STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS PHASE I - FINAL REPORT

FHWA/MT-96-8129

Final Report

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

February 1997

prepared by
Jereen J. Wolverton
John M. Mounce, Ph.D., P.E.
Civil Engineering Department
Montana State University
Bozeman, MT 59717

Study of Accidents at Signalized Intersections Phase I - Final Report

Prepared by

Jereen J. Wolverton
Research Assistant

and

John M. Mounce, Ph.D., P.E.
Principal Investigator

of the

Civil Engineering Department
Montana State University - Bozeman

Prepared for the

STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT and TECHNOLOGY TRANSFER PROGRAM
in cooperation with the
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

February, 1997

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/MT-96/8129		

4. Title and Subtitle	5. Report Date
Study of Accidents at Signalized Intersections - Phase I Final Report	**December, 1996**
	6. Performing Organization Code
7. Author(s) **Jereen J. Wolverton and John M. Mounce**	8. Performing Organization Report No.
9. Performing Organization Name and Address **Civil Engineering Department** **Montana State University** **Bozeman, Montana 59717**	10. Work Unit No. (TRAIS) 11. Contract or Grant No. **8129**
12. Sponsoring Agency Name and Address **Montana Department of Transportation** **2701 Prospect** **Helena, Montana 59620-1001**	13. Type of Report and Period Covered **Phase I - Final** **Nov. 1995 - Feb. 1997** 14. Sponsoring Agency Code **5401**

15. Supplementary Notes

Research performed in cooperation with the Montana Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The objective of the project entitled "Study of Accidents at Signalized Intersections - Phase I" is to examine accident data at signalized intersections for accident patterns and trends that are susceptible to correction in Montana. The Scope of Work consisted of conducting a literature review, assimilating accident trend statistics, establishing variables of influence and determining significant causal patterns.

Accident trend statistics were assimilated for the 3 year period from 1992 to 1994. The following variables were evaluated: type of accident, severity, alcohol involvement, roadway surface conditions, age of drivers, and contributing factors. Montana percentages for these variables were compared to other studies and were found to be similar. Accident trends between Montana's six largest cities: Billings, Great Falls, Missoula, Butte, Helena and Bozeman were also investigated. Accident type percentages were similar for these cities.

Accident rates were calculated along the State Primary Routes in Montana to establish variables of influence and significant causal patterns. Twenty-five intersections were selected for further study, in which accident report files were obtained and collision diagrams were constructed. From these collision diagrams, relationships were investigated to determine trends for Montana's signalized intersections. Variables that were determined to affect accidents in Montana were traffic volume and population of the city in which the accidents occurred. Angle and rear-end type accidents accounted for the largest percentages of accident types. When compared to other states and studies, Montana's accident characteristics are similar.

17. Key Words	18. Distribution Statement
Montana, Signalized Intersections, Accidents	**No restrictions. This document is available to the public through NTIS: Springfield, Virginia,22161**

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**148**	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Disclaimer Statement

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Montana Department of Transportation or the Federal Highway Administration.

Alternative Format Statement

Persons with disabilities who need an alternative accessible format of this information, or who require some other reasonable accommodation in order to participate, should contact the Montana Department of Transportation, Attn: Research Manager, 2701 Prospect Avenue, Helena, Montana 59620-1001; Telephone No. (406) 444-6269, TDD No. (406) 444-7696 or Fax No. (406) 444-6204. For more information, contact the MDT Personnel Services Section at (406) 444-3971.

Acknowledgments

Grateful appreciation is given to the following technical panel members for their support, guidance, and advice that facilitated the successful completion of this project. Pierre Jomini, MDT Safety; Don Dusek, MDT Traffic; Jim Stevenson, MDT Maintenance; Lee Alt, MDT Butte District; Craig Genzlinger, Federal Highway Administration; and Michelle Mitchell, MDT Research Management Unit.

Appreciation is also extended to the following people: Steve Keller, MDT Traffic; Yusuf Mohamedshah, Lendis Corporation, HSIS; Carol Bittinger, Office of Systems and Computing Service, Montana State University - Bozeman; Terry Smith, City of Billings; Bill Morgan, City of Billings; John Gibson, City of Billings; and Randy Carroll, Montana State University - Bozeman.

Abstract

The objective of the project entitled "Study of Accidents at Signalized Intersections - Phase I" is to examine accident data at signalized intersections for accident patterns and trends that are susceptible to correction in Montana. The Scope of Work consisted of conducting a literature review, assimilating accident trend statistics, establishing variables of influence and determining significant causal patterns.

Accident trend statistics were assimilated for the 3 year period from 1992 to 1994. The following variables were evaluated: type of accident, severity, alcohol involvement, roadway surface conditions, age of drivers, and contributing factors. Montana percentages for these variables were compared to other studies and were found to be similar. Accident trends between Montana's six largest cities: Billings, Great Falls, Missoula, Butte, Helena and Bozeman were also investigated. Accident type percentages were similar for these cities.

Accident rates were calculated along the State Primary Routes in Montana to establish variables of influence and significant causal patterns. Twenty-five intersections were selected for further study, in which accident report files were obtained and collision diagrams were constructed. From these collision diagrams, relationships were investigated to determine trends for Montana's signalized intersections. Variables that were determined to affect accidents in Montana were traffic volume and population of the city in which the accidents occurred. Angle and rear-end type accidents accounted for the largest percentages of accident types. When compared to other states and studies, Montana's accident characteristics are similar.

Table of Contents

Page

Table of Appendices

List of Tables

List of Figures

Scope of Work

Background

Properly located and operated signals typically reduce the frequency of certain types of accidents, especially the right-angle type. However, some accidents, especially the rear-end type, can significantly increase. These general concepts, known and accepted for a long period of time, seem to be consistently confirmed by research.

Traffic demand increase in recent years in Montana has created the need and requests for signal control at many intersections. Public perception as opposed to engineering realities differ as to the safety benefits of signalized intersections.

Study Objectives

The objective of this study is to examine historical statistical and hard copy accident data at signalized intersections from across Montana to establish magnitude and rates, patterns and trends, and casual effects susceptible to correction.

The following tasks were performed to accomplish the objectives encompassed in Phase - I on this project:

Task A - Conduct Literature Review

Task B - Assimilate Accident Trend Statistics

Task C - Establish Variables of Interest

Task D - Determine Significant Causal Patterns

Task E - Conclusions and Recommendations

Task A - Literature Review

The study entitled "Safety Effects of Traffic Signal Installations" provided an extensive review of available studies on the safety effects of traffic signals. Issues such as accident statistics by type and severity, signal control types, delay, fuel consumption, and signal coordination of signalized intersections were highlighted.

Accident Statistics by Type and Severity

In the first study reviewed, statistics by accident type and severity were provided for different traffic control devices. Table 1 shows that property damage represented the highest severity class percentage and that right-angle accidents at two-way stop controlled intersections were much higher than at other types of control (1).

Accident Rates Per Year for Signalized Intersections

Another study documented accident rates per year for signalized intersections in the cities of Skokie, Illinois and Los Angeles, California. These accident rates are displayed in Table 2 and Table 3, respectively. Two generalizations can be made from this information. The first observation is that the average daily traffic and both accident numbers and accident rates are clearly related. The second observation is that accident rates at signalized intersections, in general, have a range of 0.55 to 2.50 accidents per million entering vehicles (mev) (1).

Signal Control Types and Traffic Accidents

The next issue discussed was signal control types and traffic accidents. The study provided accident statistics categorized by control type as shown in Table 4. The statistics shown in this table are based upon accident number only. Further review of this table suggests the following (1):

Table 1. Percentages of Accidents for Each Traffic Control Type

		SEVERITY				TYPE					
Location	Control	Property Damage	Personal Injury	Ped.	Fatality	Right Angle	Rear End	Fixed Object	Side Swipe	Ped.	AADT*
S. Phila.	Traffic Signals	70	18	12	0	26	24	31	7	12	6700
	Two-Way Stops	68	20	12	0	51	12	20	5	12	4400
	Four-Way Stops	77	11	12	0	23	17	40	8	12	6200
N. Phila.	Traffic Signals	68	20	12	0	33	23	22	10	12	6900
	Two-Way Stops	69	19	12	0	50	10	22	6	12	4400
	Four-Way Stops	79	8	13	0	17	17	44	9	13	3600

*AADT = Annual Average Daily Traffic (Entering Volume)

SOURCE: Reference (1).

Table 2. Accident Rates per Year for Signalized Intersections in Skokie, IL.

Entering ADT	11000-16000	16000-21000	21000-26000	26000-31000	31000-36000	36000-41000
Avg. Accident Per Year	7.5	10.3	18.1	20.6	30.6	33.8
# of Intersections	8	13	35	41	41	10
Change of Frequencies	3-13	3-18	5-30	3-73	12-60	14-61
Avg. Annual Accident Rate Per Intersection*	1.52	1.52	2.11	1.98	2.50	2.40

*Accident Rate per million vehicles calculated for the mid point of entering ADT.
SOURCE: Reference (1).

Table 3. Accident Rates for Signalized Intersections in Los Angeles, CA.

ADT Major	ADT Minor	# of Intersections	Avg. Annual Accident Rate Per Intersection	Standard Deviation
0-32000	0-6000	170	0.55	0.38
6000-32000	6000-10000	56	0.74	0.39
10000-32000	10000-14000	25	0.95	0.44
14000-32000	14000-26000	17	1.20	0.31

SOURCE: Reference (1).

Table 4. Sample Statistics for Data Stratified by Control Type

Type of Control	# of Intersections	# of Accidents/Year	Mean Accident/Year Per Intersection	Confidence Interval at $\alpha = 0.5$	% Rear-End	% Right Angle
Not Signalized	65	571	8.78	6.85, 10.71	26	74
Pretimed	126	2054	16.30	13.81, 18.79	54	46
Semi-Actuated	37	862	23.30	16.15, 30.45	62	38
Full-Actuated	29	638	22.00	14.68, 29.32	69	31
Volume Density	5	84	16.80	11.70, 21.90	66	24
Total	2622	4209	16.06	---	--	--

SOURCE: Reference (1).

- Mean accidents per year for unsignalized intersections are half of those for signalized intersections.

- As expected, right-angle accidents constitute the major percentage of unsignalized intersection accidents. Rear-end accidents constitute the major percentage of signalized intersection accidents.

Traffic Delay and Fuel Consumption

Another study that was reviewed researched the effects of signal installation on traffic delay. Results showed that signalization of an intersection generally increases delay on all of the approaches. Additionally, proportional increases in delay can be greater on the minor street at low volume levels, and the major street may experience a greater proportion of delay at peak volume levels (1).

