidents involving at least one late model vehicle be investigated.

As shown by Table 5, the most predominant type of accident investigated during this report period was "intersection collision." These collisions comprised over one-fourth of all the cases investigated. Seven of the 22 cases studied involved a vehicle which left the roadway and struck a fixed object, emphasizing the need to provide a safe roadway environment.

Table 6 lists the trip purposes given by the 42 drivers interviewed during this phase. Business and social-recreational purposes were the purposes most frequently indicated.

All of the crashes occurred in metropolitan Atlanta, Georgia, a regional center of finance and commerce of 1.4 million population. Nine of the accidents studied occurred on urban expressways, two on urban arterials, four on collector streets, and seven at intersections. Twenty of the 22 accidents occurred during daylight hours, one at dusk, and one during a period of darkness. The roadway was dry when 20 of the accidents occurred, and wet when the remaining two occurred.

Contributing Factors.

Tables 7 and 8 list the factors which were judged to have contributed to the initiation of the various crashes. The most striking characteristic of these lists is the wide variety of factors which caused the crashes. It is also interesting that 20 of the 22 cases involved two or more causative factors and, in six cases, three or more factors were listed.

In the following paragraphs, the significant human, vehicular, and roadway contributing factors will be briefly discussed.

Human Factors. About 63 percent of the contributing factors

Table 4. Distribution of Vehicles by Year of Manufacture, Phase 6.

Year of Manufacture	Number of Vehicles
1972	7
71	16
70	8
69	2
68	4
67	3
66	1
62	1
Total	42

Table 5. Summary of Accidents by Type, Phase 6.

Type of Accident	Case Numbers	No. of Accidents
Intersection collision	101, 105, 107, 108, 117, 121	6
Leaving roadway, striking fixed object	112, 113, 115, 116, 120	5
Leaving roadway, rollover	103, 119	2
Rear-end, expressway	104, 106	2
Head-on collision, expressway	109, 122	2
Leaving roadway, striking fixed object, rollover	111	1
Intersection collision, leaving roadway, fixed object	118	1
Crossing centerline, collision with another vehicle	110	1
Emerging from driveway, collision	102	1
Car-trailer, jackknifing on expressway	114	1
	Total	22

Table 6. List of Trip Purposes of Drivers Involved in Phase 6 Crashes.

Trip Purpose	Number of Occurrences
Business	12
Social-Recreation	9
Work	7
Home	7
Medical	2
Miscellaneous	1
Unknown	4

Table 7. List of Principal Contributing Factors, Phase 6.

Principal Contributing Factors	Case Numbers	Matrix
Human factor (crash probably not accidental)	113	1
Alcohol	122	1

Table 8. List of Joint Principal Contributing Factors, Phase 6.

Joint Principal Contributing Factors	Case Numbers	Matrix
Inexperience of driver, failure to exercise due caution when emerging from driveway	102	1,1
Inattentiveness of driver (failure to observe red traffic signal), unfamiliarity with route	107	1,1
Inattention of driver (allowing vehicle to strike curb), improper driver reaction (attempting to return to roadway at high rate of speed)	116	1,1
Menacing movement and/or location of vehicle (across centerline), improper reaction of driver (sudden lane change)	118	1,1
Inattention of driver, small size of motorcycle	101	1,4
Improper reaction of driver, defective brakes	103	1,4
Excessive speed, malfunction of secondary hood latch	106	1,4
Inexperience of driver with towed unit, catastrophic failure of trailer hitch	114	1,4
Improper driver reaction, vehicle component failure (tire deflation)	119	1,4
Inattentiveness of driver, traffic stoppage	104	1,7
Failure to exercise due caution when making left turn, restricted sight distance	108	1,7
Human factor (nature of which is unknown), poor roadway design (poles too close to edge of roadway)	111	1,7
Distraction of driver by passenger, poor roadway design (pole too close to road)	120	1,7
Driver failed to properly evaluate situation and exercise due caution when making a left turn, restricted sight distance	121	1,7

Table 8 (Continued). List of Joint Principal Contributing Factors, Phase 6.

Joint Principal Contributing Factors	Case Numbers	Matrix
Driver error (failure to exercise due caution), inattentiveness of driver, severe sight distance restriction due to parked vehicles	105	1,1,7
Inability of driver to respond to emergency situation, high speed, inadequate bus zone	110	1,1,7
Improper reaction of driver (locking up brakes), improper lane change by phantom driver, wet roadway	112	1,1,7
Alcohol, restricted sight distance due to vertical curve, confusing interchange	109	1,7,7
Misjudgment due to poor eyesight, slow reaction due to age, pole too close to road, vertical curve restricted sight distance	115	1,1,7,7
Driver unfamiliar with route, inattentive, took improper evasive action, inadequate visibility of signal, restricted sight distance due to road slope	117	1,1,1,7,7

identified during this phase were human factors. The large majority of the human factors were driver errors, and the driver errors identified varied widely, ranging from simple inattention to possible suicidal intent. Ten instances of inattentiveness and seven instances of improper driver reaction were identified. Alcohol was a factor in only two of the 22 crashes, but these two crashes resulted in five deaths. Both of the intoxicated drivers were considered to be problem drinkers. A summary of contributing factors identified during this phase is given in Table 9.

Vehicular Factors. Only five vehicular contributing factors were identified during this research phase. These factors were: small size (target area) of motorcycle, defective brakes, tire deflation, failure of trailer hitch, and malfunction of a hood latch mechanism. In the latter case (number 106), the team recommended further study to ascertain the desirability of a recall campaign to correct the problem. See Figure 6.

Environmental Factors. Although environmental factors were identified in one-half of the cases, none of the accidents was attributed solely to the environment. Of the 14 environmental factors identified, six involved inadequate sight distance, three involved an inadequate recovery zone due to poles too close to the roadway (Figure 7), and one involved a confusing interchange design. Other environmental factors identified were inadequate bus loading zone, wet roadway, glare, and traffic stoppage.

Modifying Factors.

Modifying factors were identified in only two of the 22 investigations. These factors did not contribute to accident initiation but were judged to have worsened the consequences of the crash. In one accident (no. 106), the presence of an expressway median guardrail prevented a vehicle from crossing into opposing traffic lanes. High speed was judged to have worsened the consequences of one accident (no. 118).

Injuries and Injury Causation.

The accidents investigated during this phase resulted in a wide range of injury severity and a variety of injury types. There were a total of 59 vehicle occupants involved in the 22 crashes, of which 43

Table 9. Summary of Contributing Factors Identified.

Contributing Factor	Applicable Case No.	No. of Cases
A. Human Factors		
Inattention to Driving Task	101,104,105,107,108, 112,116,117,118,120	10
Improper Reaction	103,110,112,116,117, 118,119	7
Failure to Exercise Due Caution	102,105,121	3
Driver Inexperience	102,114	2
Unknown	111,113	2
Alcohol	109,122	2
Excessive Speed	106,110	2
Physical Condition of Driver	115 (2)	2
Unfamiliarity with Route	107,117	2
B. Vehicular Factors		
1. Conditions		
Size	101	1
Defective Brakes	103	1
Flat Tire	119	1
2. Malfunctions		
Hood Latch	106	1
Trailer Hitch	114	1
C. Environmental Factors		
Sight Distance	105,108,109,115,117, 121	6
Roadway Design	109,110,111,115,117, 120	6
Congestion	104	1
Wet Road	112	1

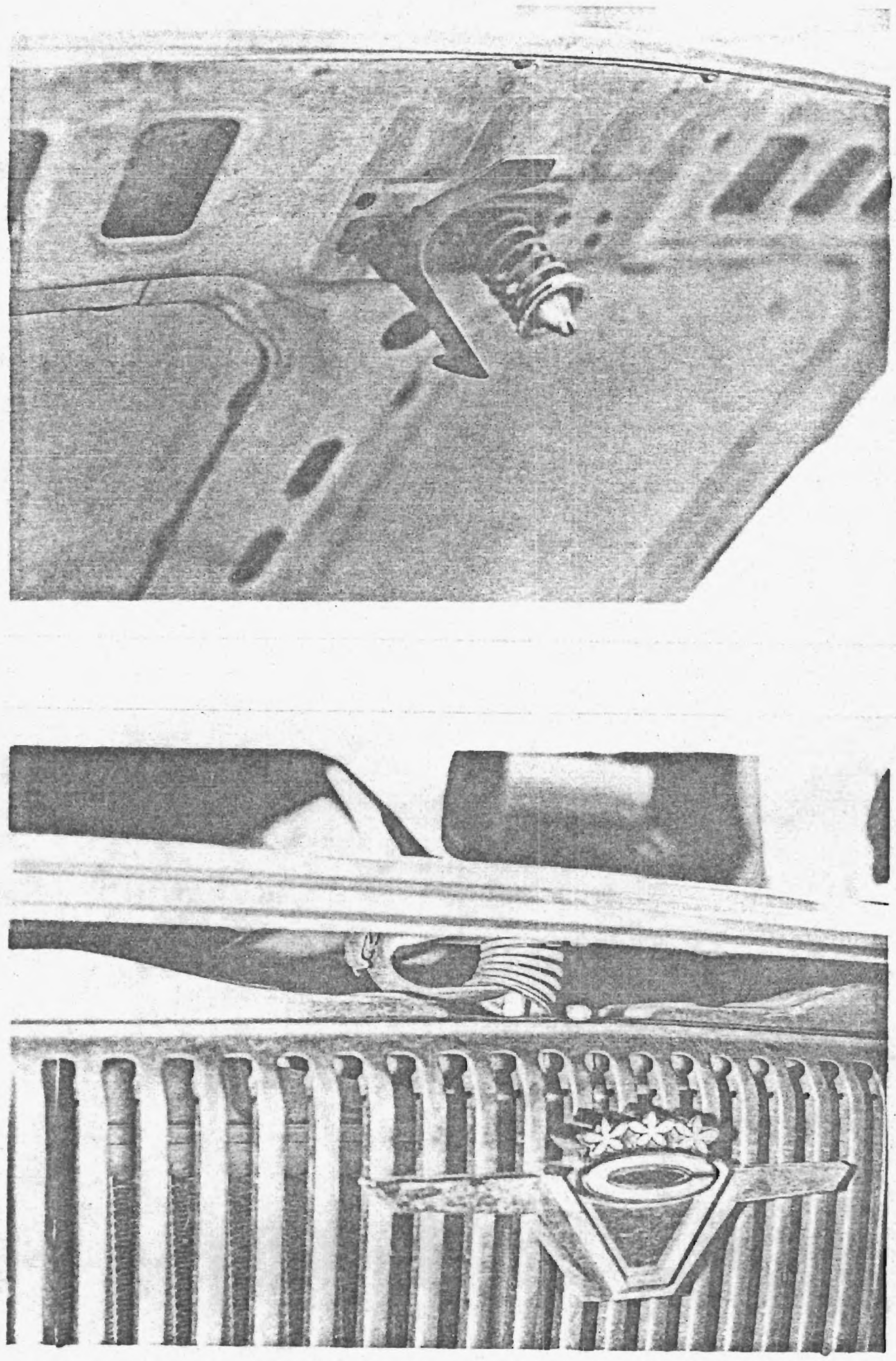
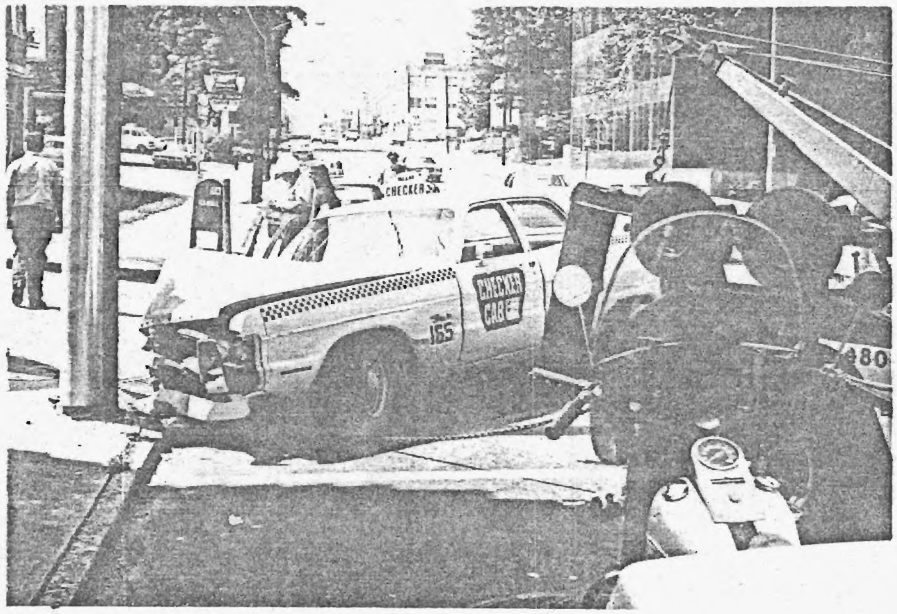


Figure 6. Photographs of Hood Latch Malfunction.



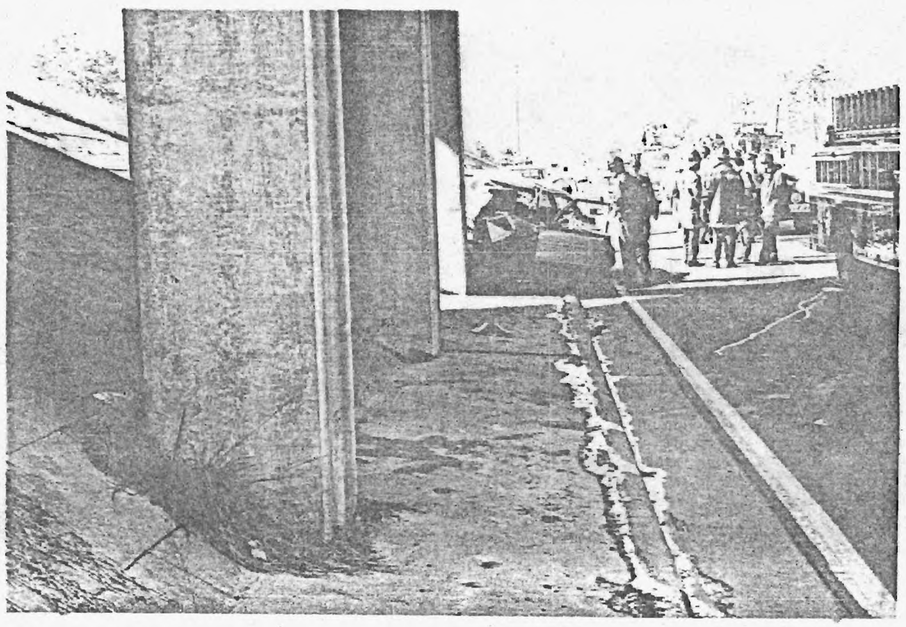
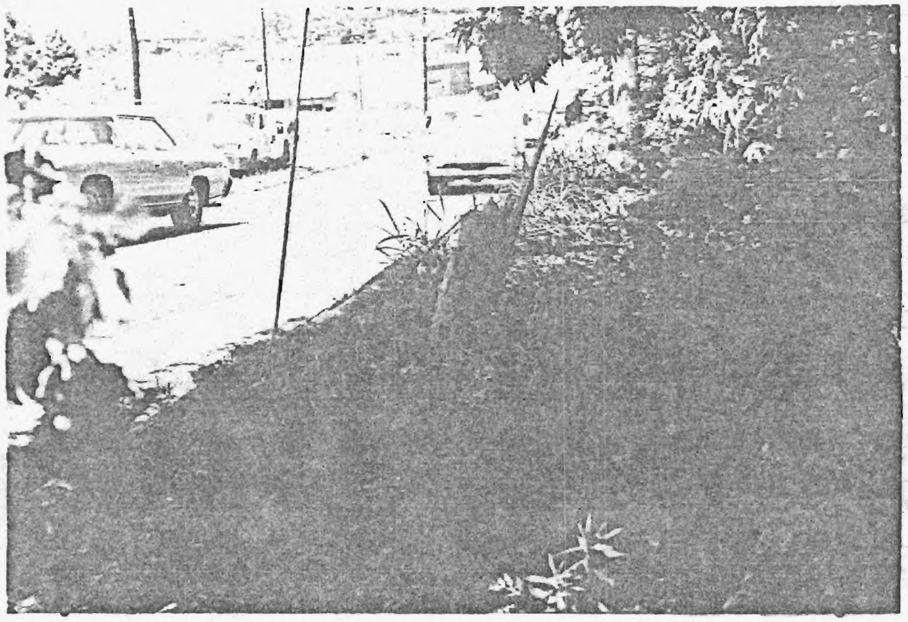


Figure 7. Photographs of Poles and Bridge Supports Struck in Phase 6.