The National Signal Timing Optimization Project, conducted in 1982, sought to develop better timing schemes with the ultimate goal of reducing delay and fuel consumption. Optimizing timing plans were developed using the TRANSYT7F computer program. It was reported that the average intersection can have annual delay reductions of 15.47 hours and an annual fuel savings of 10,524 gallons (39.8 cubic meters). These savings would translate into $28,695 per intersection per year (1).

In another study, the TRANSYT computer model was used to time intersections to examine the trade-off between fuel consumption and delay. The study reported that fuel consumption may be reduced by holding already stopped vehicles for a few more seconds to permit additional vehicles to proceed through the intersection without stopping (at the expense of delay) (1).

Signal Coordination

A study conducted in Australia investigated accidents at intersections nine months before and nine months after the signals were coordinated. The results of the study showed conclusively that there was a substantial reduction in accidents when traffic signals were coordinated. Quite high annual rates of return on the investment by accident savings alone were indicated. As an extension of this study, an investigation into approximately 15,000 accidents that occurred on eight coordinated traffic signal systems in a period of six and a half years was performed. The purpose of the study was to measure the effect of coordinated traffic signal systems. A 20 percent improvement in the total number of accidents occurring within the systems was obtained. The major improvements occurred in pedestrian-involved and right-angle accidents without any significant change in any other accident type (1).

Accident Rates and Congestion

A research project entitled "Urban Intersection Accident Rates and Congestion" investigated the existence and nature of the relationship between the degree of congestion and the level of safety at urban intersections. The method used to describe the quality of traffic flow was the ratio of traffic volume to capacity (v/c). Traffic volumes were calculated by counting and recording the number of vehicles for a specific time period. The number of vehicles per hour (vph) was determined for each intersection being analyzed during the morning and evening peak periods. The capacities of the intersections were calculated using the methods presented in the *1985 Highway Capacity Manual* (2) to find the greatest number of vehicles that a location should be able to accommodate under prevailing traffic and roadway conditions. In general, the peak hour traffic volume entering the intersection should be less than the calculated capacity; therefore $v < c$ and $v/c < 1.0$ (3).

The purpose of this research project was to evaluate the variation in accident rates that accompanies changes in the degree of congestion, as reflected by the ratio of traffic volume to capacity. Accident rates were used instead of accident frequency because accident rates incorporate a measure of the opportunity for an accident to occur. The study plan for the project consisted of the following five steps (3):

1. Collect existing peak period intersection traffic volume data from the files of the City of Albuquerque (and other cities in New Mexico, if the data were available).

2. Through appropriate field studies, assemble the information necessary to calculate the capacity of these intersections.

3. Use New Mexico's computerized record system to determine the peak period accident frequency at these locations.

4. Use the information assembled in steps 1-3 to calculate the intersection capacity, the v/c ratios, and the accident rates.

5. Analyze the results of step 4 to determine if a meaningful relationship could be established between accident rates and measures of congestion.

The sample size of 326 locations included a myriad of design and operational characteristics. For example, the sample included 3-, 4-, and 5-leg intersections including some intersections on one-way streets. Also, approach speed limits ranged from 25 mph to 50 mph. The usage and number of lanes of the approaches ranged from a single lane shared by through, left-turn, and right-turn traffic to ones with multiple through lanes, dual left-turn lanes, and exclusive right-turn lanes. The information collected is given in Table 5 (3).

The databases developed for this project were used to possibly identify the existence of a relationship between peak hour accident rates and intersection congestion. Plots of the accident rates for the morning and evening peak hours are shown in Figures 1 and 2, respectively. The scattered data points do not suggest any obvious functional relationship between the volume and intersection accident rates. The least squares linear regression has an r^2 value of only 0.01. These findings indicate that changes in the v/c ratio from values of 0.0 to 1.2 explain only a minute amount of the variation in accident rates. The morning peak hour results were similar (3).

Table 5. Characteristics of the Intersections Studied

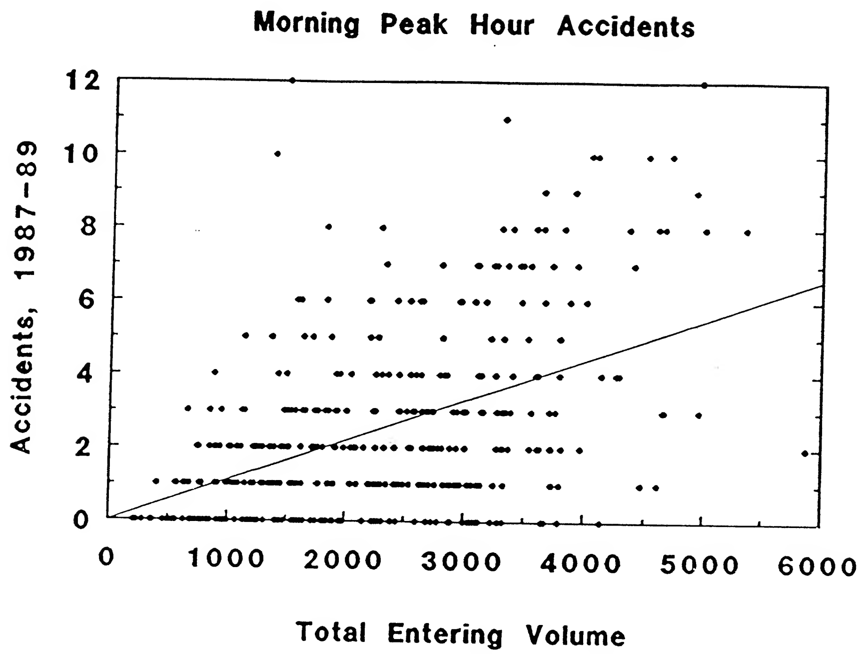
	Morning	Evening
Peak Hour Entering Volume		
Lowest	209	309
Average	2240	2840
Highest	5877	7474
Peak Hour Accidents		
Lowest	0	0
Average	2.7	3.9
Highest	14	27
Total Accidents	890	1274
Peak Hour Accident Rate (per mev)		
Lowest	0.00	0.00
Average	1.56	1.76
Highest	5.85	14.41

SOURCE: Reference (3).

The research that was presented in this report described an effort to relate the level of congestion to the peak hour accident rates at urban intersections. The following results were obtained pertaining to peak hour conditions in Albuquerque (3):

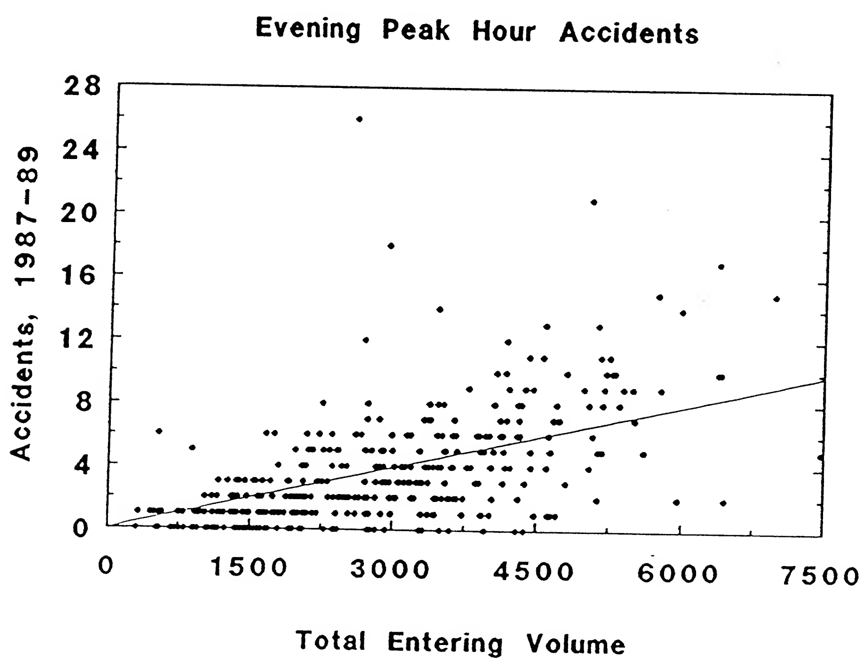
- Accident rates at signalized intersections average 1.56 and 1.76 accidents per million entering vehicles during the morning and evening peak hours, respectively.
- The number of peak hour accidents at signalized intersections is highly correlated with the number of entering vehicles; the rate of peak hour accidents is weakly correlated with the number of entering vehicles.
- Peak hour v/c ratios vary widely among intersections; these ratios have a significant positive correlation with the volume of entering traffic.
- Quadratic models explain approximately 10 percent of the observed variation in intersection peak hour accident rates as a function of v/c ratios. However, the models are not sufficiently reliable to serve as predictive tools.
- Minimum peak hour accident rates tend to occur within the range $0.6 \leq v/c \leq 0.8$; higher v/c ratios tend to be associated with increasing accident rates.

Figure 1. Morning Peak Hour Accidents



SOURCE: Reference (3).

Figure 2. Evening Peak Hour Accidents



SOURCE: Reference (3).

Clearance Interval Timing

The article entitled "Effect of Clearance Interval Timing on Traffic Flow and Crashes at Signalized Intersections" investigated the consequences of having insufficient clearance intervals (yellow and all-red phases). For instance, when a clearance interval is not properly timed, drivers may be forced to choose between abruptly applying the brakes or losing the cross-street red-light protection while crossing the intersection. Abrupt stopping can result in rear-end accidents, and the loss of cross-street red-light protection can lead to right-angle accidents (4).

A method of determining clearance interval timing was published by Gazis and others in 1960 (5). The method was used to minimize the number of drivers who can neither stop safely nor clear the intersection before the onset of the red light. The 1982 edition of the *Transportation and Traffic Engineering Handbook* (6) used 3.0 m/sec^2 (10 ft/sec^2) as the threshold value for the deceleration rate in the timing formula Gazis developed. The previous edition (7) used 4.6 m/sec^2 (15 ft/sec^2), which was later felt to be too high because drivers would normally not apply the brake that hard to stop after the yellow onset. A survey conducted in 1980 of intersections in the southeast concluded that about one-half had clearance intervals shorter than those calculated using the excessively high 4.6 m/sec^2 (15 ft/sec^2) deceleration rate recommended by the handbook at the time of the survey. Additionally, the survey reported that almost none of the intersections were adequately timed when compared with clearance intervals based on the more recently recommended lower rate of 3.0 m/sec^2 (10 ft/sec^2) (4).

To further investigate the effects of clearance interval timing on accidents, traffic flow and crash data from 91 intersections throughout the United States were collected. The intersections represented a wide range of parameters, including (4):

- Yellow signal laws (allowed to enter versus stop on yellow),
- Average approach speed (56.3 to 88.5 kmph (35 to 55 mph)),
- Cross-street width (6.1 to 37.8m (20 to 124 feet)),
- Yellow phase duration (2.8 to 5.7 seconds), and
- All-red phase duration (0 to 3.0 seconds).

Traffic data were collected using a traffic data logger (TDL). As a vehicle passed through the intersection the status of the traffic signal was recorded as well as the mean speed of the vehicles. Intersection crashes that involved two vehicles during 1979-1980 were identified using police-reported data. Crashes in which both vehicles were traveling on the monitored approach (mostly rear-end accidents) were grouped together; crashes where one of the two vehicles was traveling on the monitored approach and the other on the cross-street (mostly right-angle accidents) were placed in a second group. Crashes that did not fall into either group were not analyzed (4).

After extensive preliminary data analysis, the following six variables were identified as being related to traffic flow and crash rates at signalized intersections: cross-street width, estimated average crossing time, indirect measures of yellow signal timing, indirect measures of the yellow and all-red phases of signal timing, the average daily traffic (ADT) for the monitored street, and the ratio of the monitored street ADT to the cross-street ADT (4). Through the standard statistical procedure of cluster analysis, these variables were used jointly to sort the intersections into eight relatively homogeneous clusters. The variation in crash rates between the intersection clusters was statistically significant at the 0.05 level. The neighboring clusters with nonsignificant crash rate differences were combined into five *overlapping* intersection cluster groups, referred to as A, B, C, D, and E, to smooth out the variations in the other variables. The average values of more than 30 intersection variables were calculated for each of the five intersection cluster groups. The variables included nine crash rates based on alternative definitions, description of the physical layout, signal timing and traffic flow measures both just before and just after the onset of yellow. Cluster analysis was used to group the intersections in terms of their characteristics and then the groups were ranked in order of increasing crash rates (8). (See Table 6.)

Table 6. Intersection Averages For Characteristics By Cluster Group

Variable	*Cluster Group Average* A	B	C	D	E
Crash Rates[a]					
(Shared approach crashes)$^{1/2}$	0.54	0.68	0.78	0.96	1.21
(Cross-street crashes)$^{1/2}$	0.59	0.71	0.81	1.01	1.18
(Combined)$^{1/2}$	0.92	1.11	1.26	1.53	1.84
Signal Timing					
Recommended clearance interval, sec[b]	4.76	4.73	4.91	4.96	5.23
Actual clearance interval:					
Yellow, sec	4.07	3.73	3.72	3.70	3.88
All red, sec	1.16	1.39	1.37	1.11	0.81
Recommended/actual clearance interval	1.10	1.08	1.04	0.97	0.90
Implied Deceleration Rate[c]					
From yellow, ft/sec^2	13.5	16.1	19.2	20.0	23.8
From yellow and all red, ft/sec^2	8.5	8.7	9.5	10.6	13.2
Clearance Flow[d]					
During yellow	1.99	1.53	1.28	1.30	1.18
During yellow and all red	2.96	2.72	2.36	2.30	1.89
During recommended yellow and all red[b]	2.74	2.50	2.30	2.47	2.35
Difference	−0.22	−0.22	−0.07	0.17	0.46
Traffic Volume					
Monitored street ADT, 1000s	21.1	25.3	25.0	21.2	16.6
Cross street ADT, 1000s	8.1	11.7	15.5	14.9	19.4
ADT ratio	4.7	3.1	2.7	2.4	1.3
Approach speed, ft/sec	55.2	53.8	52.4	51.7	48.8
Cross street width, ft	38.1	39.4	48.7	52.3	67.7
Crossing time, sec	0.70	0.74	0.98	1.05	1.45

[a]Crash rate = 10,000 × (72/cycle length) × (crashes/ADT).
[b]Recommended clearance interval was calculated using current ITE formula, $Y + AR = t + (v/2a) + (w+L)/v$, with deceleration rate (a) equal to 10 ft/sec^2.
[c]ITE formula was solved using existing intersection parameters for deceleration rate a.
[d]Ratio of traffic flow after yellow onset to traffic flow just before yellow onset.

SOURCE: Reference (4).

Higher than average crash rates were more strongly associated with intersection cluster groups having less adequate average clearance intervals than with intersection cluster groups having more adequate average clearance intervals. This association was noted regardless of the manner in which the crash rate was calculated. The range of clearance interval durations extended from 10 percent shorter than recommended to 10 percent longer. The group with the least adequate clearance interval had a significantly higher crash rate than the group with the most adequate interval (8).

This study examined the overall pattern of association between intersection characteristics, clearance intervals, traffic flow, and crash rates and found that the greater the deficiency of clearance interval timing, the higher the proportion of drivers who enter intersections and do not clear them during the clearance interval. Furthermore, clearance intervals that are too short are statistically associated with larger than average crash rates. It was also noted that reduced separation of the two traffic streams and increased breaking by drivers who do not want to enter the intersection without protection from cross-street traffic lead to substantial increases in accidents. Finally, the results of this project, published in 1985, have demonstrated that even the currently accepted practices of determining clearance interval timing are commonly not employed (4).

All-Red Clearance Intervals

The use of all-red clearance intervals at signalized intersections has been a topic of debate for traffic engineers for several years. An all-red clearance interval is the period of time that the red signal is displayed after the yellow interval to clear the intersection before releasing the opposing movement. A research project entitled "The Effects of the All-Red Clearance Interval on Intersection Accident Rates in Indiana" was performed to assess the short-term and long-term accident rate reduction effects of the installation of an all-red clearance interval. Previous studies have investigated the short-term accident rate reductions with most studies showing a decrease in accident rates over the first year, but none of the studies have looked beyond the first year or two of the all-red implementation. Also, these other studies did not assign a control group to assess possible reductions in accident rates that were not related to the all-red clearance interval (9).

The approach the researchers took involved calculating annual Indiana accident rates from two years before to five years after the implementation of the all-red clearance interval. Accident rates for left-turn, rear-end, right-turn, and right-angle accidents, in addition to the total number of accidents, were investigated. Accident data for the years 1981 to 1987 were obtained for two groups of twenty-five intersections. One group was used as a control group that had not received the all-red clearance interval. The other group, the treatment group, had received the all-red clearance interval between 1982 and 1985. The control group intersections and the treatment group intersections were paired based on the entering volume, angle of intersect, and approach speed limits (9).

Statistical analyses were used to determine the effectiveness of the all-red clearance interval. The Wilcoxon Signed Rank test, the Student's t-test, and the Chi-Square test were utilized. The following results were obtained (9):

- Using the Wilcoxon Signed Rank test produced few statistically significant differences between the treatment and the comparison groups. This indicates that the all-red interval did not reduce accident rates significantly when compared to intersections that lacked the all-red interval.

- With the Student's t-test, the only statistically significant difference was found with right-angle accident rates at treated intersections for the period one-year before the all-red interval implementation and one-year after. All other tests yielded no difference. This indicated that accident rates did not decrease significantly after the implementation of the all-red interval.

- With the Chi-Squared test, few statistically significant differences were found at treated intersections. Thus, for the years analyzed before and after the all-red interval was added, no significant accident rate reduction took place.

The report advises that these results should be used cautiously to substantiate or refute sweeping statements concerning the all-red clearance interval because the study area was confined to Indiana and relatively few intersections (twenty-five pairs) were studied. Also, the results alone should not be used as justification to remove the all-red from the cycle, but they can serve as an advisory against implementing the all-red with the assumption that the all-red clearance interval will significantly decrease accidents (9).

Automatic Enforcement of Red Light Violations

A study entitled "Automatic Enforcement of Speed and Red Light Violations: Application, Experiences and Developments" reviews other recent studies pertaining to these issues. "Automatic enforcement" refers to the automatic detection and recording of the license plate number of the vehicle involved in a traffic offense. Once a violation has been identified, further processing and action must be taken.

Automatic enforcement was first used by Switzerland, Germany and Sweden in the early 1970's. Norway, Australia, Great Britain, the Netherlands, Japan, Singapore and the United States have also applied automatic enforcement since that time. The use of automatic enforcement supporting conventional traffic enforcement has been minimal and the research pertaining to it is sparse (10).

In a study performed in Stockholm, Sweden, five intersections were installed with a detector loop operated camera. At these crossings the share of violations was low initially, thus there were not any great changes. The experiment was done without posted signs informing the drivers about the red light camera or without a public information campaign. It was possible that most of the drivers were not aware of the automatic enforcement system (10).

In Great Britain on a road near London, red light running was common. Red light cameras were installed at several intersections. Within one month after the enforcement had started, violations went down considerably. At some intersections a decrease of up to 80 percent was seen (10).

At a busy intersection in Australia, red light running detection equipment was installed. Initially, no information or warning was given to the public about the automatic enforcement and

300 violations were recorded per week. After the public was notified, the number of weekly violations was reduced to about 20 (10).

More studies are needed to further verify that automatic enforcement reduces violations. One important aspect of installing automatic enforcement is public awareness of the increased risk of apprehension. If the public is not made aware of its use, the learning process will take more time and the system will not be as effective. Additional concerns are that the photographs should be used to identify the vehicle only, not the driver. Also, the system is vulnerable to vandalism; thus, vandal-proof construction is needed. Another concern is that drivers will develop an expectancy of the intersections that are equipped with the red light cameras and will modify their driving behavior accordingly (10).

An article entitled "Transportation Tips: A Review of Photo Enforcement" discusses the current use of photo enforcement in North America. The use of photo enforcement in many municipalities is due to increasing traffic accidents and cutbacks in city budgets. In addition to using photo enforcement for traffic signal red light violations, it is also used for speeding violations, railroad crossing violations, and air pollution emissions violations (11).

Permanently mounted cameras work in conjunction with the traffic signal to automatically photograph the front of vehicles that run red lights. Detectors placed in the crosswalk area are used to detect the vehicles that enter the intersection after the light has turned red. A nationwide survey was performed by the Insurance Institute for Highway Safety which showed that 66 percent of the people surveyed said they favor the use of red light cameras as compared with 28 percent opposed. In traditional enforcement, the officer often follows the vehicle through the intersection which increases the accident potential. This is one reason why photo enforcement is favorable over traditional enforcement . The City of New York has been very successful with their red light enforcement program (11).