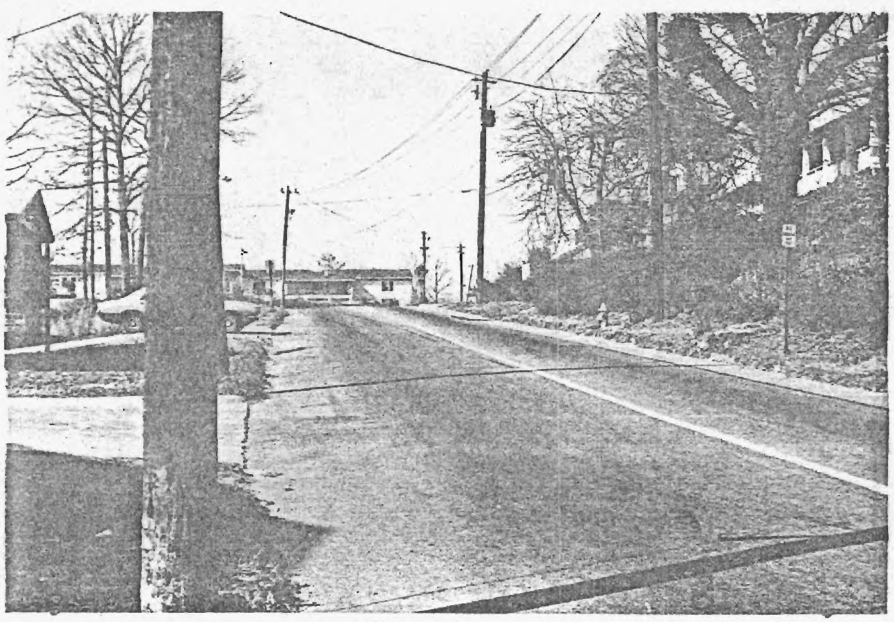


Figure 7 (Continued). Photographs of Poles and Bridge Supports Struck in Phase 6.

were not injured or received only minor injuries. Six occupants received non-dangerous, moderate injuries (severity code 02), and three received dangerous injuries (severity codes 04 and 05). Seven of the victims were fatally injured.

Only two of the 59 victims were wearing both lap and shoulder belts, and 12 were wearing lap belts. The small number of cases investigated precluded any analysis of the effectiveness of seat belt usage.

Typical traumas observed during this phase included injuries to the chest caused from impacting the steering wheel, head and facial injuries which usually resulted from contact with the steering rim or windshield, and knee and lower leg injuries caused from impacting the instrument panel. The steering wheel was the most frequently identified injury producing agent and the lower instrument panel ranked second. See Table 10.

Evaluation of Standards.

Sixty-eight comments were made in the case reports during this phase relating to safety standards. Forty-eight related to the Highway Safety Program Standards and twenty referred to Federal Motor Vehicle Safety Standards. Lists of the standards which were identified as being relevant to the case studies are given as Tables 11 and 12.

Table 10. Number of Injuries Classified by Object Struck and Seat Belt Usage.

Object Struck	Drivers		Passengers	
	No.	No. Using Seat Belt	No.	No. Using Seat Belt
Other Vehicle	2	0	0	0
Steering Wheel	15	4	0	0
Windshield	3	0	1	0
A-Pillar	3	0	0	0
Instrument Panel	1	0	2	0
Lower Dash	10	3	2	0
Rearview Mirror	1	0	1	0
Other	11	2	2	0
Unknown	7	1	3	1

Table 11. A List of Highway Safety Program Standards Identified as Being Relevant to Accident Cases.

HSPS No.	Description	No. of Cases	Applicable Case Nos.
1	Periodic Motor Vehicle Inspection	7	103,104,106,108, 113,116,118
2	Motor Vehicle Registration	1	116
3	Motorcycle Safety	1	101
4	Driver Education	7	102,110,112,114, 116,119,121
5	Driver Licensing	5	101,102,111,114, 115
8	Alcohol in Relation to Traffic Safety	2	109,122
9	Identification and Surveillance of Accident Locations	1	104
10	Traffic Records	3	110,119,121
11	Emergency Medical Services	2	104,112
12	Highway Design, Construction, and Maintenance	6	109,112,113,119, 120,122
13	Traffic Control Devices	7	101,105,108,110, 117,121,122
14	Pedestrian Safety	1	110
15	Police Traffic Services	2	108,118
16	Debris Hazard Control and Clean-up	3	105,114,116

Table 12. A List of Federal Motor Vehicle Safety Standards Identified as Being Relevant to Accident Cases.

FMVSS No.	Description	No. of Cases	Applicable Case Nos.
111	Rearview Mirror	1	108
113	Hood Latch Systems	1	106
121	Air Brake Systems	1	106
201	Occupant Protection in Interior Impact	3	103,105,117
203	Impact Protection Steering Control System	5	102,104,110, 112,113
205	Glazing Materials	1	110
208	Seat Belt Installation	1	103
209	Seat Belt Assemblies	1	112
212	Windshield Mounting	1	119
214	Side Door Strength	2	110,122
575	Consumer Information	2	103,114
---	Lack of FMVSS covering Truck Fuel Tanks	1	121

CHAPTER IV

OBSERVATIONS, CONCLUSIONS, AND RECOMMENDATIONS

Members of the Georgia Tech multidisciplinary research team have now completed in-depth studies of 122 vehicular accidents which occurred during a 52-month period. These case studies, which were performed by qualified professionals, form a valuable basis for understanding the nature and effects of vehicular crashes. This chapter presents observations and conclusions of the team based on all 122 investigations. Of course, it is not possible to establish a statistical level of confidence for these conclusions, nor do these statements apply to vehicular accidents generally. It should be remembered that the research sample was selective. Specifically, the crashes involved predominantly late model vehicles and a wide distribution of drivers. The crashes were well distributed over time, and all but four occurred in metropolitan Atlanta. Very few pedestrian accidents were studied, and the minor "fender bender" crashes were excluded from the investigation.

After the following observations on factors which contribute to vehicular crashes, recommendations for specific remedial actions are given.

Factors Which Contribute to Vehicular Crashes

Many vehicular crashes are complex events which are triggered by a combination of two or more factors. The Atlanta team identified a total of 231 factors for the 122 crashes. Sixty-one percent of the investigations conducted thus far involved two or more causative factors, and three or more contributing factors were identified in 20 percent of the cases.

No. of Factors Identified	No. of Cases
1	47
2	51
3	16
4	6
5	2

Human Factors.

It is clear that human factors constitute the most prevalent type of contributing factors. About 64 percent of the 231 factors identified were human factors, and at least one human factor was identified in 107 of the 122 cases. It is significant, however, that only 48 percent of these cases were attributed to human factors alone. That is to say, in 52 percent of the cases, the accident could have been prevented by removing a vehicular or environmental factor.

Violation of safe driving practices account for many crashes. A substantial percentage of vehicular crashes result from a variety of driver malfunctions and conditions. Driver inattention or distraction, excessive speed, and violation of other safe driving practices appear to be recurring contributing factors.

A multidisciplinary team at the Cornell Aeronautical Laboratory observed(9):

> The driving task provides a multitude of opportunities for the driver to fail. He is the only active and intelligent component of the transportation system and as such is expected--and is required--to use his intelligence to control the movement of individual vehicles. Because proper vehicle control requires the driver to continually survey his environment and vehicle for bits of pertinent information, interpret the message contained therein, make decisions in order to adjust his driving pattern in accordance with these interpretations, physically control the vehicle, and in addition perform these subtasks within a short time period, the possibilities for driver mistakes and failures become legion. It is, in fact, remarkable that the highway transportation system operates as well as it does.

Vehicular Factors.

The results of the Atlanta study suggest that vehicular factors contribute to about one-fourth of all crashes, although as many as one-half of the vehicles involved in crashes may have vehicular deficiencies. Since the study focused on crashes involving late model vehicles, vehicular factors may play an even greater role in accident initiation than shown by this research. It is significant, however, that vehicular factors typically occur jointly with human factors and/or environmental factors. In only seven percent of the cases was a vehicular factor solely responsible for the accident. It is also interesting to note that eighteen of the 30 vehicular factors could be classified as vehicular conditions as opposed to vehicle malfunctions or failures.*

Environmental Factors.

The results of this research indicates that although environmental factors contribute to about 36 percent of crashes, they are rarely explained by environmental factors alone. While a crash may result from a natural disaster or a malfunction in the highway or its appurtenances, these events are uncommon indeed. In a multidisciplinary study of 434 accidents, Tharp, et. al. (9) observed only one malfunction or total failure in the highway facilities (a burned-out traffic signal light). In the Georgia Tech study, environmental factors appeared in 42 of the 122 investigations, and as a joint principal contributing factor in 41 of these cases. These factors included such problems as wet roadway, missing or improper traffic control devices, and in a few cases, incredibly poor geometric design.

Remedial Programs in Traffic Safety

Alcohol and Traffic Safety (HSPS No. 8).

Alcohol is a major factor in accident initiation. It appeared in 22 percent of the total cases investigated by the Georgia Tech team. In comparison, researchers have consistently shown that alcohol contributes to about half of all fatal crashes (10). It should be remembered that the Atlanta research program included investigations of personal injury and property damage accidents as well as fatal crashes. It has been estimated (10) that alcohol contributes to about six percent of run-of-the-mill crashes (including "fender benders" which were excluded from this investigation). Alcohol was listed as a contributing factor in 33 percent (8 of 24) of the fatal cases investigated, and during this phase alone, the two cases in which alcohol was a factor resulted in five deaths.

Recommendations.

1. It is recommended that the Georgia implied consent law be amended to provide that a blood alcohol level of 0.05 percent be presumptive evidence that the defendant was under the influence of intoxicating liquor.

* Tharp, et. al. (9) define "malfunctions" as failures to perform as designed or intended and "conditions" as those items which require special consideration, adjustment to, or compensation for, by the driver.

2. Certain violators have found that it is possible to circumvent the implied consent law by pretending to be unable to fill the intoximeter cylinder. Legislation designed to prevent such circumvention of the implied consent law is recommended.

3. Under Georgia law, a driver charged with driving under the influence of alcohol may plead nolo contendere, the effect of which is to subject the defendant to conviction without admitting guilt to the charges. The nolo contendere plea has been used by drivers charged with driving under the influence in order to avoid the mandatory revocation of the driver's license required for drivers convicted of D.U.I. Two laws were passed in 1971 to prevent abuses relating to the habitual use of the nolo contendere plea, restricting its use without mandatory license suspension to the first D.U.I. charge. The use of the nolo contendere plea is unjustifiable even for the first D.U.I. charge, and legislation to prohibit such use is recommended.

4. The difficulties in identifying and controlling drunk drivers have been demonstrated during this study. Two intoxicated drivers initiated accidents (case numbers 109 and 122) in which a total of five persons were killed. While educational and punitive approaches to the drinking-driver problem may be useful, further research is needed in the development of a device that will prevent an intoxicated driver from driving his vehicle.

Driver Education (HSPS No. 4).

In four cases investigated during this phase (accident numbers 102, 112, 119 and 121), the Atlanta team found that drivers were not able to meet the demands of the driving task due to a basic lack of knowledge and understanding of driving. In two of these cases (numbers 112 and 119) the drivers had completed driver education courses.

Comments and Recommendation. These findings suggest that there are inadequacies in present driver education courses. Basic research in course material and teaching techniques for driver education appears to be necessary and, in light of the high costs of these programs, long overdue.

Driver License Classification (HSPS No. 5).

One of the accidents investigated during this report period (case no. 114) suggests that there is a need for special testing and licensing of drivers who operate vehicles which tow boats and recreational trailers.

Comments and Recommendation. Georgia legislation passed in 1972 classifies driver licenses into five classes: 1) automobiles, 2) motorcycles, 3) motor vehicles 80 inches and wider designed to carry more than 10 passengers and used as a common or contract carrier, 4) trucks licensed and registered for 24,000 pounds or more gross weight, and 5) tractor-trailers. In view of the increasing prevalence of automobiles towing trailers, it is recommended that the license classification law be modified to provide for special testing and licensing of drivers who operate vehicles which tow trailer vehicles.

Driver Re-Examination (HSPS No. 5).

One of the cases investigated (no. 115) by the research team involved an 86-year-old driver with poor eyesight and health problems (syncopal episodes secondary to a cardiac condition). In another investigation, it was suspected that the driver's state of health may have precipitated the crash. These cases demonstrate the need for strengthening of the driver licensing law.

Comments and Recommendation. The new Georgia licensing law, which becomes effective January 1, 1973, requires all Georgia drivers to be examined every four years for visual acuity. Passage of this legislation is an improvement towards greater compliance with Highway Safety Program Standard no. 5.

House Bill 57, which was considered but not passed by the 1971 General Assembly, would have created a 16-member Medical Advisory Board to assist the Department of Public Safety on issuance or suspension of drivers' licenses when medical questions are involved. The Georgia Tech research team has previously stated the need for medical supervision of certain aspects of the driver licensing program (4). Passage of this or a similar bill would bring the state into greater compliance with Highway Safety Standard no. 5, and such passage is recommended.

Motor Vehicle Inspection (HSPS No. 1).

The results of this study suggest that the Georgia Motor Vehicle Inspection law may be failing to detect vehicles with existing or potentially hazardous conditions. During this phase alone, the research team found three accident-involved vehicles with invalid motor vehicle inspection stickers and these violations were either overlooked or ignored by investigating officers. In addition, three vehicles were discovered with valid inspection stickers but with a hazardous condition which violated the motor vehicle inspection law.

Comments and Recommendation. The current motor vehicle inspection program in Georgia is an expensive countermeasure which apparently is not effective either in providing timely detection of relatively minor mechanical problems which develop over a short period of time or of identifying serious component degradation which occurs with vehicle aging. The current annual inspections are too infrequent to deter owners from operating vehicles with defects which occur precipitously or which develop over a short period of time (e.g., broken windshields, burned out lamps, and badly worn tires). On the other hand, the general shallowness of the inspection now performed make it unlikely that vehicular deficiencies relating to component degradation will be identified. It is recommended that the Georgia Motor Vehicle Inspection law be rewritten. Specific recommendations for changes in the inspection law were given in a previous report(5).

Design of Vehicle Interiors (FMVSS No. 201).

There is increasing evidence that design improvements incorporated in vehicles manufactured since 1968 are resulting in significant reductions in injuries and the number of deaths in crashes. The research team has been particularly well impressed with the crash performance of windshields in late model automobiles. Injury reductions due to improved design of the vehicle interior have been noted in several cases.

Comments and Recommendation. Further improvements are needed in interior vehicle design to provide better protection for unrestrained occupants in head-on type impacts. More attention needs to be given to the designing of the lower edge of the instrument panel and the area beneath the instrument panel to decrease the number and level of injuries to lower limbs. Knee and ankle injuries caused by entanglement with brake pedal or accelerator would indicate the need of a redesign in these two basic features of the interior compartment.

Side Impact Compartment Intrusion (FMVSS No. 214).

During this research program, it has become evident that current automobiles subjected to center side impacts provide inadequate protection to the driver and passengers. This is generally true even in those instances where seat belts have been used. Excessive lateral compartment intrusion has been noted even in cases involving low to moderate impact speeds. It seems unlikely that restraint systems can be devised to adequately protect the individual on the impacted side in a lateral penetration collision.

Recommendation. It is recommended that a high priority be assigned to the designing of side structures and vehicle interiors of automobiles to provide better protection to occupants in side impact crashes. Specifically, consideration should be given to better padding of roof rails and the use of laminated glass in doors.

Collapsible Steering Columns (FMVSS No. 203).

The results of this study indicate that energy absorbing steering columns are not consistently effective. The team has conducted one investigation in which the proper performance of the energy absorbing column was credited with saving the life of the driver, and there have been several instances in which the level of injury has been reduced. On the other hand, there have been numerous cases in which the steering failed to properly collapse. There were four such instances in this phase alone (accident numbers 102, 104, 112, and 113).

Comments and Recommendation. Members of the Atlanta team have noted that steering column energy absorbing devices do not function properly unless struck in a head-on position within a narrow range of directions. Impacts by occupants in a direction outside this range often result in the bending rather than collapsing of the energy absorbing device. Further research to improve the performance of energy absorbing steering assemblies is recommended.

Restraint Systems (FMVSS No. 208).

The Atlanta research has identified numerous instances in which the use of seat belts would have lessened the severity of injuries of occupants involved in a crash. There were eight such instances in this phase alone (accident numbers 102, 105, 108, 112, 115, 117, 118, and 121).

Comments and Recommendation. One of the most discouraging aspects of the traffic safety picture is the indifference of the travelling public to the use of seat belts. As was previously reported(5), an Atlanta survey indicated that only about one-third of the drivers were using lap belts. During the seat belt survey, it was observed that the shoulder belts being used were predominantly the three-point type where the lap and shoulder belt could not be used separately.

Although the Atlanta team has not attempted to learn why vehicle occupants do not wear seat belts, it would seem that a major deterrent to their use is one of design. Use of seat belts in most vehicles today requires deliberate and often difficult and time-consuming efforts on the part of the user.

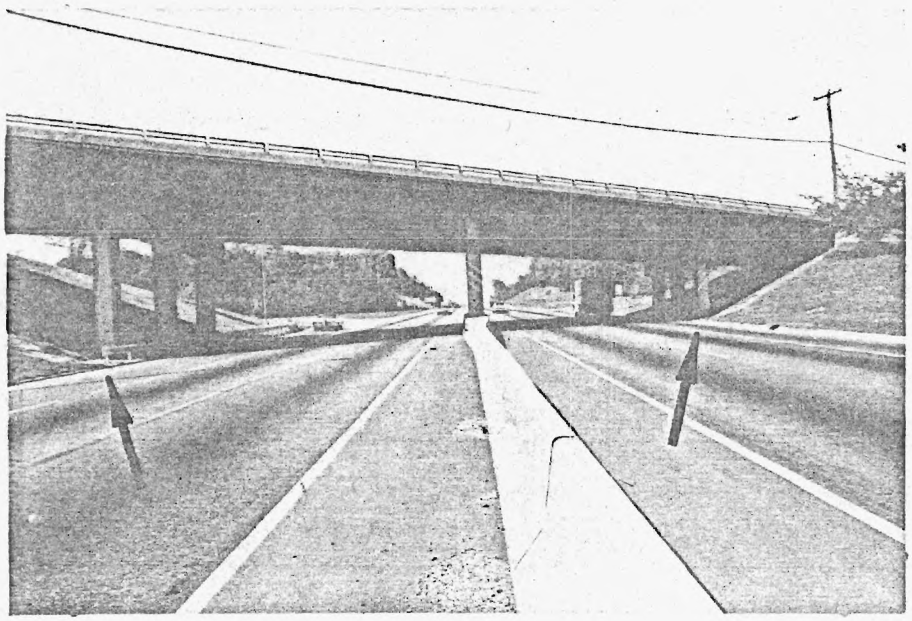
In the long run, it appears that a passive restraint system may be required to significantly reduce the injuries and the number of deaths in moderate and high speed crashes. In the meantime, until the suitability of air bags or other passive restraint systems have been proven, seat belt systems should be designed so as to facilitate their use.

Environmental Countermeasures (HSPS No. 12).

The need for remedial programs to improve the roadway environment is shown by the fact that environmental deficiencies were reported in 75 of the 122 cases investigated. Sixty-nine of these cases occurred on expressways, arterials, or collector streets.

Comments and Recommendations. These findings seem to indicate that these heavily-travelled and relatively high speed roadways have numerous characteristics which are hostile to the driving population, and that roadway improvements have not kept pace with traffic growth and increases in vehicle speeds. Yet, roadway safety improvements are being made, particularly on streets and highways in the Federal-aid system. Significant safety improvements have been made to the expressway system in metropolitan Atlanta including installation of median barriers, clearance of roadside areas, and the installation of breakaway sign supports. There is some evidence, however, that the needed highway safety improvements that remain are being made on a piecemeal rather than a systematic basis. For example, there have been instances in which safety improvements have been made on one side of a roadway and overlooked on the other side. See Figures 8 and 9.

In contrast to Federal-aid roadways, it appears that few safety improvements are being made on local streets and highways. It has been



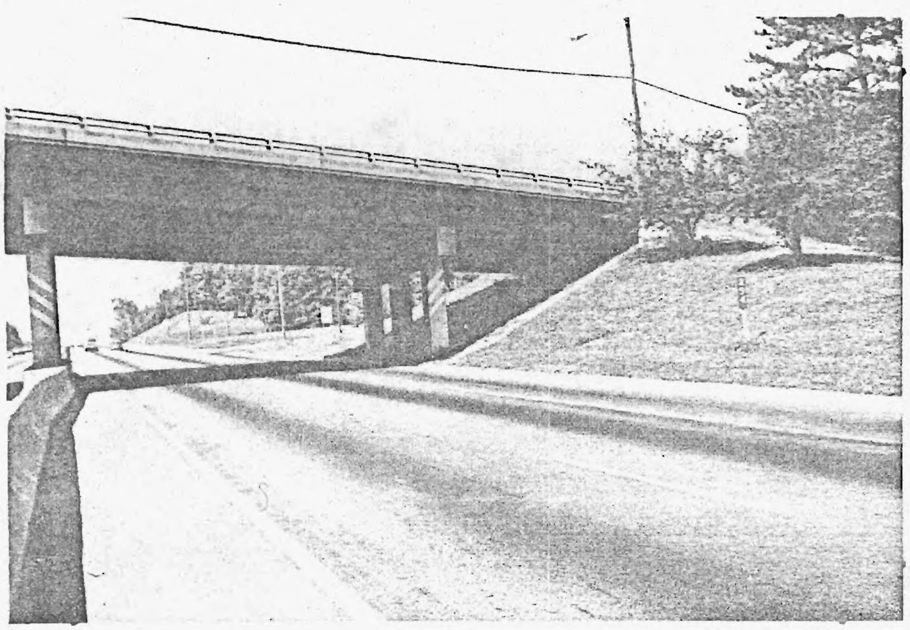


Figure 8. Photographs of Spot Roadside Improvements at Location of Accident No. 113.

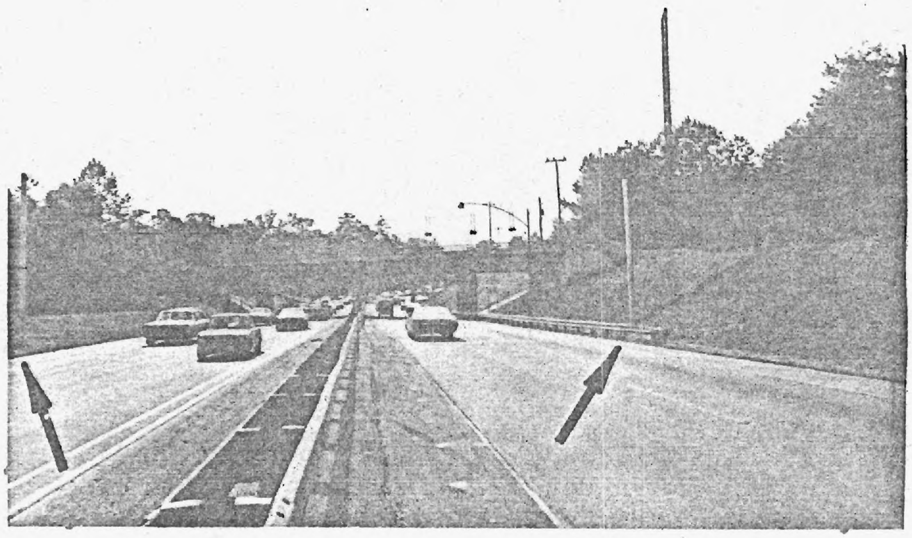


Figure 9. Photographs of Spot Roadside Improvements at Location of Accident No. 85.

observed that there are numerous safety hazards on local streets and highways resulting from easily identifiable design deficiencies. It is believed that the benefits to be gained from correcting these deficiencies would far exceed the costs of the improvements. A Federally-assisted Program for the Improvement of Local Roads for Safety (with the acronym PILRS) similar to the TOPICS program is recommended to correct these hazards.

Finally, it should be noted that the problem of unsafe roadways relates more to inadequate finance and insufficient concern on the part of public officials than to a lack of technology. The techniques of providing suitable roadway geometric design features have been well understood by street and highway designers for several decades. There has been a substantial amount of research and development work relating to highway safety design and operating practices and this work has been well documented(11). These design improvements include the provision of clear roadside areas and the utilization of breakaway sign supports, protective guardrail, energy absorbing barriers, and improved drainage structures.

A comprehensive and thorough program to improve all the safety features of the driving environment is obviously an extremely expensive undertaking, and cannot be quickly accomplished. Nevertheless, it is apparent that continuing remedial programs with established priorities are needed to bring about a safer driving environment in spite of the limited amount of funding.

Medically Related Countermeasures (HSPS No. 11).

During this study certain progress in injury severity reduction has been noted, not only in the packaging of the passenger but also in the transportation and care of the injured. Unfortunately, many of the same problems exist and the degree of progress in emergency care management is not satisfactory. Difficulties of rendering timely first aid and suitable emergency medical services were noted in three accidents studied during this phase (accident numbers 104, 112, and 122).

Comments and Recommendations. With matching funds through grant projects of the Department of Transportation and the Office of Highway Safety Coordinator, the number of ambulances in the Atlanta area have been significantly increased during the study period. Direct communication between the emergency rooms of Grady Hospital and the ambulance have provided more direct medical attention to the injured.

A major problem still exists in the routing of the injured. Custom prevails that the ambulance carry the injured to the hospital of choice if the injured so requests. Since certain of the hospitals do not have full time physicians nor the expertise in trauma management, delay of definitive care does exist. Further delay is caused by walk-in non-emergency patients at these clinics, and on occasions overloading of the emergency facilities with true emergencies causes undesirable delays. The lack of centralized overall management of emergency care units remains, and correction of this need does not seem likely in the immediate future.

With regard to the medical care of the injured, it appears that better training of physicians in total care of the injured is necessary. Certain hospitals are equipped and staffed to care for the critically as well as the not so critically injured. The design and function of other hospitals is not such that duplication of all services should be available. Proper routing of emergency injuries would correct this particular problem. It is recommended that a community plan be developed to allocate medical facilities and personnel to provide proper emergency medical services. Such a plan would establish well-staffed trauma care centers to which victims of all accidents could be transported to receive prompt emergency medical care.

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PART II

FINAL REPORT

PROJECT E-20-620

RELATIONSHIPS BETWEEN OFF-ROAD FIXED-OBJECT ACCIDENT RATES AND ROADWAY ELEMENTS OF URBAN HIGHWAYS

GEORGIA TECH VEHICULAR COLLISION RESEARCH TEAM

Paul H. Wright, Ph.D., Principal Investigator
King-Kuen Mak, M.S., Research Engineer

Prepared for
U. S. Department of Transportation
National Highway Traffic Safety Administration
Washington, D. C. 20591

September, 1972

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Prepared for the
U. S. Department of Transportation
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15. Supplementary Notes

16. Abstract

This report describes the results of a study of the relationships between accident rates and traffic and roadway elements of urban streets. The research was performed as a special pilot study by the Georgia Tech Vehicular Collision Research Team.

Thirty one-mile sections of arterial and collector streets in Atlanta, Georgia, were selected for study. By means of aerial photographs and field surveys, data were collected on ten roadway and traffic characteristics. Rates of single-vehicle, off-road, fixed-object accidents and total accidents (all types) were determined by an examination of police accident records for four years. Correlation and factor analyses, simple linear regression, and stepwise multiple linear regression were used to establish relationships between roadway and traffic characteristics and accident rates.

17. Key Words	18. Distribution Statement
Traffic accidents; single-vehicle accidents; traffic and roadway elements; factor analysis; stepwise multiple regression.	Releasable to the public.

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ABSTRACT

This report describes the results of a study of the relationships between accident rates and traffic and roadway elements of urban streets. The research was performed as a special pilot study by the Georgia Tech Vehicular Collision Research Team.

Thirty one-mile sections of arterial and collector streets in Atlanta, Georgia, were selected for study. By means of aerial photographs and field surveys, data were collected on ten roadway and traffic characteristics. Rates of single-vehicle, off-road, fixed-object accidents and total accidents (all types) were determined by an examination of police accident records for four years. Correlation and factor analyses, simple linear regression, and stepwise multiple linear regression were used to establish relationships between roadway and traffic characteristics and accident rates.

It was found that off-road accident rates were most closely related to average daily traffic (ADT), pavement width, vertical alignment, and the number of fixed objects per mile. The rate of total accidents was closely related to ADT, speed limit, vertical alignment, and the number of intersections per mile.

It was concluded that complex inter-relationships exist between average daily traffic, general class of roadway, and land use.

CHAPTER I

INTRODUCTION

In Atlanta, 8.6 percent of the crashes involve single vehicles, but 32.3 percent of the traffic deaths occur in single vehicle accidents. Similar data have been reported for other urban areas. Data reported by Baker(1) indicates that for urban areas single-vehicle accidents are more than four times as likely to result in deaths as other motor vehicle accidents.* Thus, the problem of single-vehicle crashes is far more serious than is indicated by accident rates alone.

> But there is a more significant reason for paying special attention to single-vehicle accidents. They represent, in the simplest form, failure of the road-vehicle-driver transportation system to perform properly. Studying them to learn about accident causes avoids the difficulty of having to decide how each of two or more vehicles contributed to an accident.(1)

Single-vehicle accidents may include accidents of the following types:

1. vehicle ran off road and struck fixed object
2. vehicle ran off road and overturned
3. vehicle overturned on road
4. vehicle collided on road with fixed object

In 1971, a study was undertaken at the Georgia Institute of Technology of the relationships between single-vehicle, off-road, fixed-object accidents (i.e. the first type of single-vehicle accidents) and roadway elements of urban highways. Accidents in which an out-of-control vehicle struck an off-road fixed object and then overturned were included in this category. It should be noted that these single-vehicle accidents were also "lone vehicle" accidents. Accidents in which the damaged vehicle left the roadway to avoid another vehicle were not included in this investigation.

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* There is reason to suspect that this statement is an exaggeration. Discussing a paper by Penn(2), Baker pointed out that minor one-car accidents are probably much less fully reported than multiple-car accidents because of the desire of drivers in the latter instance to get the accident on record for claim settlement purposes.

This project was performed as a special pilot study by the Georgia Tech Vehicular Collision Research Team under contract with the National Highway Traffic Safety Administration. It was prototypal in concept and scope and subordinate to multidisciplinary accident investigations performed under the same contract.(3)

Such a study of single-vehicle accidents provides an opportunity to evaluate the effect of roadway design features on accident occurrence. One would expect that narrow pavements, sharp curves, frequent grade changes, and similar undesirable design features would increase the rate at which vehicles leave the traveled way. It also seems reasonable to hypothesize that the frequency of single-vehicle accidents (particularly off-road, fixed-object accidents) are affected by the number of fixed objects per mile and the proximity of these objects to the pavement edge. The presence of numerous poles, trees, and other fixed objects near the edge of the pavement make it unlikely that the driver of an out-of-control vehicle will regain control and avoid a crash.

The primary objective of this study was therefore to examine the relationships between single-vehicle, off-road, fixed-object accidents (hereafter referred to as off-road accidents) and roadway design elements. A secondary objective was to develop equations for the prediction of these accident rates on urban roadways.

CHAPTER II

BACKGROUND

Several research studies have been undertaken to determine relationships between roadway accidents and highway traffic and design characteristics. These studies have been similar in concept and design. Typically, they have involved making inventories of traffic and geometric design features for a selected number of highway sections and determining accident rates for these studies from police accident reports. In most of the previous studies, linear multiple regression equations have been developed relating total accidents per mile or per vehicle mile to various measures of traffic and roadway design characteristics. Several of the previous research studies are briefly described in the following paragraphs.

A study was conducted in 1957 by the Oregon State Highway Department(4) of the relationship between total annual accidents per mile and roadway elements of rural two-lane highways. Using a sample of 1,400 miles of roadway, equations were developed for the prediction of accidents from roadway elements such as average daily traffic (ADT), lane width, shoulder width, sight distance restrictions, and the presence of driveways and intersections. Separate equations were reported to allow for geographical differences and for various ranges of average daily traffic. Regression equations were also given for non-intersectional accidents. It was concluded that traffic volume is the most important predictor of traffic accidents, that points of access are second in importance, and other design features third. It was further stated that on highways which have a primarily local service function, accidents are more closely related to the design features of the road than on "long haul" highways.

A similar study(5) was reported in 1959 for urban extensions of state highways in Oregon. In that study, traffic accidents per vehicle mile were related to ADT, commercial and residential units, driveways, intersections, traffic signals, traffic speed, pavement width and the number of lanes. The study utilized a sample of 426 roadway sections averaging about 0.4 mile in length. In order of importance, the following predictors of accident rates for urban highways were: 1) the number of commercial units adjacent to the section; 2) number of traffic signals; 3) number of intersections; 4) indicated speed; 5) ADT; and 6) pavement width.