Additionally, the use of photo radar speed enforcement can reduce accidents. Recently, several cities in North America have begun utilizing this technology. Depending on the type of system used, the program will involve a radar gun, two cameras, an enforcement officer, and a speed display board. Normally, the enforcement officer will set the speed limit at which the citations are issued based on the present conditions. A photograph is taken of the front and rear of the vehicles that exceed the set limit. A citation is then sent to the registered owner of the vehicle. The registered owner of the vehicle is then given the opportunity to review the photo and discuss the citation. Two examples of the effectiveness of photo radar enforcement were cited in the article. National City, California, experienced a 26 percent reduction in accidents over the first 10 months of their program. Additionally, the town of Paradise Valley, Arizona, experienced a 50 percent reduction (11).

Flashing Signal Operation

The study entitled "Flashing Signal Accident Evaluation" assessed the relative accident impacts of flashing signal operation and stop-and-go signal operation in Oakland County, Michigan. The analysis was conducted to determine the following (12):

- Whether an accident problem exists at intersections where signals are placed on a flashing mode during off-peak, nighttime hours;
- What levels of accident experience can be expected under different options; and
- Appropriate criteria for the development of signal-operation procedures during off-peak, nighttime hours.

The relative accident impacts of flashing versus stop-and-go (the standard green-yellow-red cycle) signal operation were investigated. The study was conducted in two phases. The first phase involved a before-and-after analysis of accidents at six 4-leg intersections where flashing operations had been eliminated. The next phase was a comparative analysis (with-and-without study) of accidents at intersections categorized by signal operation (such as flashing versus stop-and-go), by intersection type (such as 3-leg or 4-leg) and by the functional classification of the intersecting roadways (12).

In the first phase of this research project, the six study sites for the before-and-after analysis were chosen at random from a listing of pretimed signals where flashing operation had been eliminated. At least three years of before and after accident data were required for the study. Paired t-tests were utilized to determine if the accident frequency and accident rate per million vehicles changed significantly in the after period for the six study sites. Accident types were categorized as right-angle accidents, left-turn accidents, rear-end accidents, and other accidents. Ten additional intersections, where signals remained on flash operation during the off-peak, nighttime hours throughout the study period, were randomly chosen to provide a control group for the before-and-after study and to supplement the analysis of other factors that may have some influence on accidents levels. These factors included hourly intersection traffic volume, main street hourly volume to minor street hourly volume (the volume ratio), and drinking involvement (12).

The second phase of the analysis included a with-and-without study to compare the mean right-angle accident rates and frequencies per year-hour of flashing signal locations and stop-and-go locations. Flashing signal locations were categorized by intersection type and functional classification of the intersecting roadways. The mean frequency and rate of right-angle accidents per year-hour were calculated for hours when the signals flash for each intersection type. Several t-tests were conducted to determine if the means differed significantly from each other and the mean for the hours of 11 p.m. to 6 a.m. at a sample of 21 4-leg intersections where the signals operate on a stop-and-go basis 24 hours a day. Three years of accident data were analyzed for all intersections (12).

The results of both the before-and-after study and the with-and-without study clearly indicated that significant reductions in nighttime right-angle accident frequency and rate can be attained by eliminating flashing signal operation at 4-leg intersections of two arterial roadways. The 4-leg intersections of arterial roadways where signals flash during off-peak, nighttime hours experienced significantly greater frequencies and rates of right-angle accidents than other intersection types. The results of the with-and-without study are shown in Table 7.
Other results include the following (12):

- The rate of right-angle accidents for volume ratios of 2 to 1 or less was significantly higher than the rate for volume ratios of 4 to 1 or greater at flashing locations. This result confirms the findings of other studies.

- Hourly intersection traffic volume had a negligible impact on right-angle accident frequency during hours of flashing operation.

- Drinking involvement was significantly over-represented in right-angle accidents at flashing signal locations.

- Right-angle accidents at flashing signal locations peaked between midnight and 3 a.m., after which they dropped dramatically. Right-angle accidents at stop-and-go locations peaked between 2 a.m. and 3 a.m. (bars close at 2 a.m. in Michigan).

- Although it was found that rear-end accident frequency was significantly higher at stop-and-go locations during late night hours, no significant difference in rear-end accident rates per million vehicles was found between the two operating modes. Therefore, the difference in rear-end frequencies may be attributable to the relative volumes of traffic at stop-and-go and flasher locations.

Table 7. T-Test Results: Comparative Right-Angle Accident Frequencies

Hourly Mean	Intersection Type (operational)	Arterial-Arterial, 4-Leg (flash)	Arterial-Collector, 4-Leg (flash)	Arterial-Arterial, T (flash)	Arterial-Collector, T (flash)	Arterial-Arterial, 4-Leg (stop-and-go)
0.224	Arterial-arterial, 4-leg (flash)	-	SIG	SIG	SIG	SIG
0.049	Arterial-collector, 4-leg (flash)	-	-	SIG	SIG	NS
0.019	Arterial-arterial, T (flash)	-	-	-	SIG	SIG
0.000	Arterial-collector, T (flash)	-	-	-	-	SIG
0.092	Arterial-arterial, 4-leg (stop-and-go)	-	-	-	-	-

Note: $\alpha = 0.01$, SIG = significant difference, NS = not significant.
SOURCE: Reference (12).

In addition to the right-angle accident reduction benefits resulting from flash elimination, the disadvantages must be considered. Increased delay may result as well as an increase in rear-end accidents. Also, the elimination of flashing signal operation will result in an increase of hydrocarbon and carbon monoxide emissions because of increased delays. These disadvantages can be minimized through signal optimization, synchronization, altering cycle lengths, or semiactuation (12).

Several criteria for eliminating flashing signal operation were suggested. For example, right-angle accident frequency and rate should be major factors. Also, intersections with sight restrictions should be considered for eliminating flashing signal operation to reduce right-angle accident frequency. Accident warrants should be based on the critical levels of right-angle accidents at stop-and-go locations, but not flashing signal locations, because the objective of eliminating flashing signal operation is to reduce right-angle accidents to levels experienced at stop-and-go locations (12).

The article entitled "Evaluation of Flashing Traffic Signal Operation" states that operating traffic signals in the flashing mode is a viable alternative to operating traffic signals in normal (green-yellow-red) operation in many instances. Some of the common uses for flashing traffic signals include: railroad preemption, in school areas, during low-volume periods, as the result of a signal malfunction, and prior to/following signal installation/removal. This report described the following activities: a literature review of previous flashing signal research, a survey of current practice related to flashing signal operation, an operational analysis comparing flashing signal operation to other types of signal operation, and an investigation of accident trends. The findings were then used to develop a series of guidelines addressing the conditions under which it is appropriate to place traffic signals in flashing operation, and the selection of the flashing mode (yellow/red or red/red) (13).

The conclusion from the literature review for this report shows that flashing operation of traffic signals has been widely used over the years as an alternative to operating signals in the normal mode (green-yellow-red) at all times. However, there are no comprehensive guidelines for the operation of flashing signals, nor is there a great amount of information about the impacts of flashing signal operation. Most of the studies about flashing signal operation have focused on the relationship between flashing operation and accidents. These evaluations have attempted to establish a relationship between accidents at flashing intersections and some other measurable factors, such as traffic volume, volume ratio, and time of night. Additional factors that have been considered include a reduction in delay, energy conservation, and driver comprehension of flashing signal operations. The following conclusions about flashing signal operation were obtained (13):

- The use of flashing operation during low-volume conditions has the potential to reduce stops and delay for major street traffic and reduce delay to minor street traffic. This in turn can result in reduced fuel consumption and reduced fuel emissions.

- Flashing operation will reduce electrical consumption of the traffic signal.

- Accidents during flashing operation appear to be more numerous than accidents during normal operation. In particular, right-angle accidents seem higher with flashing operation than with normal operation.

- Several studies have identified a relationship between the volume ratio and accident rates at intersections with flashing operation. However, the threshold value for the volume ratio varies between studies. The literature review identified the following volume ratio thresholds at which flashing operation reduces the likelihood of accidents:

  - Volume ratio of three or more.
  - Volume ratio of four of more.
  - Volume ratio of two or less.

- The relationship between volume and accidents at intersections with flashing operation is uncertain. The following relationships were found in different studies:

  - Flashing operation appears to be safer when the two-way volume on the major street is less than 200 vph.
  - There is no relationship between accidents and volume.

- The volumes used as the basis for the volume ratio vary between studies.

- Yellow/red flashing operation should not be used if the following accident levels are reached or exceeded at an intersection:

  - Three right-angle accidents in one year during flashing operation (short-term rate).
  - Two right-angle accidents per million vehicles during flashing operation, if the rate is based on an average of three to six observed right-angle accidents per year (long-term rate), or

- 1.6 right-angle accidents per million vehicles during flashing operation, if the rate is based on an average of six or more right-angle accidents per year (long-term rate).

- If the accident rate is low with normal operation, it will remain low with flashing operation.

- Accidents at intersections with flashing operation are more common in the hour following the time that the nightclubs close.

- Drivers facing a flashing red indication do not appear to understand that the conflicting traffic may be facing a flashing yellow or a flashing red indication.

- Red/red flashing is a safer mode because all vehicles must stop.

- Yellow/red flashing is the more efficient mode because major street vehicles are not required to stop.

- The delays and congestion which can result from red/red flashing may be undesirable during daytime hours.

- Congestion resulting from red/red flash may delay the arrival of police, ambulance, or signal technicians during some portions of the day.

- Yellow/red flashing produces less delay than all other forms of signal control.

- Some of the findings of previous studies are based on data from a limited number of intersections for a limited period of time.

Several surveys focusing on the use of flashing signal operation were conducted or identified. The most extensive survey, the Texas Current Practices Survey performed by the Texas Transportation Institute, was conducted as part of the research to identify how flashing operation is utilized in Texas. The responses to the different surveys show some of the flashing signal practices in Texas and the United States and also provide some insight into the decision-making process related to implementing flashing operation. The following conclusions are from the results of the various flashing signal surveys (13):

- Flashing operation of traffic signals is a widely used practice.

- Some types of flashing operation are more common than others. Among the most common forms of flashing operation are:

    - Emergency or conflict flash.
    - Signal installation and/or removal.
    - Low-volume periods, typically late-evening/early-morning hours.
    - Railroad preemption.

- There is a lack of adequate guidelines for implementing flashing operation; therefore, the decision to implement flashing operation varies widely from one locale to another.

- There is a significant interest in the development of guidelines for flashing traffic signal operation.

- Several different factors are typically considered when evaluating whether to implement flashing operation. The most commonly considered factors are:

    - Traffic volume.
    - Traffic volume as a percentage of signal warrant.
    - Time of day.
    - Accidents.
    - Day of the week.

- The use of flashing operation within the same geographic area may vary between neighboring agencies.

- Although flashing operation appears to be more common with pretimed controllers, it is also often used with actuated controllers.