Cribbins, et. al.(6) reported in 1967 of a study of the effects of certain roadway and operational characteristics on accidents in multi-lane highways. Accident data were collected for 92 highway sites, including a total of over 6,000 accident reports. Eight highway characteristics were correlated with all injury accidents: median width, speed limit, volume, level of service, access-point index, intersection openings per mile, signalized openings per mile, and median openings per mile. The significant independent variables were: 1) access-point index; 2) signalized openings per mile; 3) speed limit; 4) volume; and 5) level of service.

In a 1968 NCHRP study(7), accident rates were related to highway types and highway design elements using data from five states. Phase I of the study related number of accidents to segment length and average daily traffic using regression analysis techniques on a logarithmic model. Four specific highway geometric features, considered in binary form, were then studied in Phase II.

1. Grade: under 4%, 4% and over.
2. Curvature: under 4°, 4° and over.
3. No intersections, one intersection or more.
4. No structures, one structure or more.

Graphs were provided relating ADT to the annual number of accidents per 0.3 mile segment. The report concluded:

1. That the number of one-vehicle accidents decrease with increased ADT.

2. The presence of gradient, curves, intersections, and structures increase accident rates and that the single-vehicle accidents rate is primarily affected by the presence of curvature or structures.

3. The larger the number of roadway factors simultaneously present, the higher the accident rates.

4. The partitioning of gradient and curvature by magnitude above 4% and 4° respectively, showed no change in the effect on accident rates, i.e. consideration of these factors in binary form was judged to be satisfactory.

Chapman(8) examined accident data for a 29-mile section of the Pacific Highway in New South Wales for which the ADT was practically constant throughout its length. He concluded that at most half of the accidents for this road occurred at random locations and the remainder could be associated with the design of the road. Chapman further reported that the percentage of accidents which involve only one vehicle decreases exponentially with increasing flow, based on a study of injury accident data for a New Zealand "dual carriageway" (4-lane expressway) without intersections.

A study(9) was conducted in 1970 by Louisiana State University to determine the contribution of roadway geometry to accidents and to predict the accident potential of sections of Louisiana highways. Using a sample of 1,000 miles of rural highways and accident records covering a 5-year period from 1962 to 1966, equations were developed for the prediction of total accidents from 10 roadway variables, namely percentage of trucks, traffic volume ratio, lane width, shoulder width, pavement cross slope, horizontal alignment, vertical alignment, percentage of continuous obstructions, marginal obstructions per mile, and traffic access-points per mile. The study concluded:

1. That only 46 percent of the variations in accident rates is explained by the geometric factors.

2. That the two geometric variables appearing to have the most important effect on accident rates, based on their interactions with traffic volume, are pavement cross slope and the number of traffic conflicts per mile.

3. That the factors of continuous obstructions, marginal obstructions, and their interaction terms had the least effect on accidents, indicating that the variation in accidents was least caused by obstructions off of the right-of-way.

To summarize, several previous studies have been undertaken similar to the present study. Most of these studies have been concerned with rural highways, and practically all of them have been concerned with total accident rates exclusively. The major findings and conclusions of these previous studies were:

1. The following roadway and traffic characteristics appeared to have significant effects on accident rates.

(i) average daily traffic volume.

(ii) number of access (conflict) points, including number of intersections, both signalized and unsignalized, and the number of driveways.

(iii) design features of the roadways, such as vertical alignment, horizontal curvature, pavement width, and speed limit.

2. Two studies(8,9) indicated that less than 50 percent of the variations in accident rates were explainable by roadway and traffic factors.

3. The Louisiana study(9) concluded that the presence of fixed objects along the roadway had little effect on accident rates.

CHAPTER III

METHODOLOGY

Scope of Study

Thirty sections of streets in Atlanta, Georgia, were selected for study, the number being limited by available time, personnel and financial resources. Each of the sections was approximately one mile in length. The sections were selected from arterial and collector streets, and an attempt was made to obtain a reasonable geographical distribution of locations throughout the city as shown in Figure 1. Criteria for selection of the segments was based on the need to provide reasonably uniform roadway features and traffic volumes throughout the segment. To facilitate collection of data from police accident files, section termini were chosen at street intersections. A list of the streets studied is given in Table 1.

Roadway and Traffic Variables

Ten roadway and traffic characteristics were identified for the analysis:

X_1 - Total pavement width, (feet)

X_2 - Number of lanes

X_3 - Speed limit, (miles per hour)

X_4 - Horizontal curvature, (degrees per curve)

X_5 - Vertical curvature, (percent per station)

X_6 - Number of intersections per mile

X_7 - Number of driveways per mile

X_8 - Continuous objects, 0-10' from pavement edge, (stations)

X_9 - Number of discrete objects, 0-10' from pavement edge

X_{10}- Average daily traffic, (per 1,000 vehicles)

As-built drawings were not available for these 30 roads, and practically none of the desired roadway data was available from the city engineering office or the State Highway Department. It was therefore

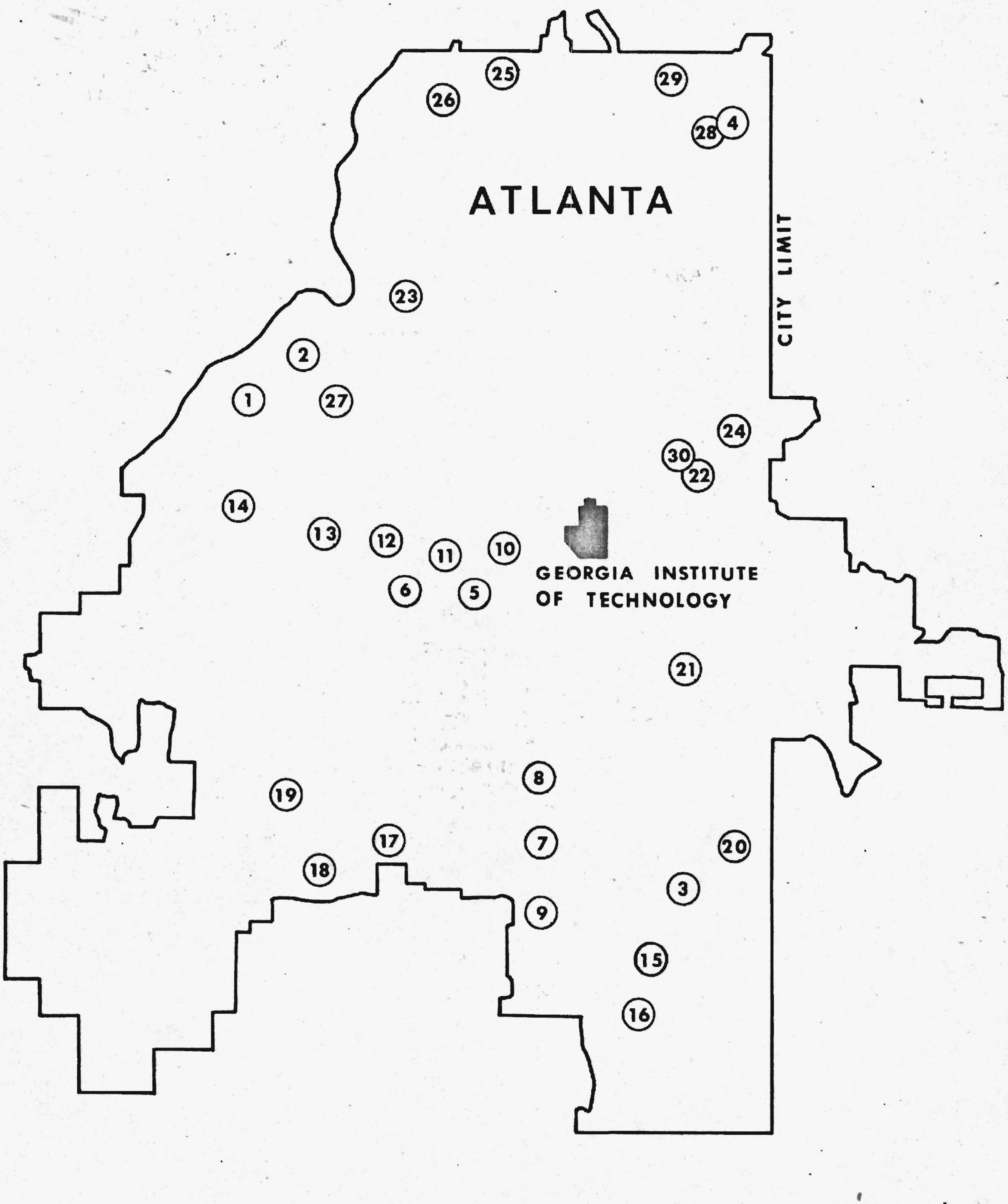

Figure 1. A Sketch of the Study Area.

Table 1. A List of the Streets Studied

Sec. No.	Street Name	Termini		Length of Sec., Mile
		From	To	
1	Bolton Rd.	J. Jackson Pkwy.	Northwest Dr.	0.99
2	Bolton Rd.	Marietta Rd.	J. Jackson Pkwy.	1.12
3	Jonesboro Rd.	Constitution Rd.	Sawtell Ave.	1.30
4	P'tree-Dunwoody Rd.	Peachtree Rd.	Carmain Dr.	1.24
5	Simpson Rd.	Ashby St.	Chappel Rd.	0.97
6	Simpson Rd.	Chappel Rd.	Dixie Hills Cir.	0.97
7	Stewart Ave.	Fair Dr.	Manford Rd.	1.09
8	Stewart Ave.	Manford Rd.	Shelton St.	1.21
9	Stewart Ave.	Perkerson Ave.	Fair Dr.	1.30
10	Bankhead Hwy.	Northside Dr.	Glass St.	0.93
11	Bankhead Hwy.	Glass St.	Florence Pl.	1.05
12	Bankhead Hwy.	Florence Pl.	Wood St.	1.07
13	Bankhead Hwy.	Wood St.	J. Jackson Pkwy.	1.05
14	Bankhead Hwy.	J. Jackson Pkwy.	I-285	1.38
15	Browns Mill Rd.	McWilliams Rd.	Cleveland Ave.	0.90
16	Browns Mill Rd.	Cleveland Ave.	Oak Dr.	1.06
17	Campbellton Rd.	Kenilworth Ln.	Pinehurst Dr.	1.05
18	Campbellton Rd.	Delowe Dr.	Dodson Dr.	1.16
19	Cascade Rd.	Beecher Rd.	Veltre Cir.	1.03
20	McDonough Blvd.	Boulevard	H. Thomas Dr.	1.03
21	Memorial Dr.	Conally St.	Pearl St.	1.14
22	Monroe Dr.	10th St.	Piedmont Ave.	1.18
23	Moores Mill Rd.	W. Wesley Dr.	Coronet Way	1.29
24	E. Morningside Dr. & E. Rock Spring Rd.	Piedmont Ave.	N. Highland Ave.	1.18
25	Mt. Paran Rd.	Northside Dr.	Garmon Rd.	1.14
26	Mt. Paran Rd.	Garmon Rd.	I-75	0.98
27	Perry Boulevard	Hollywood Rd.	Clarissa Dr.	1.40
28	Wieuca Rd.	Peachtree Rd.	Whittington Dr.	1.22
29	Wieuca Rd.	Whittington Dr.	Roswell Rd.	1.14
30	Piedmont Ave.	14th St.	Pelham Rd.	1.32

necessary to collect some of the roadway data by field surveys. Twenty of the surveys were performed by a consultant land surveying firm, and ten were performed by the research team.

For each roadway segment, information was recorded on the section lengths, pavement width, number of lanes, speed limit, and the number of intersections and commercial and residential driveways. An inventory was made of fixed objects within 20 feet from each side of the curb or pavement edge. Lateral distances of fixed objects from the edge of the pavement were measured to the nearest 0.1 foot. Lengths of fences, earth banks, and other continuous fixed objects were recorded as well as lateral distances from the edge of the pavement to these objects.

Longitudinal distances were measured to an estimated precision of 0.5 percent with a model 180T Rolatape measuring device. Specific stations of intersecting streets, driveways, and fixed objects were not recorded, but topographic features were recorded in 100-foot segments. Gradients were measured at each 100-foot station to an estimated precision of 0.1 percent using a special instrument devised by the research team consisting of a four-foot carpenter's level with a calibrated leg.

The curvature of each horizontal curve, expressed in degree of curve, was measured from 1"=200' scale aerial photographs. The following measures of horizontal curvature were considered for the analyses:

1. $\Sigma_1^N D_i$ 2. $\Sigma_1^N D_i/N$ 3. $\Sigma_1^N D_i W_i/N$

where

D_i = the degree of curve for the i^{th} horizontal curve

N = the number of curves in the section

W_i = a weighting factor to allow for the non-linear effect of horizontal curvature on accident occurrence. The following weights, which are based on empirical data reported by Glanville(14), were used:

Degree of Curve	Weight, W
0-3.9	1.0
4-9.9	1.4
10 and over	5.5

The first measure of curvature, $\Sigma_1^N D_i$, was simply the sum of degree of curvature for all curves in the section. The second measure, $\Sigma_1^N D_i/N$, was the average degree of curve in the section. The third measure was a weighted average of all the curves in the section. The third measure of horizontal curvature, judged to be the best measure, was used in subsequent analyses.

A profile of each roadway section was plotted and the algebraic difference in grade and length were measured for each vertical curve. The following measure was used for vertical alignment: $\frac{\Sigma_1^N (A/L)}{NS}$, where

A = algebraic difference in grade, percent

L = length of vertical curve, stations

N = number of vertical curves in the section

S = section length, miles

Several variations of measures of fixed objects were used employing different band widths along the roadside and it was determined that a band width extending 0-10 feet from the pavement edge gave the most satisfactory results.

Average daily traffic data for 22 of the street sections were obtained from the Georgia State Highway Department. An average of the ADT's for 1969 and 1970 was used for these sections. For the remaining streets, estimates of ADT were made from 24-hour machine counts adjusted for seasonal and annual variations.

A summary of the roadway and traffic characteristics data for the 30 sections studied is given in Tables 2 and 3.

Accident Data

Annual single-vehicle, off-road, fixed-object accident rates, which were expressed both on a per mile and on a per million vehicle mile (MVM) basis, were related to these roadway and traffic variables:

Y_1 = single-vehicle, off-road, fixed-object accident rate per mile per year

Y_2 = single-vehicle, off-road, fixed-object accident rate per million vehicle mile per year

Although the examination of total accident*-roadway relationships was not an objective of this research study, it was possible to collect

* Total accidents are defined as all reported vehicular accidents.

Table 2. Roadway and Traffic Data

Sec. No.	Pvmnt. Widths	No. of Lanes	Horiz. Curvature*	Vert. Alignment*	Intersections Per Mile	Driveways Per Mile	Speed Limit (MPH)	ADT
1	30'	2.0	28.90	0.970	10.10	30.30	35.0	11,217
2	30'	2.0	14.46	0.654	8.00	58.90	35.0	18,257
3	30'	2.0	14.94	0.262	6.90	49.20	32.3	11,096
4	30'	2.0	98.56	1.064	6.50	64.50	35.0	10,254
5	32'	3.0	0.0	2.223	12.40	94.0	35.0	12,812
6	30'	2.0	78.11	1.911	12.40	62.0	35.0	11,163
7	40'	4.0	0.0	1.195	9.20	88.10	35.0	17,678
8	40'	4.0	0.0	0.590	10.70	86.80	35.0	17,295
9	40'	4.0	0.0	0.830	7.70	88.50	35.0	17,659
10	40'	4.0	4.20	0.620	17.20	75.30	35.0	21,409
11	40'	4.0	31.26	5.98	15.20	57.10	35.0	20,011
12	44'	4.0	33.21	0.986	18.70	57.00	35.0	17,927
13	40'	4.0	28.52	0.634	16.20	41.00	35.0	15,843
14	29'	2.0	8.77	0.600	9.40	65.90	35.0	12,382
15	30'	2.0	91.30	0.740	7.80	47.80	29.4	3,820
16	30'	2.0	72.20	1.690	5.70	67.00	24.5	5,290
17	29'	2.0	20.19	0.670	9.50	54.30	35.0	10,970
18	29'	2.0	15.48	0.610	7.80	52.60	35.0	10,969
19	34'	2.0	19.21	0.520	6.80	42.80	35.0	6,709
20	30'	2.0	3.98	0.536	10.70	44.70	35.0	11,203
21	50'	5.0	0.0	1.309	18.40	57.00	30.0	14,368
22	41.5'	4.0	39.05	0.791	18.88	99.12	33.0	16,904
23	30'	2.0	51.41	0,880	4.65	67.44	35.0	12,026
24	32.5'	2.0	34.22	1.184	9.32	92.37	25.0	9,780
25	23'	2.0	98.65	0.830	3.50	40.40	23.0	3,180
26	24'	2.0	93.02	0.970	10.20	33.70	30.0	3,180
27	32'	2.0	18.54	0.960	5.71	26.43	35.0	6,500
28	34'	2.0	48.50	0.410	8.20	50.00	35.0	10,150
29	30'	2.0	72.38	0.720	8.80	36.80	35.0	10,150
30	47'	4.2	33.62	0.960	6.82	47.72	35.0	25,450

* Horizontal curvature is expressed in degrees and average vertical curvature in percent/station.