- Although flashing operation is widely used, few agencies have evaluated the effectiveness of flashing operation.

- Selecting the mode of flashing operation (yellow/red or red/red) varies between agencies. The following factors are considered by some agencies in deciding the mode of flashing:

    - Volumes.
    - Accident history.
    - Consistency with other flashing signals.
    - Geometrics and sight distance.
    - Speeds.

- It is not unusual to use both modes of flashing operation at the same intersection. Yellow/red flash is used for low-volume or other normal flashing operation and red/red flash is used for emergency flashing operation.

- Traffic engineers are concerned with driver understanding of flashing operation, particularly with respect to whether drivers recognize that major street traffic may be facing a yellow indication.

- The use of flashing operation of traffic signals as a response to snowy or icy weather does not appear to be a common occurrence.

- Many of the agencies which have implemented flashing operation have not experienced an increase in accidents at those intersections with flashing operation.

- Dimming the signal indications at night may reduce electrical power consumption.

- Some agencies start flashing operation for all signals at one time instead of varying the start of flashing operation according to the volume levels at a specific intersection.

- Some agencies delay the start of flashing operation on Thursday through Saturday nights until after the nightclubs have closed.

- Traffic engineers are concerned about driver behavior at intersections which may use yellow/red during low-volume flashing and red/red for emergency flash.

- The guidelines found in the Manual on Uniform Traffic Control Devices (MUTCD) for flashing signal operation are limited.

- The Texas MUTCD states that flashing operation can be implemented at intersections with pretimed control when volumes are 50 percent of the signal warrant volumes for 4 or more hours. However, it makes no mention of the use of flashing operation with actuated controllers. The national MUTCD does not contain any mention of when it is appropriate to use flashing operation.

- Previous editions of both the national and Texas MUTCDs contained more detailed guidelines about when flashing operation could be used.

- The origin of the 50 percent of warrant volumes for implementing flashing operation could not be identified. The decision to use 50 percent was most likely based on engineering judgment.

- The MUTCD (both Texas and national) do not mention the use of the red/red flashing mode.

- The MUTCD states that a flashing yellow indication should normally be displayed to traffic on the major street.

- The MUTCD states that if a flashing red indication is used for the left-turn movement and a flashing yellow is used for the through movement, the flashing red indication should be shielded or positioned so that through traffic will not be exposed to visual conflict from the left-turn indication.

No formal guidelines exist that suggest when it is appropriate to place a signal in the flashing mode of operation (emergency flash excluded). However, several studies in the literature review contained recommendations indicating when flashing signal operation is favored over normal operation. This study evaluated various types of signal operation using the TEXAS and NETSIM computer models for an isolated intersection and a three-intersection signal system. The results of the operational analysis compared favorably with the findings of a Federal Highway Administration (FHWA) study. The following conclusions were the results of both studies (13):

- Yellow/red flashing operation produces less delay (overall versus stopped) than any other form of normal operation under all combinations of major and minor street volumes.
- Red/red flashing operation produces less delay (overall versus stopped) than pretimed operation under most traffic volume combinations, even where signals are coordinated on an arterial.
- Red/red flashing operation produces more delay (overall versus stopped) than actuated (coordinated or isolated) at most traffic volume ratios.

In general, red/red and yellow/red flashing operation produced less delay than the other signal operations for traffic volumes that were more than approximately 50 percent of the MUTCD Volume Warrant, which is about 450 vph per approach. The analysis indicated that for traffic volumes greater than 500 vph per approach, both red/red and yellow/red flashing operation start to produce as much or more delay as most normal signal operations (13).

The study identified different circumstances in which it may be advantageous to use flashing operation from a delay standpoint. The situations are described below (13):

Use of Red/Red Flashing Operation

Pretimed Operation. Red/red flashing operation reduces delay only for the larger intersection geometrics where pretimed operation is in use. Typically, red/red flashing operation can reduce delay when: the major street traffic is less than 50 percent of the MUTCD Volume Warrant (approximately 500 vph), the existing traffic signal control is pretimed operation, and the intersection is large (e.g., 5x4 lanes or 5x2 lanes). Red/red flashing operation does not reduce delay for any of the scenarios where pretimed operation was the existing condition and the geometric configurations were small.

Actuated Operation. In general, there are no advantages in changing actuated operation to red/red operation.

Use of Yellow/Red Flashing Operation

Pretimed Operation. Yellow/red flashing operation can reduce the total delay for any geometric configuration when traffic volumes are less than 50 percent of the MUTCD Volume Warrants. The amount of delay saved in changing to yellow/red flashing signal operation from pretimed operation ranged between $^1/_2$ to $^5/_6$. The exception to this is for 5x2 and 4x2 lane intersections with major street volumes greater than 250 vph and a volume ratio less than two. For those intersections, the delay from yellow/red flashing operation was more than the delay for the pretimed operation.

Actuated Operation. Yellow/red flashing operation can reduce the total delay when the geometric configurations are large (e.g., 5x4 and 5x2 lanes) and the traffic volume ratio is greater than three. Delay can be reduced by approximately 50 percent.

The study found that the statistical analysis of nighttime accidents did not provide a clear advantage for operating signalized intersections in the flashing mode during nighttime hours with respect to accidents. This is partially due to the large percentage of intersections that did not have an accident during the four year study period. Approximately 56 percent of the intersections had no accidents. The complete absence of rural nighttime accidents impeded any further collision or collision-severity evaluation for those locations. However, in the urban analysis certain results correlated with previous research findings, such as an increase in angle accidents and in the severity of accidents for flashing operations. These two measures have shown statistically significant increases in all of the previous studies investigated. In the studies reviewed, it was reported that volume ratios between two and four showed significant increases in intersection accidents. Additionally, the studies revealed that angle accidents contributed heavily to the increase in total accidents. One of the previous studies examined the total traffic volume entering the intersection for several volume ratio classes and concluded that accidents increased when the main street two-way volume was greater than 200 vph during flashing operations (13).

The findings of this study and a previous study point to the fact that daytime accident frequency can be used to evaluate the safety impacts of implementing flashing operation. A previous study stated that "*...locations with low accident experience during the flashing operation will not have increased accident experience during the same time period if the signals are placed on 24-hour operation.*" The accident analysis described in the Texas Transportation Institute study discovered that intersections which had zero accidents in the two-year period after flashing operation was implemented also had zero daytime accidents during the two-year period prior to the implementation of flashing operation. This finding can be helpful in determining the feasibility of implementing flashing operation. If an intersection has experienced zero accidents during the previous two-year period, it appears that flashing operation can be safely implemented. However, the presence of one daytime collision does not indicate an accident trend or an unsafe condition because of the random nature of accidents. Thus, the presence of one daytime accident during the previous two-year period should not prevent flashing operation from being implemented (13).

The study findings indicate that the decision to implement flashing operation relies heavily on the use of engineering judgment to evaluate the various factors which impact the use of flashing operation at a traffic signal. This research project developed a number of guidelines or procedures that can be used to aid the traffic engineer in making a decision. However, it should be noted that some of these guidelines have not been tested in actual practice. Additionally, the findings of this research indicate that flashing operation should not generally be used unless an engineering study of the intersection conditions indicate that flashing operation would be of greater benefit than normal operation. The following guidelines were presented in the research (13):

- **Mode of Flashing Operation.** The decision to use yellow/red or red/red flash should be based on the delay and accident impacts. The operational analysis conducted for this study indicated that yellow/red flashing operation is most effective when the volume ratio is three or more. At ratios below three, red/red flashing operation results in lower delay. Several previous research studies have also found that accidents tend to increase as the volume ratio drops to a range between three and four. Based on these findings, the following guidelines should be considered in the selection of flashing mode, *unless the guidelines for specific types of flashing operation indicate otherwise*:

    - Yellow/red flashing operation should be considered if the volume ratio is three or more unless adequate sight distance is not available.

    - Red/red flashing operation should be considered if either of the following conditions exist:

        - The volume ratio is less than three.
        - Adequate sight distance is not available.

- **Adequate Sight Distance.** Sight distance should be checked at all intersections where flashing operation is used. If yellow/red flashing operation is to be used, the intersection sight distance should meet the requirements set forth for Case III in the AASHTO Green Book. If the proper sight distance is not available, then red/red operation should be used.

- **Accident Experience.** If the total number of accidents during the most recent two-year period of normal operation is one or less, then the nighttime flashing operation can be considered as an alternative control strategy. The accident analysis conducted for this study indicated that although flashing operation as a whole typically causes an increase in accidents, intersections with low accident experiences in normal operation also have low accident experiences in flashing operation. The research was not able to determine a statistically significant relationship between nighttime accidents during normal operation and nighttime accidents during flashing operation.

- **Time of Flashing Operation.** When flashing operation is used on a regularly scheduled basis at several intersections in an area, flashing operation should start and end at the same time for all intersections.

- **Flashing Compatibility.** If more than one type of flashing operation (such as low-volume and emergency flash) is used at a single intersection, the compatibility should be checked to make sure that all types use the same flashing mode (yellow/red or red/red). This typically means that emergency flashing should use the same mode as the other types of flashing operation at the intersection. This guideline is intended to reduce the possibility that a driver can encounter two different types of flashing operation during the same day.

- **Education.** Educational efforts should be undertaken to improve driver knowledge of flashing signal indications. Potential methods of improving driver knowledge include increasing the emphasis in driver education/defensive driving courses and/or including flashing signal operations in a series of public service announcements on traffic control devices.

- **Left-Turn Signal Head.** Section 4B-6 of the Texas MUTCD indicates that a left-turn signal head may use a flashing yellow or a flashing red indication. If the color of the flashing indication in the left-turn signal head is different from that of the through lanes, then the left-turn signal head must be "*adequately shielded or positioned so that through traffic on the approach will not be exposed to substantial visual conflict from the left-turn signal indications*".

- **Flashing of Left-Turn Signal Head.** If the left-turn signal head uses a flashing red indication while the signal head for through movements uses a flashing yellow, the two indications should be flashed alternately. Although this issue was not investigated in the study, the guideline is based on the philosophy that indications of different colors should not be shown simultaneously.

- **Volume Ratios.** In the absence of hourly volume data, the ratio of major to minor street traffic can be determined from the ADT for each street.

- **Pedestrian Signals.** Pedestrian signals should not be illuminated when the traffic control signal is using flashing operation.

The following Guidelines for Flashing Operation during Nighttime, Low-Volume Conditions were presented. The thought process for using these guidelines is indicated by the flow chart in Figure 3 (13).