Table 3. Inventory of Roadside Objects.

Sec. No.	Length of Continuous Fixed Objects (Sta./Mile)				Number of Fixed Objects (Per Mile)			
	Offset Distance				Offset Distance			
	0-5'	6-10'	11-15'	16-20'	0-5'	6-10'	11-15'	16-20'
1	12.58	21.02	3.82	1.00	133	83	104	46
2	5.22	6.28	1.72	0.14	224	77	55	24
3	14.48	24.48	1.39	0.37	128	51	28	12
4	9.97	20.91	0.62	0.35	213	137	159	70
5	0.51	18.26	0.43	0.0	148	48	52	22
6	10.80	17.71	11.31	0.28	173	130	111	35
7	0.67	13.17	1.06	0.0	161	61	67	22
8	1.43	25.91	1.40	0.42	176	29	36	20
9	0.24	13.41	1.60	0.54	136	200	99	36
10	0.0	24.80	4.73	0.0	226	96	59	19
11	6.40	15.77	0.86	1.07	219	106	44	14
12	10.24	19.12	0.38	0.64	204	80	50	26
13	2.62	17.14	0.78	0.13	197	102	43	16
14	5.49	2.45	1.49	0.19	130	78	40	21
15	1.66	2.12	4.71	4.28	210	129	86	51
16	3.43	1.66	4.20	1.13	213	92	90	57
17	17.02	13.01	1.79	0.10	152	63	70	31
18	4.10	10.70	3.59	0.42	138	89	86	41
19	4.11	14.95	2.23	0.0	199	47	29	40
20	3.80	25.95	1.12	1.94	179	181	69	37
21	19.40	21.79	1.58	0.73	207	80	38	5
22	0.0	23.40	7.94	0.19	264	34	30	29
23	12.86	6.30	2.70	0.0	167	77	81	40
24	0.0	1.04	4.88	0.0	315	17	42	17
25	14.41	16.89	5.08	0.0	152	154	137	150
26	9.80	8.52	2.40	2.15	150	155	65	105
27	17.10	14.01	4.67	0.71	131	29	16	6
28	2.62	0.60	1.33	0.0	173	69	56	31
29	23.15	12.49	6.03	0.0	177	54	29	8
30	2.78	16.10	2.41	3.20	184	49	46	18

analyze these data with little additional work. Two additional total accident rates were therefore added to the analyses:

T_1 = total accident rate per mile per year

T_2 = total accident rate per million vehicle mile per year

It is the practice of the Atlanta Police Department to place all of the accident records for a given calendar year in inactive status at the end of that year and to discard these records after an inactive storage period of three years. By examining the accident records in December, 1971, and January, 1972, it was possible to obtain accident data for four years:* 1968, 1969, 1970, and 1971. For each of these years, the number of off-road accidents that occurred along the road sections was determined by examining each police report between the section termini and at each street intersection. The total number of crashes that occurred along each section was also recorded. Accident data for the 30 road sections are given in Table 4.

Analytical Techniques

The roadway and accident data was first coded so as to be compatible for computer usage and the data was analyzed statistically using the following analytical techniques:

1. Correlation and factor analysis** were first performed to identify any inter-relationships between the roadway and traffic variables.

2. Simple linear regression and stepwise multiple linear regression analyses were then used to establish relationships between the roadway and traffic characteristics to accident rates. First order interactions and square terms of the roadway and traffic variables were also incorporated in the analyses.

3. The regression models and regression coefficients were tested for their significance. All tests for significance were performed on the basis of a 5 percent significance level.

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* In a study of 21,916 accidents which occurred at 433 rural Illinois intersections over a period of 13 years, May(10) recommended a minimum accident study period of three years and indicated that little accuracy is gained using a longer study period.

** Factor analysis as an analytical technique has been described by Mouchahoir(12). An example of its use to analyze accident data has been published by Allen(13).

Table 4. Accident Data.

Sec. No.	Off-Road Accidents Per Year		Total Accidents Per Year	
	Per Mile	Per Million Veh. Miles	Per Mile	Per Million Veh. Miles
1	4.38	1.0698	22.56	5.5102
2	4.76	0.7143	41.67	6.2532
3	2.88	0.7122	20.96	5.1756
4	3.02	0.8069	17.54	4.6860
5	9.54	2.0400	164.43	3.5162
6	9.28	2.2772	85.31	20.9374
7	2.75	0.4266	57.75	8.1755
8	2.89	0.4582	55.79	8.8370
9	8.27	1.2829	117.88	18.2894
10	11.02	1.4104	154.57	19.7804
11	13.81	1.8907	116.19	15.9078
12	9.35	1.4283	120.09	18.3535
13	12.14	2.1000	80.48	13.9167
14	4.53	1.0021	40.10	80.8988
15	3.61	2.5899	10.83	7.7697
16	4.72	2.4430	14.62	7.5732
17	6.43	1.6055	33.33	8.3249
18	9.05	2.2609	42.24	10.5506
19	2.67	1.0903	16.26	6.6409
20	6.31	1.5433	24.51	5.9951
21	9.21	1.7563	105.92	20.1973
22	16.31	2.6440	90.47	14.6623
23	6.78	1.5453	20.54	4.6800
24	2.54	0.7122	19.92	5.5790
25	4.83	4.1566	10.29	8.8800
26	2.55	2.1978	7.40	6.3737
27	7.86	3.3130	28.57	12.0421
28	4.30	1.1616	20.49	5.5312
29	10.31	2.7821	27.85	7.5176
30	9.85	1.0602	121.78	13.1098

4. Residual analysis was employed to examine any non-linearity and regularity that might exist in the regression analyses.

These analyses were performed using standard statistical computer programs(11) and ran on a UNIVAC 1108 computer using a COPE remote terminal.

CHAPTER IV

METHODS OF ANALYSIS

The statistical analytic techniques employed in this study as listed in Chapter III consist basically of: 1) correlation analysis, 2) factor analysis, and 3) linear regression. A brief description of each method of analysis is outlined in the following paragraph.

Correlation Analysis

The linear dependency or inter-relationship between two variables is expressed by means of their correlation coefficient, which ranges in value between (-1,0) and (0,1). In general, a correlation coefficient of 0 between two variables X and Y suggests that X is independent of Y, while a correlation coefficient of ± 1 points to the existence of a complete linear dependency between the two variables, i.e. $Y = a + bX$ where a and b are constants.

A variable may be positively or negatively correlated with another variable. The significance of the sign of the correlation coefficient between two variables may be visualized as the pairing of values of the variables. A positive correlation will pair larger value of one with larger value of the other (or smaller with smaller), while a negative correlation will pair larger value of one with smaller value of the other. For example, the number of lanes and pavement width are positively correlated with a high correlation coefficient of 0.92, indicating that larger number of lanes will have wider pavements. Average daily traffic and horizontal curvature have a negative correlation coefficient of -0.57, suggesting that roadways with high ADT usually have few horizontal curves.

Factor Analysis

Correlation analysis accounts for the inter-relationship between two variables while factor analysis attempts to account for the whole domain and their inter-correlationships. The domain in this study is the set of all the traffic and roadway characteristics. Factor analysis is based on the conviction that the variables within a domain are related and they are determined, at least in part, by a relatively small number of derived variables or common-factors.

Factor Structure

Each variable may be considered as composed of two parts:

1. A common-factor portion which correlates with the common-factors and whose variations are accountable by the factors; and

2. A specific-factor which is unique to that particular variable and whose variation cannot be accounted for by the common-factors.

Mathematically, this is expressed as:

$$X_i = \underbrace{\lambda_{i1}Y_1 + \cdots + \lambda_{im}Y_m}_{\text{Common-factor}} + \underbrace{S_i}_{\text{Specific-factor}}$$

where

X_i = i^{th} variable

Y_j = j^{th} common-factor variate

λ_{ij} = parameter reflecting importance of j^{th} factor in composition of i^{th} variable

S_i = i^{th} specific-factor variate

Factors

The set of common-factors may be viewed as a reference frame with unit orthogonal axes in the sample space. The correlations between the factors and the variables are then the projections of the variables onto these axes.

The number of factors involved is determined by the level of acceptable residual error. In a factor problem, one is concerned about how to account for the observed correlations among the variables in terms of the smallest number of factors and with the smallest possible residual error. However, as more and more factors are postulated to account for the observed correlations, the residuals get smaller and smaller. Hence, it is necessary to establish an acceptable level of residual error to determine when the addition of a new factor causes only a negligible reduction in the residuals.

Factor Loadings

The nature of the factor loadings may be viewed in the same light as that of correlation coefficients. For example, a factor loading of zero will indicate that there is no correlation between the variable and the factor or they are orthogonal to each other. On the other hand, a factor loading of 1 may be interpreted as perfect correlation between the variable and the factor or they are parallel to one another. Positive and negative values of the factor loadings also have the same significance as that of correlation coefficients.

Rotation of Factor Matrix

It should be noted that the first set of factors and the reference axes are chosen arbitrarily. It is therefore desirable to examine the initial factor matrix to see if the number of factors may be reduced or the residual error minimized. This is done by rotating the factor matrix about the origin. The algorithm for rotation of factor matrix is too complicated to present in this report and reference should be made to books in 'factor analysis' for further explanation. The factor matrices presented in this study are rotated factor matrices.

Linear Regression

All models relating accident rate to traffic and roadway characteristics were developed using simple and multiple linear regression techniques. Basically, linear regression involves determining the parameters or coefficients in a linear equation which best describes or fits a set of observations. In simple linear regression, the problem is to determine the coefficients of α and β in an equation of the form:

$$Y = \alpha X + \beta$$

For example, the number of single-vehicle, off-road, fixed-object accidents per million vehicle mile, Y_2, was related to average daily traffic, X_{10}, by the following simple linear regression equation:

$$Y_2 = -0.168\, X_{10} + 3.362$$

A dot chart and regression line for this relationship is shown as Figure 2.

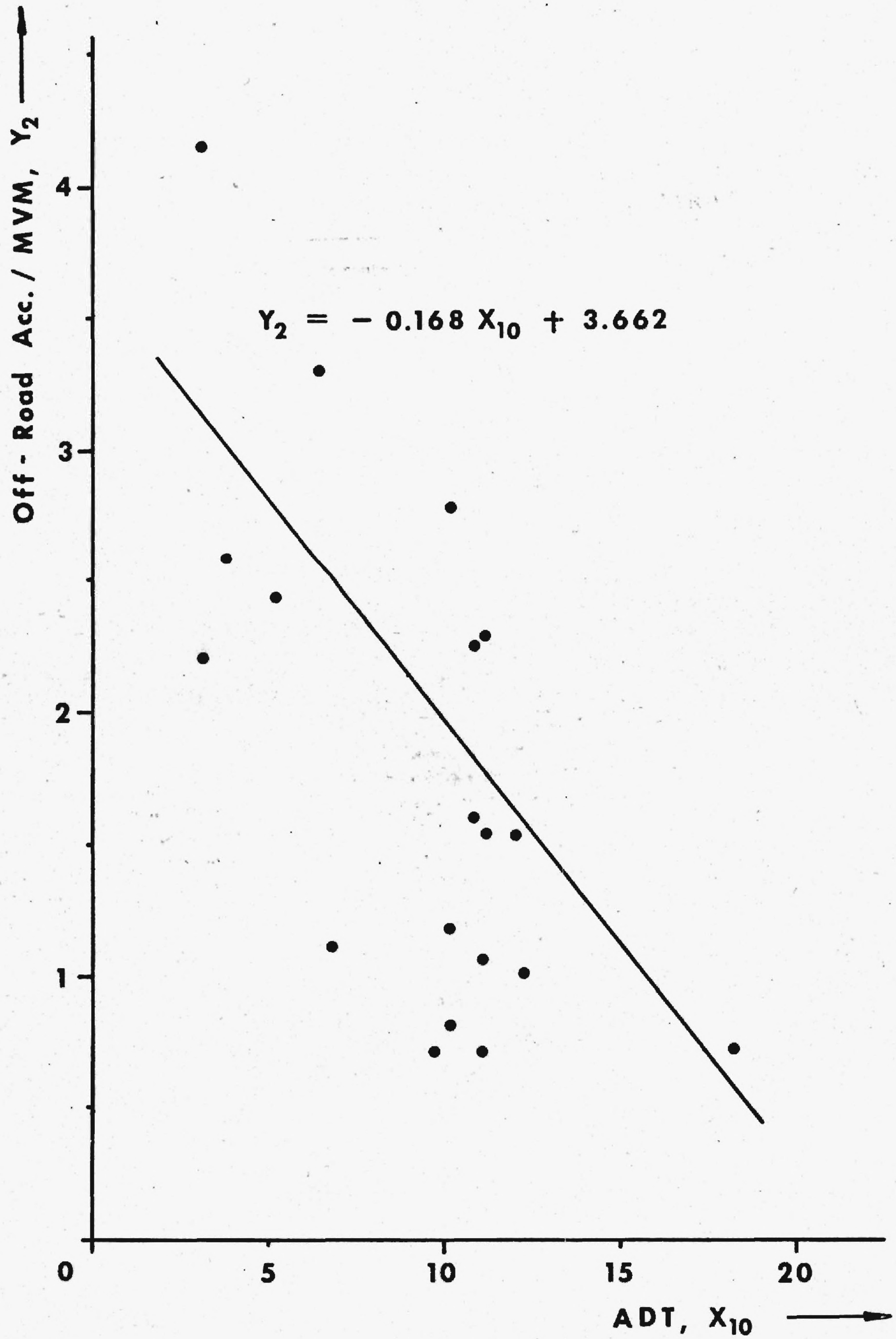

Figure 2. An Example of a Simple Linear Regression Model.

Similarly, in multiple linear regression, it is necessary to determine the coefficients α_1, α_2, α_3, . . ., and β in an equation of the form:

$$Y = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + . . . + \beta$$

In this case, it is assumed that the dependent variable is influenced not by one but by two or more independent variables. While the method for determining the multiple regression coefficients are similar to those used for simple regression, the multiple regression surface exists in three or more dimensions and cannot be easily plotted or sketched.

Essentially the problem of regression is to determine the line or surface which "best fits" the observed points. While there are a number of methods for determining the line or surface of "best fit," the technique used in this study was the well-known method of least squares.

The method of least squares may be defined as follows: If, for the dependent variable Y, the difference between the observed values and the predicted values is determined, squared, and summed; then this sum will be a minimum for the least squares line or surface. That is to say, the least squares line or surface is the "best fit" in the sense that the sum of the squares of the errors is as small as possible.

Statistical Measures of Correlation and Regression

In the paragraphs which follow, certain measures of importance are discussed, both for the regression model as a whole and for the individual variables.

Measures of Importance of the Regression Model

Having developed a predictive regression model, it is helpful to obtain some measure of its effectiveness. Several statistics may be computed which serve to evaluate the model and to measure its worth. The meanings of four such statistics, which were used in this study, are briefly stated below. For more detailed information on these statistical measures, reference may be made to any available textbooks on statistics.

Standard Error of Estimation. The standard error of estimation measures the closeness with which the estimated values agree with the observed values. A "small" standard error indicates close agreement between accident rates computed by the regression models and the accident data actually observed. The standard error is expressed in the same unit as the dependent variable, which in this study will be annual accidents per mile or per million vehicle mile.

Coefficient of Multiple Determination, R^2. The coefficient of multiple determination measures the proportion of variation in the dependent variable which is explained by, or associated with, differences in the independent variable or variables. Large values of the coefficient of multiple determination, which range from 0 to 1, are indicative of a high degree of association between the dependent and independent variables. In this study, for example, a coefficient of multiple determination of 1 would indicate that all the variations in accident rate could be explained by variations in the traffic and roadway characteristics, while a value of zero would indicate that they are not related.

Coefficient of Multiple Correlation, R. The square root of the coefficient of multiple determination is called the coefficient of multiple correlation, or more simply, correlation coefficient. It also serves as a measure of the degree of association between the dependent and independent variables. However, it tends to overestimate the association between the dependent and independent variables, and in this sense is inferior to the coefficient of multiple determination as a measure of this association.

The F Ratio. The F Ratio is the ratio of the variation explained by the model to the residual or unexplained variation. Roughly speaking, it may be stated that "large" values of the F Ratio are indicative of "good" predicative models. An F Ratio of zero would indicate no correlation between the dependent and independent variables, while perfect correlation between the variables would require an F Ratio of infinity. The F Ratio of each model was tested for significance at the 5 percent level of significance using the F test. To say the F Ratio of a model is significant at the 5 percent level means that the probability of rejecting a good model is expected to be less than 5 percent.

Measures of Importance of Individual Variables

In addition to attempting to measure the effectiveness of the total mathematical model, measures were made of the regression and correlation of the individual variables. The importance of each variable was shown by a study of its regression coefficient, standard error, partial correlation coefficient, and level of significance. The meaning of each of these measures is briefly stated in the paragraphs that follow.

The Regression Coefficient. A simple regression coefficient shows how many units the dependent variable changes for each unit change in the independent variable. In simple regression, the regression coefficient measures the slope of the regression line. Similarly, in multiple regression, a net regression coefficient shows the relation of the dependent variable to the concomitant independent variable, excluding the influence of the other independent variable or variables. The net regression coefficient of an independent variable measures the slope of the regression line when all other independent variables are taken to be zero.

The Standard Error of the Regression Coefficient. The standard error of the regression coefficient furnishes a measure of the accuracy of the estimated regression coefficient. Expressed in the same units as the regression coefficient, the standard error measures the closeness with which the estimated coefficient agrees with the "true" regression coefficient. Assuming that the observations are normally distributed about the regression plane, a confidence interval may be computed using the "t"- distribution at the desired level of risk.

Partial Correlation Coefficient. A partial correlation coefficient measures the correlation between the dependent variable and each of the independent variables. For a given independent variable, the partial correlation coefficient measures only the effect of that variable; any linear tendency of the remaining independent variables to obscure the effect is eliminated. Squared, the partial correlation coefficient shows how much that variable reduces the variation after all of the other variables are taken into account.

Level of Significance. Each regression coefficient was tested at the 5 percent level of significance using the Student's "t" test. To say that a regression coefficient is significant at the 5 percent level of significance means that this result would be expected five times in 100 replications purely by chance.

It should be noted that the calculation of meaningful correlation statistics requires that strictly random samples be taken from normal bivariate or multivariate universes. This means: 1) that the joint frequency distributions of the variables in the sample must be representative of the corresponding distribution in the universe; 2) that the distribution of each variable must tend to follow the normal frequency curve; and 3) that the standard deviations of the dependent variable must remain constant within normal sampling fluctuations.

There are reasons to believe that certain of these requirements were not met by the variables. For example, the number of lanes only takes on discrete values of 2, 3, 4, and 5. Furthermore, the choice of number of lanes was not done randomly, but depended on the judgement of the individual who selected the study sites.

Fortunately, estimates of the regression coefficients are not as seriously affected by departures from the required conditions as are estimates of correlation coefficients. The most serious results of these departures is to cause the computed correlation statistics (correlation coefficient, partial correlation coefficient, standard error, etc.) to be misleading.

While it is risky to base strict probability statements upon the correlation statistics, it is believed that these values do serve as an approximate measure of the effectiveness of the variables and the models.

Residual Analysis

After developing the regression models and performing all the necessary tests of significance, it is vital to examine the validity of the underlying basic assumption of linear relationship between the dependent and independent variables. This test is achieved by examining the residuals of the model. The residuals are obtained as the difference between the predicted values of the dependent variable and the observed values. In this study, the residuals are the difference between the predicted accident rate and the observed data.

The residuals are then plotted on a graph, an example of which is shown in Figure 3. Any significant departure from linearity may be observed from the pattern of the residuals on the graph. Some common forms of departure are sinusoidal, exponential, and logarithmic patterns. If any form of non-linearity is observed, the linear regression models will be discarded and further analysis will be needed to determine the exact nature of relationship between the dependent and independent variables.

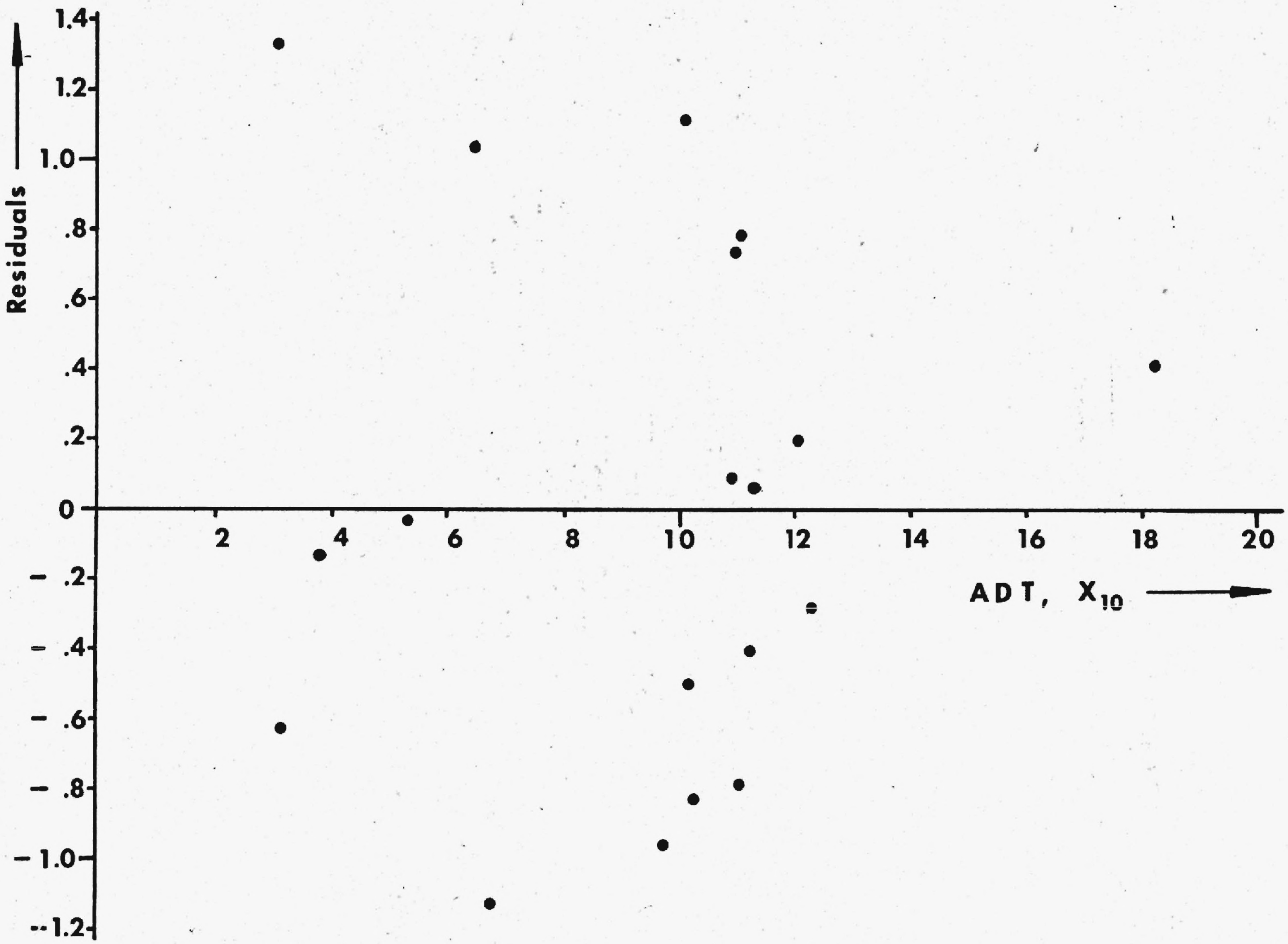

Figure 3. An Example of a Graph Used for Residual Analysis.

CHAPTER V

ANALYSIS OF RESULTS

Initial correlation and factor analyses of the roadway data showed that the number of lanes was strongly related to ADT, pavement width and number of intersections per mile. These variables in turn were strongly inter-related while ADT was also correlated with horizontal curvature (negative) and speed limit. These relationships may be seen in the correlation matrix and the rotated factor matrix for ten roadway and traffic variables, shown respectively by Tables 5 and 6.

The highest correlations shown by Table 5 are between:

1.	Number of lanes and Pavement Width	0.92
2.	Pavement widths and ADT	0.76
3.	Number of lanes and ADT	0.75
4.	Number of lanes and Number of intersections	0.68
5.	Pavement width and Number of intersections	0.62
6.	ADT and Horizontal curvature	-0.57
7.	ADT and Speed limit	0.53

In Table 6, four factors are indicated by Roman numerals. These factors are new entities which are orthogonal to each other, and therefore each represents an independent piece of information. The entries in the table, which are called factor loadings, measure the correlation between each variable and each factor.

The variables, pavement width, number of lanes, horizontal curvature (negative), number of intersections and ADT, are strongly associated with Factor I. This factor evidently measures the size or class of the roadway and, as expected, is the most important factor relating to accident rates. However, the number of lanes and pavement width are observed to be the dominant variables which overshadow the other variables.

In Factor II, high factor loadings are shown for the following variables: speed limit (negative), horizontal curvature, and the number of discrete objects zero to ten feet from the pavement edge. These results seem to be explained by the observed tendency of low speed roads to be

Table 5. Correlation Matrix for Roadway and Traffic Variables with 30 Observations.

Variable	1	2	3	4	5	6	7	8	9	10
1. Pavement Width	1.00	.92*	.27	-.49	.01	.62	.33	.14	.09	.76
2. Number of Lanes		1.00	.19	-.45	.06	.68	.40	.16	.11	.75
3. Speed Limit			1.00	-.46	-.23	.22	-.02	.22	-.34	.53
4. Horizontal Curvature				1.00	.16	-.31	-.32	-.04	.41	-.57
5. Vertical Alignment					1.00	.10	.33	-.07	.04	-.10
6. Number of Intersections						1.00	.26	.21	.17	.49
7. Number of Driveways							1.00	-.35	.13	.41
8. Continuous Objects, 0-10'								1.00	-.22	.04
9. Discrete Objects, 0-10'									1.00	.06
10. ADT										1.00

* Note: High correlation coefficients are underlined.

Table 6. Rotated Factor Matrix for Roadway and Traffic Variables with 30 Observations.

Characteristic	Factor			
	I	II	III	IV
Pavement Width	.922*	-.109	-.026	.020
Number of Lanes	.942	-.062	-.026	-.065
Speed Limit	.279	-.668	.124	.313
Horizontal Curvature	-.439	.719	.216	-.094
Vertical Alignment	.033	.095	-.059	-.940
Number of Intersections	.809	.048	.156	-.106
Number of Driveways	.412	-.086	-.677	-.399
Continuous Objects 0-10'	.193	-.158	.889	-.050
Discrete Objects 0-10'	.242	.856	-.196	.137
ADT	.792	-.376	-.200	.156

* High factor loadings are underlined.

characterized by frequent horizontal curves and by numerous poles, trees, and other fixed objects along the roadside.

Factor III is highly correlated with continuous objects and negatively to the number of driveways. It is logical that these factor loadings are opposite in sign because by nature these two variables are mutually exclusive.

Vertical alignment is the only variable strongly correlated with Factor IV. This factor serves as an indicator of the topography and frequency and magnitude in grade changes along the roadway. This factor also appears to be a measure, at least partially, of the sight distance availability along the highways.

Various regression models were then developed based on the roadway and traffic characteristics. However, from these initial analyses, it became apparent that because of inherent differences in geometric features and traffic flow patterns, it is necessary to have separate analyses for two-lane and multi-lane facilities. Of the 30 sections investigated in this study, there were 19 two-lane, nine four-lane, and one each of three- and five-lane roadways. Due to the small number of observations, statistical analysis of data for roadways with three or more lanes was not possible. Subsequent analysis was therefore limited to the 19 sections of two-lane highways.

Analysis of Results, Two-Lane Roadways

Correlation and factor analyses were performed on the roadway and traffic characteristics for the 19 sections of two-lane streets. The results appeared to be easier to interpret than those of all 30 roadway sections despite the reduction in observations. The correlation matrix and the rotated matrix for the two-lane roadways are shown in Tables 7 and 8.

In Table 7, the highest correlations shown are between:

1.	ADT and Speed limit	0.61
2.	ADT and Horizontal curvature	-0.58
3.	Discrete objects and Horizontal curvature	0.56
4.	Continuous objects and Number of driveways	-0.56

Three factors are shown in Table 8. Factor I again seems to

Table 7. Correlation Matrix for Roadway and Traffic Variables for Two-Lane Streets.

X	Variables	1	3	4	5	6	7	8	9	10
1.	Pavement Width	1.00	.40	-.45	-.10	.10	.23	-.15	-.04	.34
3.	Speed Limit		1.00	-.46	-.34	.35	-.25	.34	-.42	.61
4.	Horizontal Curvature			1.00	.48	-.19	-.02	.01	.56	-.58
5.	Vertical Alignment				1.00	.16	.32	-.12	.36	-.20
6.	Number of Intersections					1.00	.04	-.08	-.05	.31
7.	Number of Driveways						1.00	-.56	.35	.34
8.	Continuous Objects, 0-10'							1.00	-.32	.00
9.	Discrete Objects, 0-10'								1.00	-.30
10.	ADT									1.00

Note: The variable X_2, number of lanes, has been removed from the independent variables.

Table 8. Rotated Factor Matrix for Two-Lane Roadway and Traffic Variables.

Characteristic	Factor		
	I	II	III
Pavement Width	.605	-.335	.102
Speed Limit	.679	.390	.415
Horizontal Curvature	-.887	-.022	.043
Vertical Alignment	-.590	-.309	.509
Intersections Per Mile	.159	.014	.841
Driveways Per Mile	.077	-.883	.137
Continuous Objects, 0-10'	-.013	.817	.093
Discrete Objects, 0-10'	-.564	-.524	.077
ADT	.749	-.142	.386

characterize the size or class of the roadway. Pavement widths, speed limit, and average daily traffic have the largest positive loadings for this factor, while horizontal curvature, vertical alignment, and discrete objects have large negative loadings. This is interpreted to mean that wide, high-speed, heavily-travelled streets are characterized by a lack of horizontal and vertical curvature and fixed objects.

Factor II characterizes the "roadside." It has large loadings on driveways and roadside objects. It is noted that the loadings for driveways per mile and discrete fixed objects have the same sign while continuous fixed objects have an opposite sign. This may reflect the practice of property owners to place mail boxes, shrubs, and other fixed objects adjacent to driveways, while driveways and continuous fixed objects are mutually exclusive.

Factor III, which has large factor loadings for vertical alignment and the number of intersections per mile, apparently characterizes the topography of the roadway and the sight distance condition along the roadways. This pairing of vertical alignment and number of intersections may not be self-evident. However, it is observed that most of the two-lane roadways were upgraded from old gravel roads which closely followed the topography or terrain of the area. Hence, the locations of intersections are usually associated with a change in vertical alignment.

Off-Road Accident Relationships

Single-vehicle, off-road, fixed-object accidents per mile (Y_1) and per million vehicle mile (Y_2) were related to the roadway and traffic characteristics, using both simple linear regression and stepwise multiple linear regression analysis.

Off-Road Accidents Per Mile

The multiple linear regression model for off-road accidents per mile is summarized in Table 9. A four-dimensional model was chosen relating off-road accidents per mile (Y_1) to the following roadway and traffic characteristics:

Variable	Factor
(1) Speed limit, X_3	I, IV
(2) Vertical alignment, X_5	I, V
(3) Discrete fixed objects, X_9	I

Table 9. The Relationship Between Off-Road Accidents Per Mile and Roadway and Traffic Characteristics.

$$Y_1 = 0.205\ X_3 + 2.798\ X_5 - 0.0186\ X_9 + 1.214$$

Variables in Equation

	Variable	Coefficient	Standard Error	Factor
(1)	Speed Limit, X_3	0.205	0.129	I
(2)	Vertical Alignment, X_5	2.798	1.272	I, III
(3)	Discrete Fixed Objects, X_9	-0.0186	0.009	I, II

F Ratio = 3.72

Multiple Correlation Coefficient $R = 0.62$

$R^2 = 0.42$

Standard Error of Estimation = 2.01

Forty-two percent of the variation in off-road accidents per mile are explained by this model. Moreover, only the regression coefficient for vertical alignment is significantly different from zero.* This model, however, has the desirable feature of having one variable highly correlated with each of the factors in Table 8.

By simple regression, off-road accidents per mile were related to the three independent variables appearing in the multiple linear regression models as shown in Figure 4. F-tests revealed that only one of the variables, discrete fixed objects, was significantly related to off-road accidents per mile at a 10 percent level. It is not intuitively obvious why off-road accidents per mile decrease with increases in the number of discrete objects per mile. This negative relationship could mean that drivers use more caution along roads with hostile environments. It more likely results from the fact that roads with many fixed roadside objects tend to have relatively low traffic volumes.