- **Actuated Traffic Signal.** If a traffic signal is capable of operating in the actuated mode, then flashing operation generally should not be used as a control strategy during low-volume conditions. The delay resulting from actuated operation is not significant enough compared to flashing operation to justify the use of flashing operation.

- **Pretimed Traffic Signal.** In general, flashing operation can be considered at an intersection if all of the following conditions are present for yellow/red or red/red flashing operation:

    - *Yellow/Red Flashing Operation:*

- Major street two-way volume is less than 500 vph.
- Minor street higher approach volume is less than 100 vph.
- Major to minor street volume ratio is three or more.
- The total number of accidents at the intersection during the preceding two years of normal signal operation is one or less.

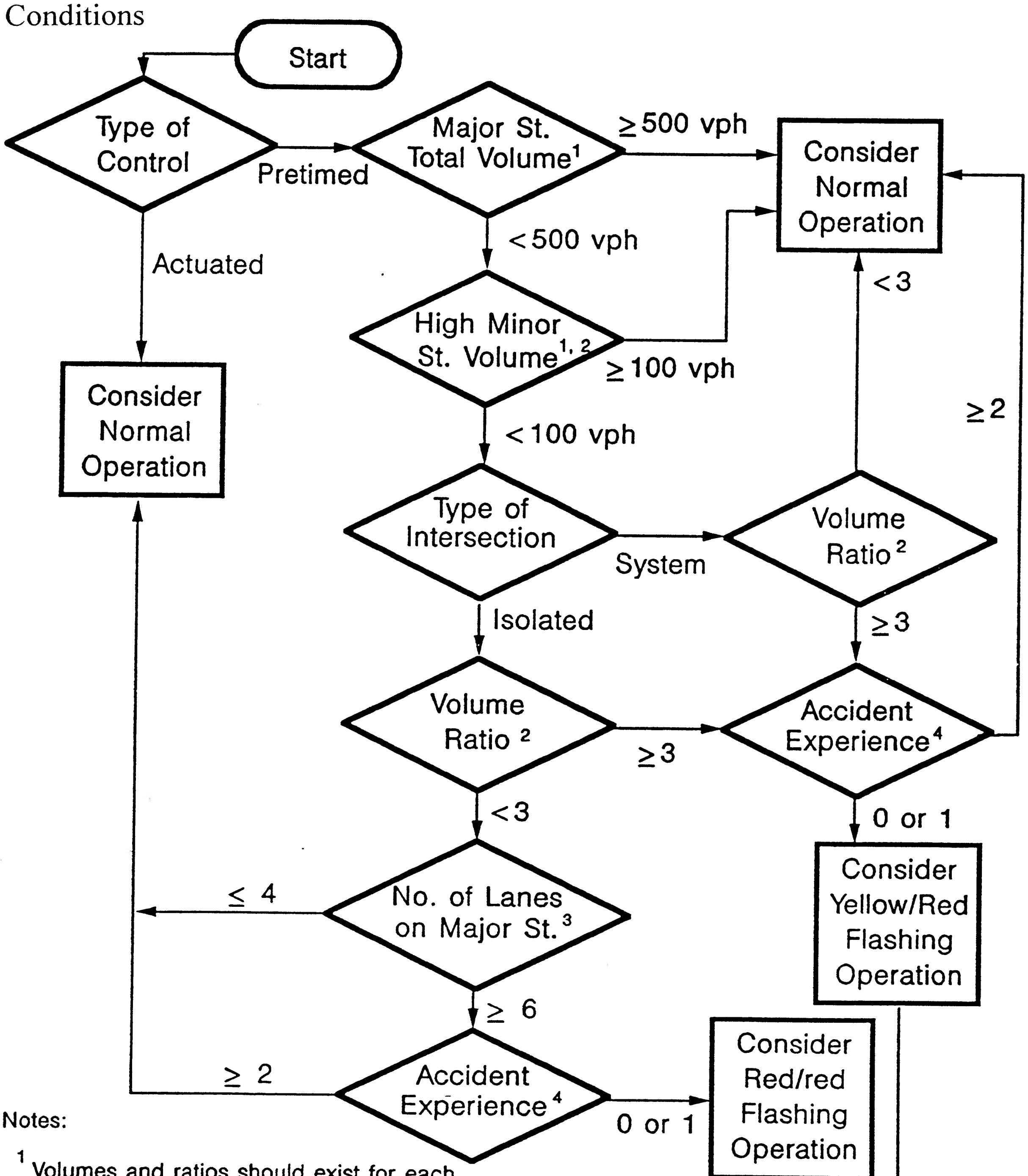
- *Red/Red Flashing Operation:*

    - Major street two-way volume is less than 500 vph.
    - Minor street higher approach volume is less than 100 vph.
    - Major to minor street volume ratio is less than three.
    - The total number of accidents at the intersection during the preceding two years of normal signal operation is one or less.
    - It is an isolated intersection (no other signalized intersection within one-half mile (800 meters)).
    - There are six or more through lanes on the major street.

- *General Guidelines.* Before low-volume, nighttime flashing operation is implemented at an intersection, the general guidelines for all types of flashing operation should also be checked.

- *Length of Flashing Operation.* In general, flashing operation should be used for those hours which meet the criteria described for each type of flashing operation. However, in order to avoid constant changing from flashing to normal operation and vice versa, flashing operation should be implemented only when the appropriate criteria are present for at least four hours.

Figure 3. Flowchart for Implementing Flashing Operation during Low-Volume Conditions



Notes:

[1] Volumes and ratios should exist for each hour of operation for a minimum of 4 hours.

[2] Highest approach volume.

[3] Through lanes only.

[4] Number of accidents in the last 2 years during the time period for which flashing operation is being considered.

SOURCE: Reference (13).

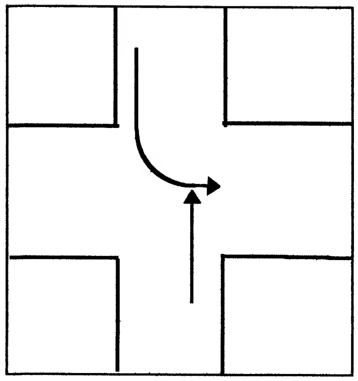
Task B - Accident Trends

Summary Statistics (1992 to 1994)

The next task of this study was to assimilate accident trend statistics. First, the state-wide yearly data summaries for accidents at signalized intersections were evaluated for the years 1992 through 1994. The data were sorted by the following variables: type of accident, severity, alcohol involvement, roadway surface conditions, light conditions, age of drivers, and contributing factors.

The primary variable of interest for this study was the type of accident that occurred at Montana's signalized intersections. Montana accidents are categorized as head-on, rear-end, angle, sideswipe meeting, sideswipe passing, backed into, other and parking maneuver. The angle accidents represented the largest percentage of the three year averages with 57.1 percent. Rear-end accidents represented the next major percentage of accidents with an average of 34.9 percent. (See Appendix A page A-1.) However, for the State Primary Routes, angle accidents were subdivided from total accidents by the drivers' intents. The average percentage of right-angle accidents for the cities was approximately 19 percent and 25 percent for left-turn accidents. (See Appendix B pages B-3 and B-4.)

At this point it should be noted that there are two prevailing types of left-turn accidents. For example, if both vehicles are traveling north/south or east/west and one vehicle makes a left-turn, an accident can occur. (See Figure 4.) Also, if one of the vehicles is traveling north/south, the other vehicle is traveling east/west and one of the vehicles proceeds through the intersection when the driver does not have the green light, an accident can occur. (See Figure 5.) Some engineers classify the left-turn accident type 2 as a right-angle accident. For this study, all accidents in which at least one driver was attempting a left-turn was classified as a left-turn accident. However, less than 5 percent of the left-turn accidents could be classified as right-angle accidents.



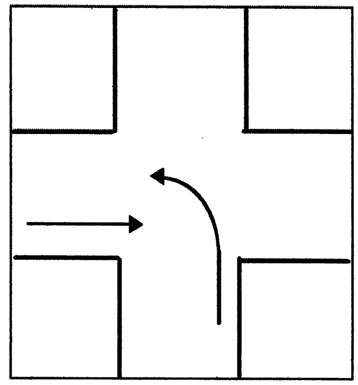


Figure 4. **Figure 5.**
Left-Turn Accident Type 1 Left-Turn Accident Type 2

As a comparison, the study entitled "Safety Effects of Traffic Signal Operations" reported that for signalized intersections, 26 percent of the accidents were right-angle and 24 percent were rear-end accidents in South Philadelphia, and 33 percent were right-angle and 23 percent were rear-end accidents in North Philadelphia. (See Table 1.) The Philadelphia study categorized accidents into the following types: right-angle, rear-end, fixed object, sideswipe, and pedestrian (1). Thus, there are differences when this study is compared to Montana. The Philadelphia records show 22 to 31 percent of fixed object collisions and 12 percent of pedestrian accidents at signalized intersections compared to 1.9 percent of other accidents in Montana (Table A-1).

The Federal Highway Administration (FHWA) has developed a highway safety database called the Highway Safety Information System (HSIS), which provided 1994 accident data for Minnesota that was used for comparison purposes. Right-angle accidents represented 34.6 percent, rear-end accidents represented 32.1 percent and left-turn accidents represented 13.2 percent of total accidents. (See Appendix A page A-15.) As previously shown for comparison, Montana right-angle accidents represented approximately 19 percent, rear-end accidents represented approximately 35 percent, left-turn accidents represented approximately 25 percent, and right-turn and other accidents represented approximately 21 percent of total accidents.

A study prepared by the MOVITE Technical Committee entitled "MOVITE Area Accident Rate Comparison "(1984) compared accident frequencies and traffic volumes for different intersection geometric configurations and signal phases. The study included data from Arkansas, Iowa, Kansas, Minnesota, Missouri, Nebraska, Oklahoma, South Dakota, and Texas. Therefore, there are differences in the dates of the MOVITE study data and the Montana data. Also, technologies in signalization have changed since that date (14). The accidents at signalized intersections on the State Primary Routes for Montana were plotted on the graph which best approximated the conditions of the intersections. For each graph, the Montana points were plotted as squares.

For the 2 Phase Signals with two lanes total for each approach, the Montana data approximated the linear regression line fairly well. (See Figure 6.) For the 2 Phase Signal with four lanes total on the major approach and two lanes total on the minor approach, Montana showed fewer accidents than the other states. (See Figure 7.) For the 2 Phase Signal with four lanes total on each approach, Montana again experienced lower accident frequencies than the other states. (See Figure 8.) For the 8 Phase signal with 5 lanes total (four through lanes and one left-turn lane) for each approach, Montana's data were close to the average or slightly below average. (See Figure 9.) These figures show that Montana's overall accident numbers are average or below average when compared to the states studied in the MOVITE report.