Although speed limit appears in the multiple linear regression model, its usefulness in the prediction of accident rate is probably debatable. It is believed that the speed limits on most of these two-lane roadways have been arbitrarily established and the posted limit does not necessarily represent the 85 percentile speed. (See Figure 4.) However, since the speed limit of roadways is much more readily available than actual speed, the former variable is therefore used in the regression equations.

Vertical alignment was positively related to off-road accidents per mile. This relationship should be expected since the presence of grades, vertical curves and intersections (Factor III) does affect off-road accident rate, and this finding is supported by previous research(7).

Off-Road Accidents Per Million Vehicle Mile

A five-dimensional multiple linear regression model relating off-road accidents per MVM to roadway and traffic characteristics is summarized in Table 10. The variables appearing in the model are as follows:

Variable	Factor
(1) Pavement width, X_1	I
(2) Vertical alignment, X_5	I, III
(3) Discrete fixed objects, X_9	I, II
(4) ADT, X_{10}	I

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* Significance level of 5 percent was used in all testing of hypotheses.

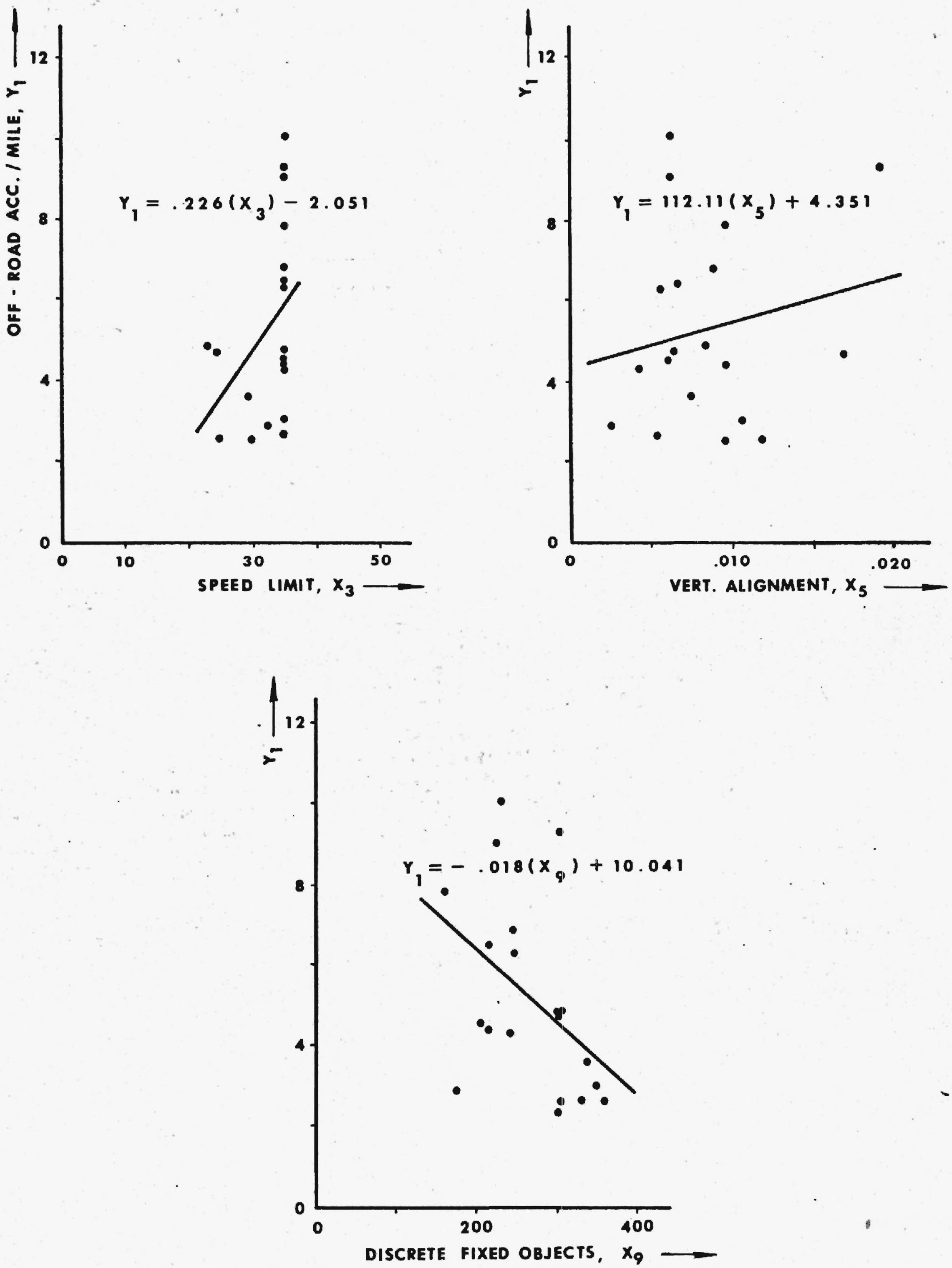

Figure 4. Simple Linear Regression Models for Off-Road Accidents Per Mile.

Table 10. The Relationship Between Off-Road Accidents Per MVM and Roadway and Traffic Characteristics.

$$Y_2 = -0.104\ X_1 + 0.556\ X_5 - 0.0053\ X_9 - 0.156\ X_{10} + 7.277$$

Variables in Equation

	Variables	Coefficient	Standard Error	Factor
(1)	Pavement Width, X_1	-0.103	0.065	I
(2)	Vertical Alignment, X_5	0.556	0.435	I, III
(3)	Discrete Fixed Objects, X_9	-0.0053	0.0031	I, II
(4)	ADT, X_{10}	-0.156	0.049	I

F Ratio = 5.34

Multiple Correlation Coefficient $R = 0.78$

$R^2 = 0.60$

Standard Error of Estimation = 0.70

This model is statistically superior to that of off-road accidents per mile. Sixty percent of the variation in off-road accidents per MVM can be explained by this model. It also has the desirable feature of having variables highly correlated with each of the factors in Table 8. However, only the regression coefficient for ADT is significantly different from zero.

Figure 5 shows the simple linear regression models relating off-road accidents per MVM to each of the variables appearing in the multiple linear regression model. Two of the variables, vertical alignment and number of discrete fixed objects per mile, remain in the equation with similar relationship.

Since the calculation of off-road accidents per vehicle mile is based on average daily traffic, a significant relationship between these variables is not surprising. This negative relationship between ADT and off-road accidents per MVM reinforces conclusions of various previous researchers that the rate of off-road accidents decreases with increased traffic flow(7,8).

Pavement width, similar to speed limit, has a very narrow range of values and little variability. (See Figure 5.) This lack of variability renders pavement width as a questionable predictor. Also, both speed limit and pavement width have high factor loadings on Factor I, so it is probable that both variables are actually representing the same roadway characteristic.

Summary of Off-Road Accident Relationships

It is possible to develop statistically significant multiple regression equations relating off-road accidents to roadway and traffic characteristics. Statistically, the equation for off-road accidents per million vehicle miles is superior to that for off-road accidents per mile. This may result from the fact that ADT, by which the former measure is computed, is strongly related to certain of the independent variables.

It should be noted that, in each of the two models developed, normally only one of the regression coefficients is significantly different from zero. This fact, coupled with the low coefficients of multiple correlation, casts doubt on the usefulness of the models for predictive purposes. The results of this study indicate that only about 40-60 percent of the variation in off-road accident rates is explained by the variation

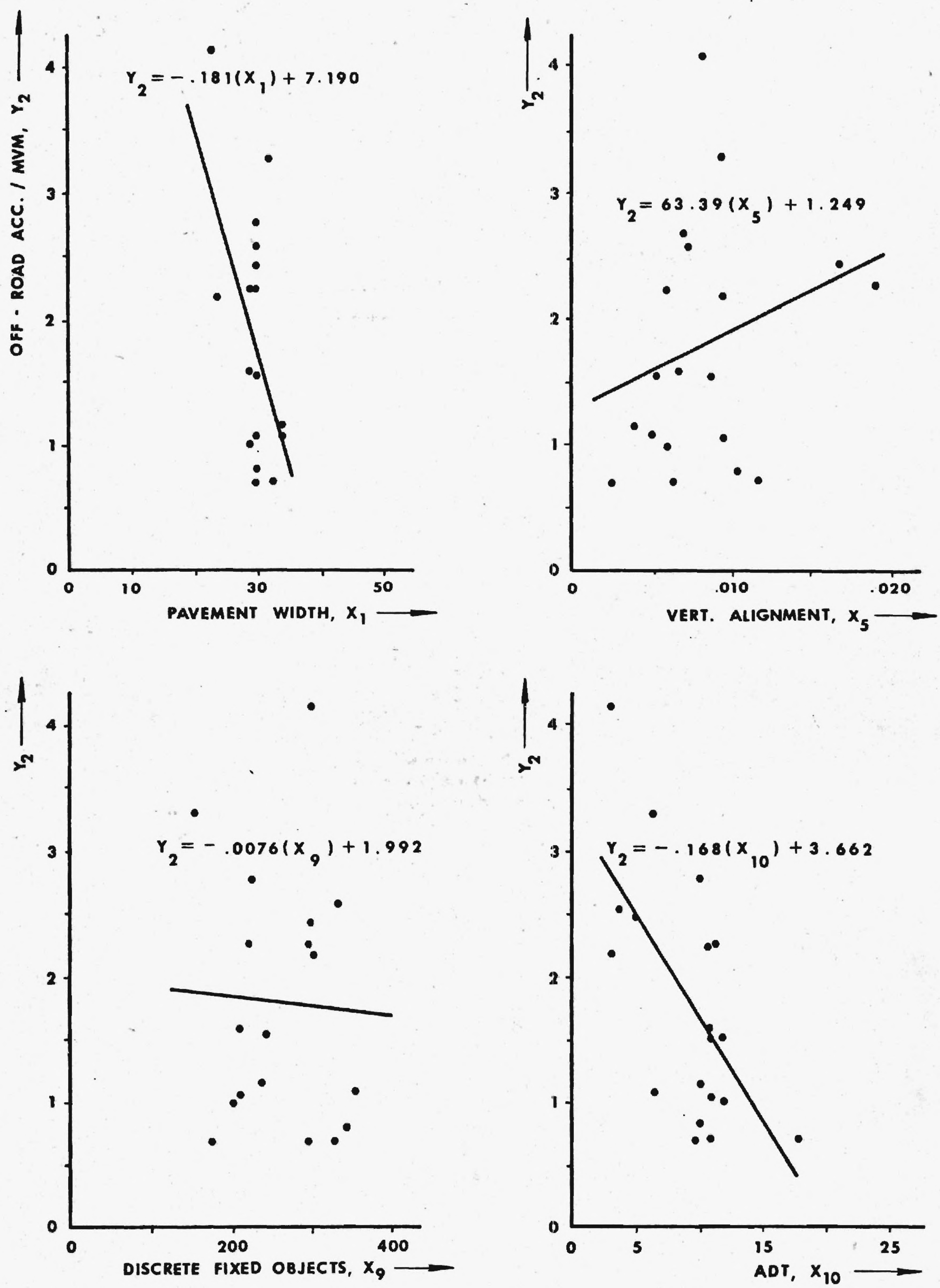

Figure 5. Simple Linear Regression Models for Off-Road Accidents Per MVM.

in the roadway and traffic variables examined. One can only speculate as to the reasons for the low coefficients of multiple determination shown by the regression equations.

It is possible that these results are due in part to the small number of observations which was limited by available time, personnel and financial resources. Several of the roadway and traffic variables have the undesirable feature of lack of variability which greatly reduces the significance of regression models. This calls for a much larger sample size in order to cope with this problem of small variability.

It is more likely that off-road accidents are related to other roadway and traffic variables not examined in this study, or to social, economic, and other non-roadway characteristics, such as human and vehicular variables. It is recalled that Chapman(8) concluded that up to half of traffic accidents which happened along a 29 mile highway in New South Wales occurred randomly with little or no relation to highway design. Unfortunately, all these variations in accident rate not explained by the ten roadway and traffic variables selected for this study are summed up as residual error. This makes the residual error so large that the significances of individual variables in the regression model are masked.

Total Accident Relationships

It has been pointed out previously that although the analysis of total accident-roadway features relationship is not an objective of this study, it is performed because of readily available data and little additional work involved. Moreover, it is interesting and instructive to examine the relationships of both off-road and total accident and compare the results with previous research findings. Simple and stepwise multiple linear regression techniques were used in relating roadway and traffic variables to total accidents per mile (T_1) and per million vehicle mile (T_2).

Total Accidents Per Mile

From the stepwise multiple linear regression analysis, a five-dimensional equation was chosen as the best model and is summarized in Table 11. Total accidents per mile are related to the following roadway and traffic characteristics:

Table 11. The Relationship Between Total Accidents Per Mile and Roadway and Traffic Characteristics.

$$T_1 = 1.299\ X_3 + 21.65\ X_5 + 1.744\ X_6 + 1.799\ X_{10} - 64.99$$

	Variables	Coefficient	Standard Error	Factor
(1)	Speed Limit, X_3	1.299	0.934	I
(2)	Vertical Alignment, X_5	21.615	7.683	I, III
(3)	Number of Intersections, X_6	1.744	1.425	III
(4)	ADT, X_{10}	1.799	0.950	I

F Ratio = 6.29

Multiple Correlation Coefficient $R = 0.80$

$R^2 = 0.64$

Standard Error of Estimation = 11.894

	Variable	Factor
(1)	Speed Limit, X_3	I
(2)	Vertical Alignment, X_5	I, III
(3)	Number of Intersections, X_6	III
(4)	ADT, X_{10}	I

The equation has a coefficient of multiple correlation coefficient of 0.80 which indicates that about 64 percent of the variation in total accidents per mile can be explained by these roadway and traffic variables. The regression coefficient of vertical alignment is the only one significantly different from zero. Also, the absence of variables from Factor II suggests that roadside characteristics has little effect on total accidents per mile.

Graphs showing the relationships between total accidents per mile and each of the four independent variables appearing in the multiple regression model are shown as Figure 6. As expected, all four variables are positively related to total accidents per mile indicating that increases in one or a combination of these variables are accompanied by increase in total accidents per mile.

Average daily traffic may be viewed as a measure of accident exposure and therefore it is not surprising to see that it is positively related to the number of accidents per mile. This relationship also agrees with findings of previous researchers(4,5,6). Average daily traffic is also highly correlated with speed limit in Factor I which serves as an indicator of the size or class of the roadway. It has been pointed out that speed limit has its shortcomings as a predictor. However, it is also observed that speed is an important variable as related to accident rate. Actual speed may therefore be a better choice except for the difficulty in obtaining the necessary data. The variables vertical alignment and number of intersections both have high factor loadings on Factor III and are highly correlated because of the general topography of the area. It is not surprising to have them both positively related to total accidents per mile.

Total Accidents Per Million Vehicle Mile

A four-dimensional multiple regression model is recommended for relating total accidents per MVM to roadway and traffic characteristics.

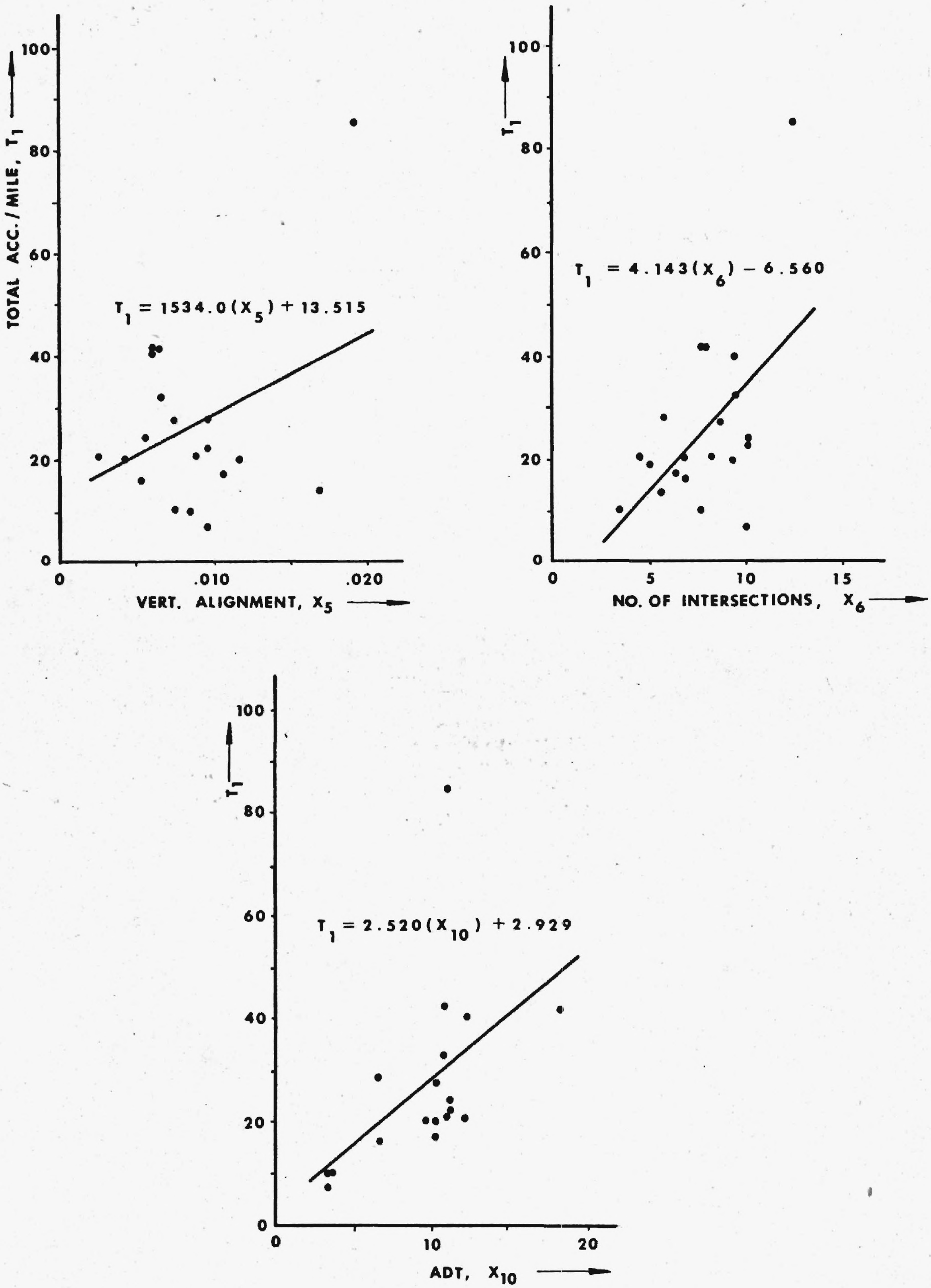

Figure 6. Simple Linear Regression Models for Total Accidents Per Mile.

This model is as shown in Table 12 with the following variables in the equation:

	Variable	Factor
(1)	Speed Limit, X_3	I
(2)	Vertical Alignment, X_6	I, III
(3)	Number of Driveways, X_7	II

This model is not as good as that of total accidents per mile from the statistical point of view. The relatively low coefficient of multiple correlation of 0.65 indicates that only 42 percent of the variations in total accidents per MVM is explained by variations in roadway and traffic variables. T-tests revealed that only the regression coefficient of variable vertical alignment is significantly different from zero. However, this model has a term highly correlated with each of the three orthogonal factors in Table 8.

The variables vertical alignment and speed limit appear in both models for total accident rates with similar relationships, as shown in Figure 7. The effect of ADT as a measure of accident exposure is already taken into consideration in this model for total accidents per MVM, and ADT does not show up in the equation.

The presence of numerous driveways along the roadway probably has an effect on motorists causing them to be more cautious and slower in speed. This may account for the negative relationship between number of driveways per mile (Factor II) and total accidents per MVM.

Summary of Total Accident Relationships

The regression equations for total accidents are, in general, slightly better from a statistical view point than those for off-road accidents. Multiple correlation coefficients (R) ranged from 0.65 to 0.80. This indicates that from 42 percent to 64 percent of the variation in total accident rates was associated with variations in the roadway and traffic variables. On this basis, these models compare favorably with those developed by other researchers(8,9). The adverse effects of small number of observations and large residual error are also evident in total accident relationships. In both equations, only the regression coefficient of vertical alignment is significantly different from zero.

Table 12. The Relationship Between Total Accidents Per MVM and Roadway and Traffic Characteristics.

$$T_2 = 0.261\ X_3 + 6.483\ X_5 - 0.046\ X_7 - 3.826$$

	Variables	Coefficient	Standard Error	Factor
(1)	Speed Limit, X_3	0.261	0.191	I
(2)	Vertical Alignment, X_6	6.483	1.971	I, IV
(3)	Number of Driveways, X_7	-0.046	0.049	II

F Ratio = 3.70

Multiple Correlation Coefficient $R = 0.65$

$R^2 = 0.42$

Standard Error of Estimation = 3.105

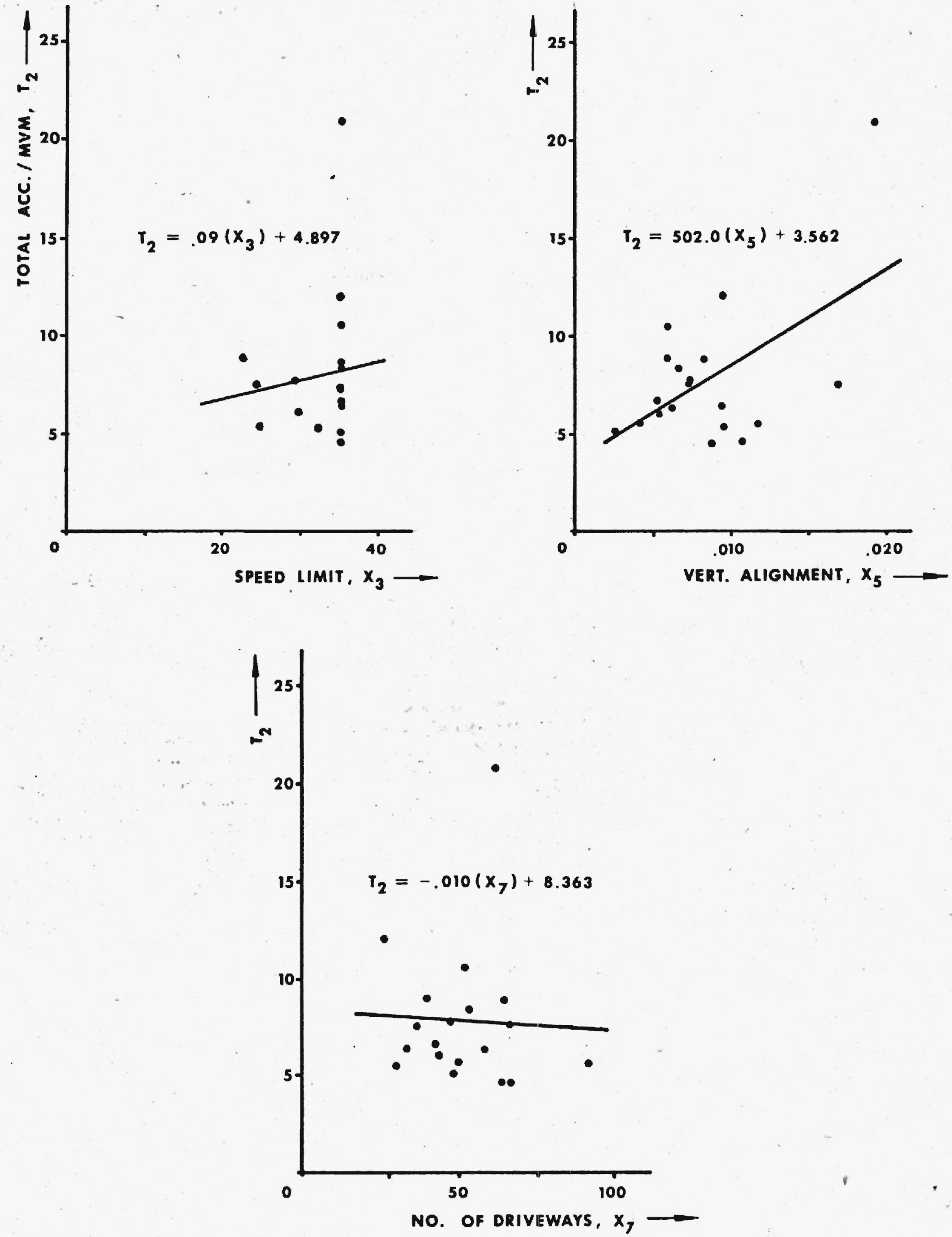

Figure 7. Simple Linear Regression Models for Total Accidents Per MVM.

The variables vertical alignment and speed limit are closely related to both total accidents per mile and total accidents per vehicle mile. Other roadway and traffic variables which are significantly related to one of the total accident rates included ADT, number of intersections per mile, and number of driveways per mile. These variables may be summarized into four general groups:

1. Average daily traffic;
2. Topography and sight distance condition along the roadway;
3. Number of conflict points along the streets; and
4. Speed limit.

Interpretation of Results

The relationships between accidents and roadway and traffic variables are complex. Analysis of the data collected in this study suggests the existence of inter-relationships between average daily traffic, general class of roadway, and land use. These factors then contribute to the accident experience as shown in Figure 8.

A measure of exposure, average daily traffic is positively related to total accident experience, but negatively with off-road accident rates. It is also closely related to speed limit and to several roadway variables, namely: pavement width, horizontal curvature, vertical alignment, and the presence of fixed objects along the roadside. These roadway and traffic variables are closely related to a common factor which might be characterized as roadway class. The class of roadway both influences and is influenced by traffic demand (ADT), land use, and accident rates. It has been well established that traffic volumes are influenced by land use adjacent to the roadway, and this and other studies have shown that accident rates are also affected by abutting land use.

In the hierarchy of urban roads that are built to precise engineering standards, the higher classes (e.g., major arterials) are designed to be safe and capable of carrying large traffic volumes. Though characterized by wide pavements, straight alignment, gradual changes in gradient, and clear roadsides, these roadways generally have high ADT's and thus a greater prevalence of accident-producing situations. Furthermore, higher classes of streets tend to create corridors of intense land development which have an undesirable effect on accident rates.

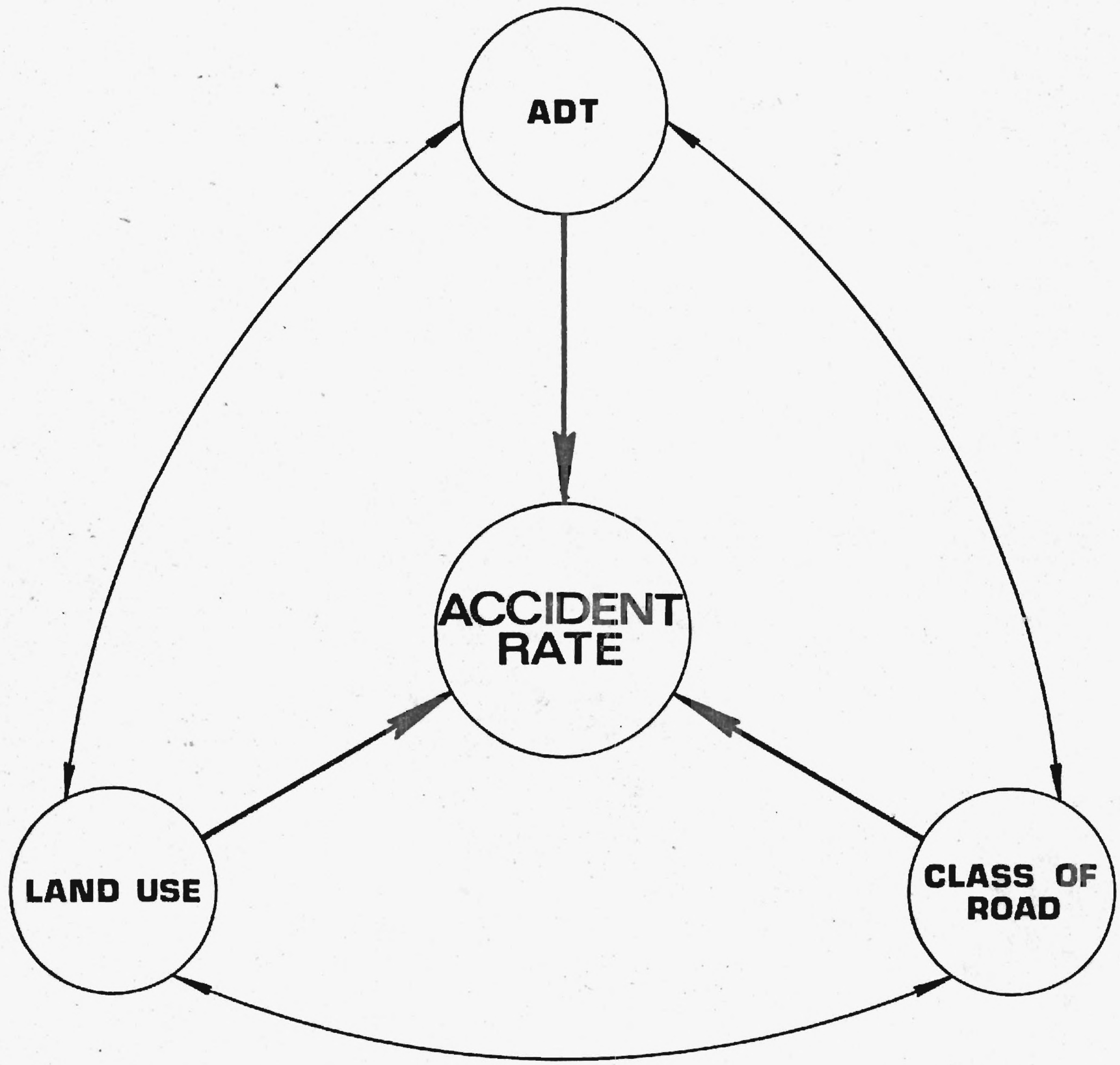

Figure 8. Relationships Between Accident Experience and Average Daily Traffic, Class of Roadway, and Land Use.

Viewed within this framework, it is understandable that researchers have concluded that accident rates are related to ADT, to various roadway characteristics, and to driveways, number of commercial units and other measures of development of abutting land.

CHAPTER VI

FINDINGS AND CONCLUSIONS

In evaluating and employing the specific conclusions given in this chapter, it should be remembered that they are based on a pilot study which involved a sample size of only 30 observations. The conclusions for two-lane streets were based on only 19 observations. While a larger sample size would have been more desirable, the results from this limited study are nevertheless valid and useful.

1. Roadway and traffic data for two-lane urban streets may be grouped into three common categories: (1) the "class of roadway" which is closely correlated with horizontal curvature, ADT, speed limit, pavement width, vertical alignment, and the presence of discrete objects along the roadside; (2) a "roadside" factor which had large loadings for driveways and roadside objects; and (3) a "topography-land development" factor which was strongly correlated with vertical alignment and number of intersections.
2. Off-road accidents are significantly related to roadway and traffic characteristics. However, only about 40-60 percent of the variation in off-road accidents can be explained by variations in the roadway and traffic variables as concluded in other researches(8,9). Great caution should be exercised when using these models for predictive purposes.
3. In the multiple correlation and regression analysis of the data for two-lane roads, off-road accidents per mile are most closely related to speed limit, vertical alignment, and the number of discrete fixed objects along the roadside. On a per million vehicle mile basis, off-road accidents for two-lane roads are most closely related to pavement width, vertical alignment, average daily traffic, and the number of discrete fixed objects per mile. Summarizing these relationships in general terms, off-road accident experience is related to:
   - (i) Average daily traffic.
   - (ii) Topography of roadway.
   - (iii) Speed limit and pavement width.
   - (iv) Presence of roadside objects.

4. The presence of fixed objects along the roadside has little effect on off-road accident experience. Off-road accident rates are not closely related to the presence of continuous roadside objects. Also, the number of discrete fixed objects per mile is the least significant of the variables appearing in the equation and actually the relationship is negative. This finding is in close agreement with that of the Louisiana study(9).

5. The number of single-vehicle, off-road accidents per MVM decreases with increase in ADT. This finding compares favorably with other previous researches(7,8).

6. From a statistical point of view, the multiple regression equations for total accident rates are generally better than those for off-road accident rates. Coefficients of multiple determination for the total accident models range from 0.42 to 0.64. Nonetheless, the application of these models for predictive purposes should be used with great caution.

7. Total accidents per mile are related to speed limit, vertical alignment, number of intersections and ADT. On a per million vehicle mile basis, total accidents are related to speed limit, vertical alignment and number of driveways. Again summarizing these relationships in general terms, total accident experience is related to:

   (i) Average daily traffic.
   (ii) Topography of roadway.
   (iii) Number of conflict points: number of intersections and driveways.
   (iv) Speed limit.

8. The results of this study indicate that, in studies of this type, accident and roadway data should be segregated according to size and class of roadway.

9. Some of the roadway and traffic variables have a very small range of variability which renders them questionable predictors, for example, speed limit and pavement width. This undesirable effect may be minimized by using a larger sample size.

10. The presence of large residual error in the regression equations is of serious concern as it may mask the significance of the equation as well as that of individual variables.

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