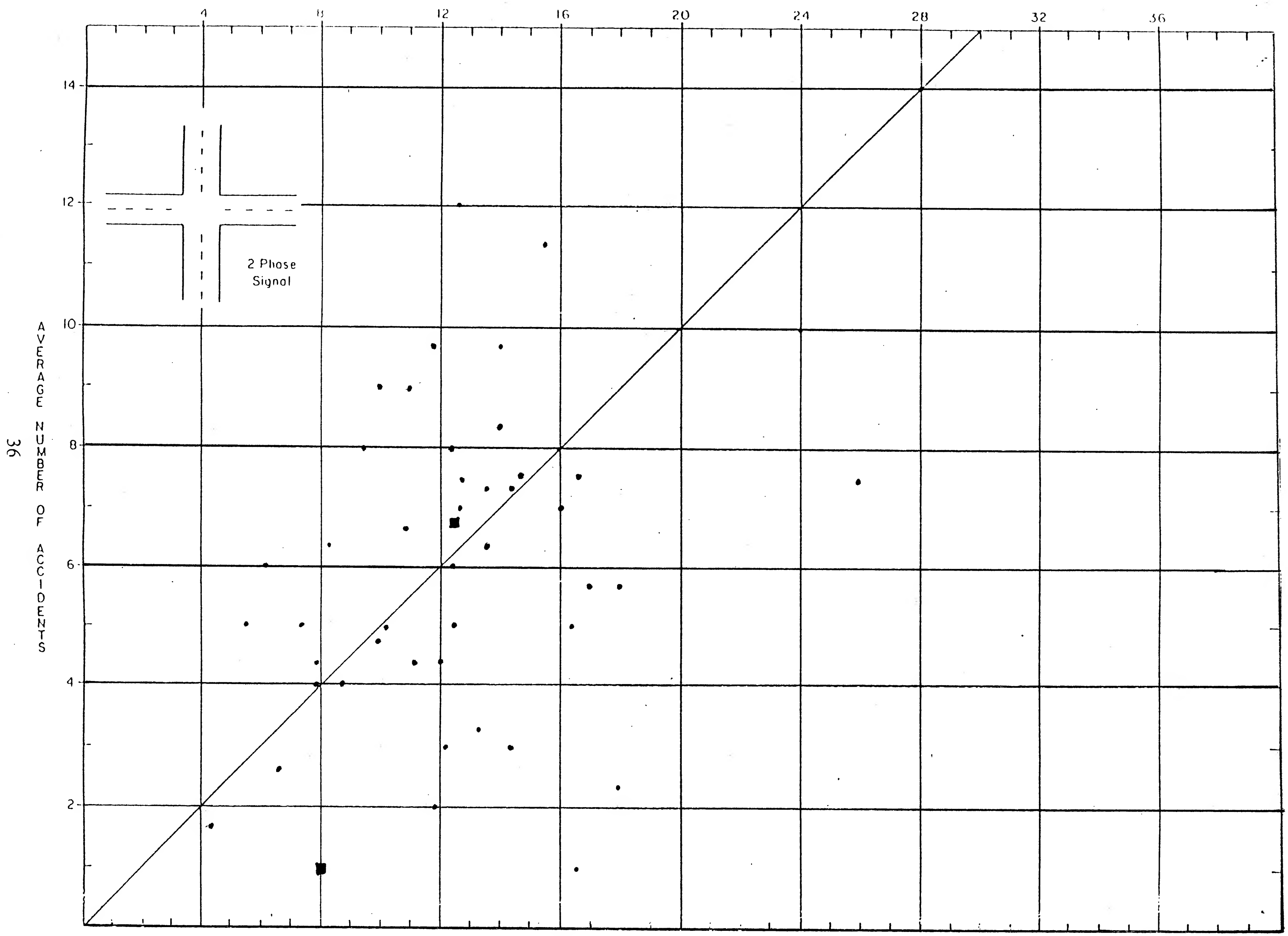


Figure 6. SOURCE: Reference (14).

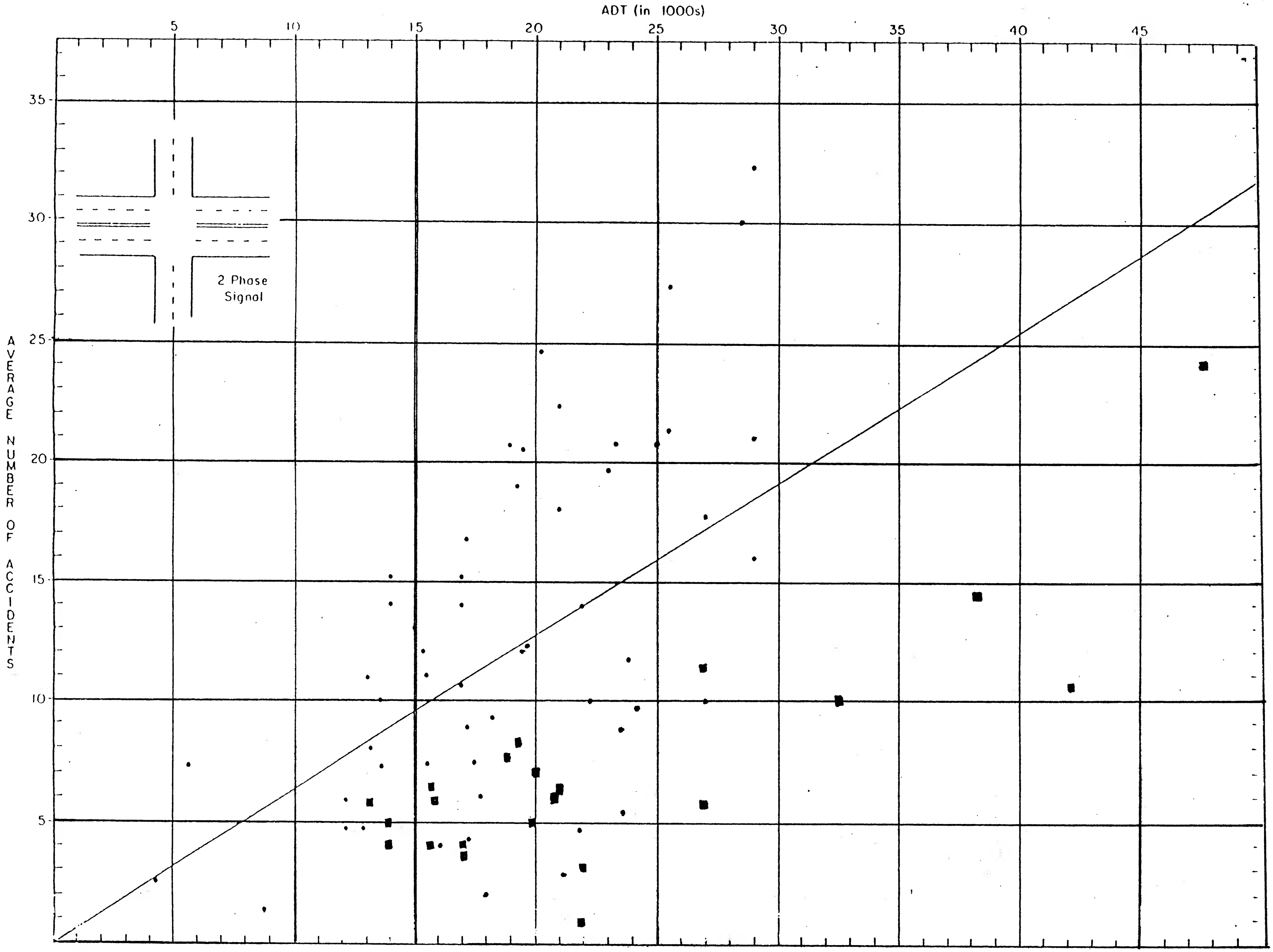


Figure 7. SOURCE: Reference (14).

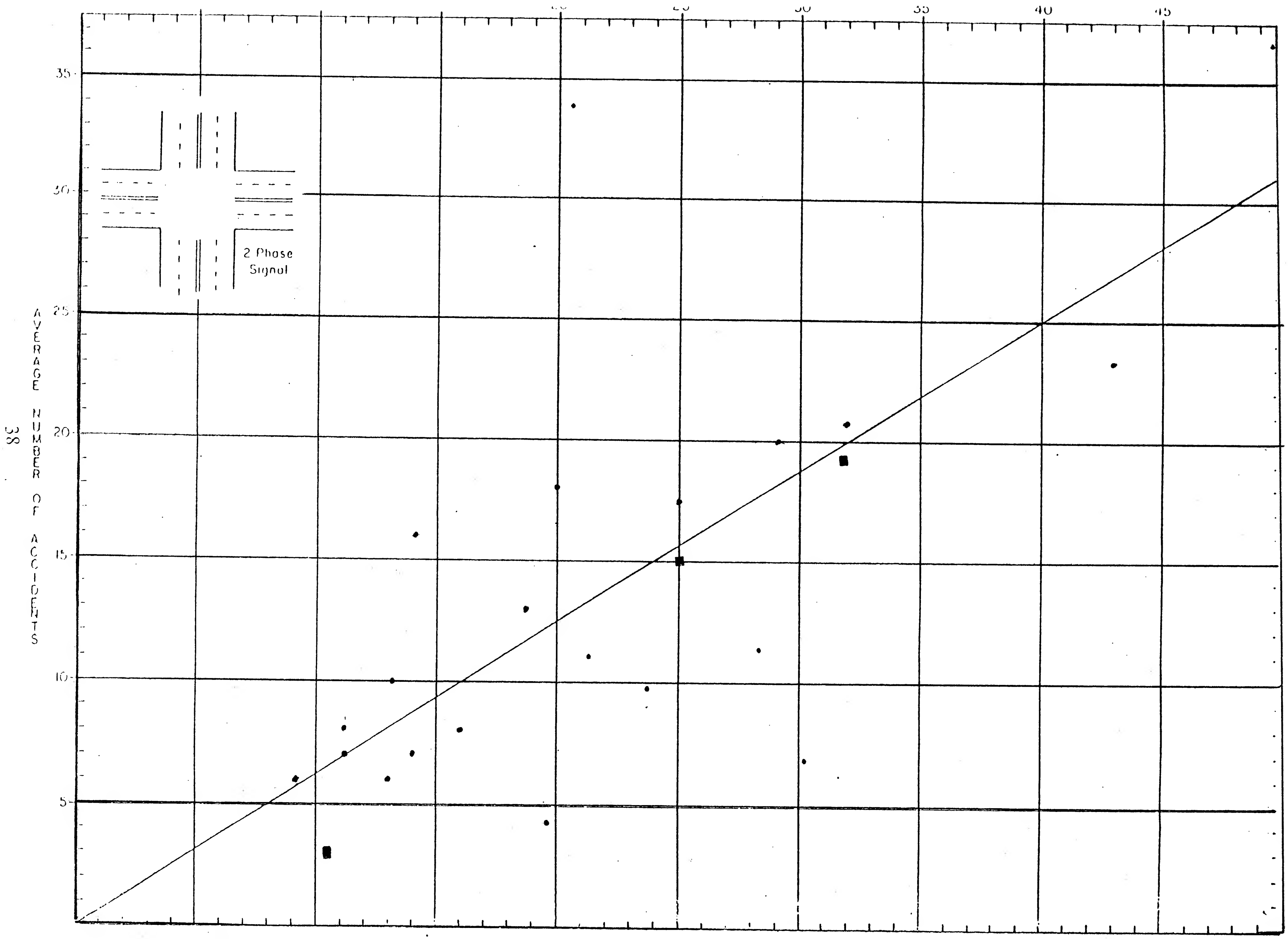


Figure 8. SOURCE: Reference (14).

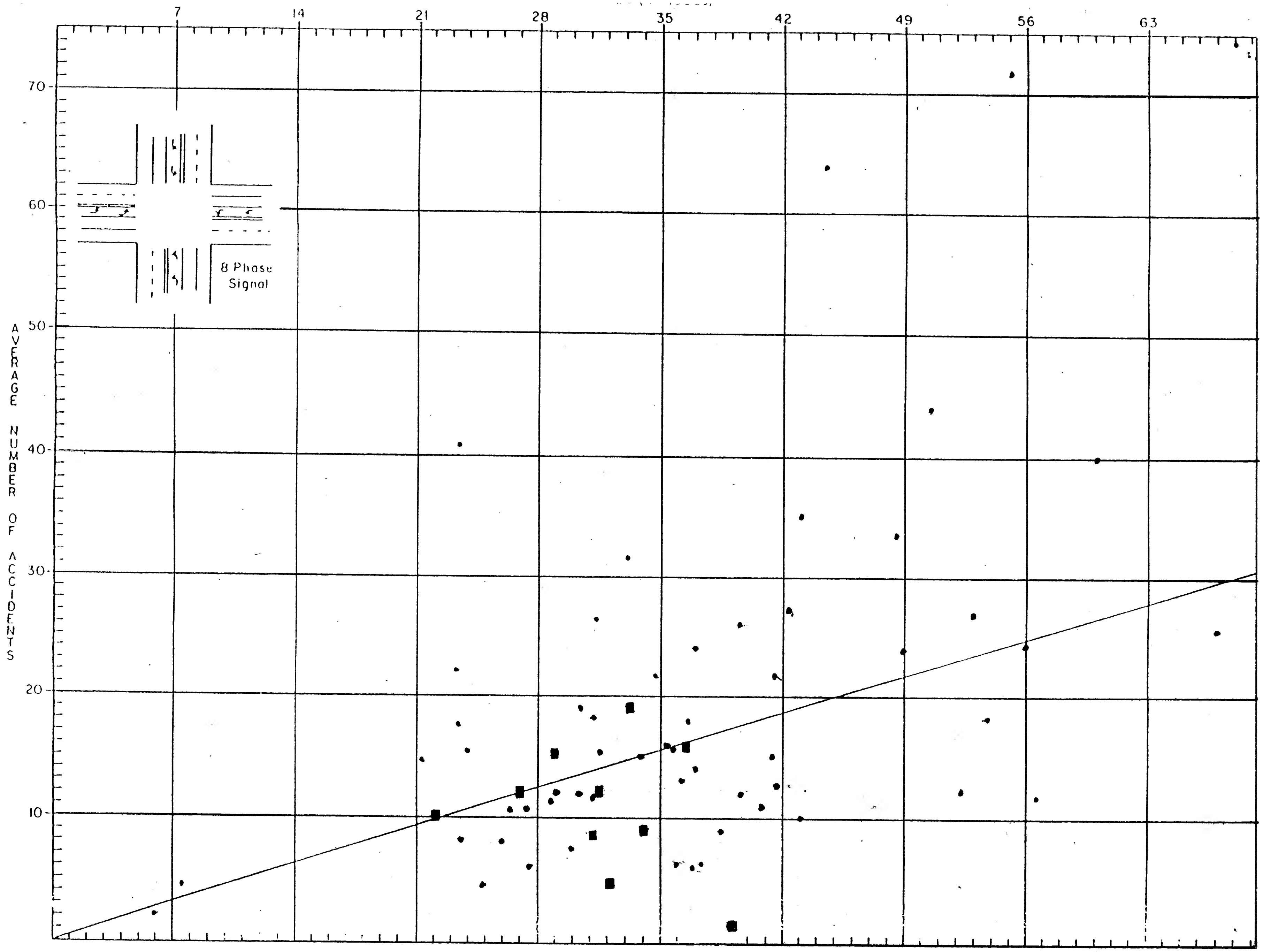


Figure 9. SOURCE: Reference (14).

Next, accidents were sorted by severity. The three-year averages for property damage, injury and fatal accidents were 70.6 percent, 29.3 percent, and 0.1 percent, respectively. (See Appendix A page A-2.) These percentages compare favorably to the percentages of accidents for traffic signals in Table 1. In South Philadelphia, the percentage breakdowns of accidents were 70 percent property damage, 30 percent injury (18 percent personal injury to vehicle occupants plus 12 percent injured pedestrians), and zero percent fatal. North Philadelphia was similar with 68 percent property damage, 32 percent injury (20 percent personal injury to vehicle occupants plus 12 percent injured pedestrians), and zero percent fatal. The HSIS study reported 55.5 percent property damage, 44.2 percent injury (4.2 percent incapacitating injury, 14.6 percent non-incapacitating injury and 25.4 percent possible injury), and 0.3 percent fatal accidents. (See Appendix A page A-15.)

Accidents involving alcohol were also evaluated. Less than 10 percent of the accidents at signalized intersections involved alcohol and less than 5 percent of the drivers had been drinking. Each year of the study period showed a slight decrease in the number of accidents involving alcohol and the number of drivers who had been drinking. (See Appendix A pages A-3 and A-4.)

Roadway surface conditions for accidents at signalized intersections were categorized into the following conditions: dry, wet, icy, snowy, slushy and natural debris. The majority of accidents, an average of 73 percent, occurred on dry pavement. The percentages of accidents that occurred on wet, icy and snowy streets were 12 percent, 9 percent, and 4 percent, respectively. (See Appendix A page A-5.) The high percentage of accidents on dry pavements is due to a greater percentage of exposure time on dry roadways than on the other roadway conditions. The HSIS study reported 63.9 percent of accidents occurred on a dry surface. The percentages of accidents that occurred on wet, snowy/slushy, and ice/packed snow were 22.1 percent, 5.6 percent, and 7.2 percent, respectively. The difference between Montana and Minnesota percentages is assumed to be a reflection of different weather conditions between the two states. (See Appendix A page A-16.)

Next, the light condition at the time of the accidents was investigated. The largest percentage of accidents occurred during daylight, with an average of 75 percent of the accidents classified in this manner. This, too, could be due to a greater exposure time. The accidents that occurred when the intersection was dark, but lighted, accounted for an average of 20 percent of the accidents. (See Appendix A page A-6.) The HSIS study reported comparable figures of 72.1 percent of accidents occurring during daylight and 21.4 percent of accidents occurring when the intersection was dark, but lighted. (See Appendix A page A-16.)

The age of drivers was also examined. The age group with the highest accident percentage, approximately 30 percent, was drivers age 24 and under. The percentage of accidents decreased as age increased. Drivers 65 years of age and older accounted for approximately 10 percent of the accidents at signalized intersections. (See Appendix A pages A-7 and A-8.) The HSIS study reported similar percentages for the various age groups. (See Appendix A page A-17.) The involvement of older drivers in accidents at signalized intersections will be discussed later in this report.

Finally, contributing factors such as vision obstruction, road defects, mechanical defects and driver-related circumstances were analyzed. (See Appendix A pages A-9 to A-14.) Approximately 98 percent of the drivers reported their vision was not obscured. In those instances when vision was obscured, the leading vision obstruction was another vehicle. Less than 0.5 percent of the drivers experienced defects in the roadway and 0.9 percent experienced mechanical defects. Approximately 55 percent of all drivers did not commit an apparent violation. However, 12.1 percent of the drivers failed to yield the right of way. Additionally, 11.2 percent of the drivers received careless driving citations and 4.0 percent of the drivers were cited for traveling at a speed too fast for the conditions. The HSIS study reported 47.5 percent of drivers were not driving improperly, although 12.5 percent failed to yield the right of way. (See Appendix A page A-18.)

To summarize, the three-year accident statistics explored a variety of variables. The numbers and percentages were fairly consistent throughout the study period for Montana.

Comparison of Accidents Between Cities at Signalized Intersections

Next, accident trends between Montana's six largest cities: Billings, Great Falls, Missoula, Butte, Helena and Bozeman were investigated. The 1994 populations for these cities range from approximately 87,000 people in Billings to 25,000 people in Bozeman (15). Accident frequencies using 1994 data were sorted by accident type for each city.

The two accident types with the largest percentages were angle and rear-end accidents. Angle accidents represented the largest percentage of accidents with an average of 53 percent for the six cities. Rear-end accidents accounted for an average of 37 percent. These percentages compare favorably with the three-year state averages (1992 to 1994 data) where 57 percent of all accidents were angle accidents and 35 percent of accidents were rear-end accidents. (See Appendix B pages B-1 to B-3.) In all of the cities, angle accidents represented the largest percentage of accident types, except in Bozeman where angle accidents and rear-end accident percentages were equal.

The total number of accidents was compared to the population within the city limits. A fairly linear relationship was determined, $r^2 = 0.95$. Usually the population within the urban limits is used for planning purposes. However, the relationship between the population in the city limits and the number of accidents can be expanded to the urban limits with no anticipated change. (See Figure 10.) Additionally, the number of signals was compared to each city's population. Again, the relationship was fairly linear, $r^2 = 0.94$; however, Billings had substantially less people per signal. (See Figure 10.)

Table 8. Population And Accident Number Relationship

CITY	# ACC.	POPULATION	PEOPLE/ACC
BILLINGS	740	86578	117
GREAT FALLS	398	58202	146
MISSOULA	279	45364	163
BUTTE	138	34190	248
HELENA	203	26339	130
BOZEMAN	142	25067	177

MEAN	163
STD DEV	47

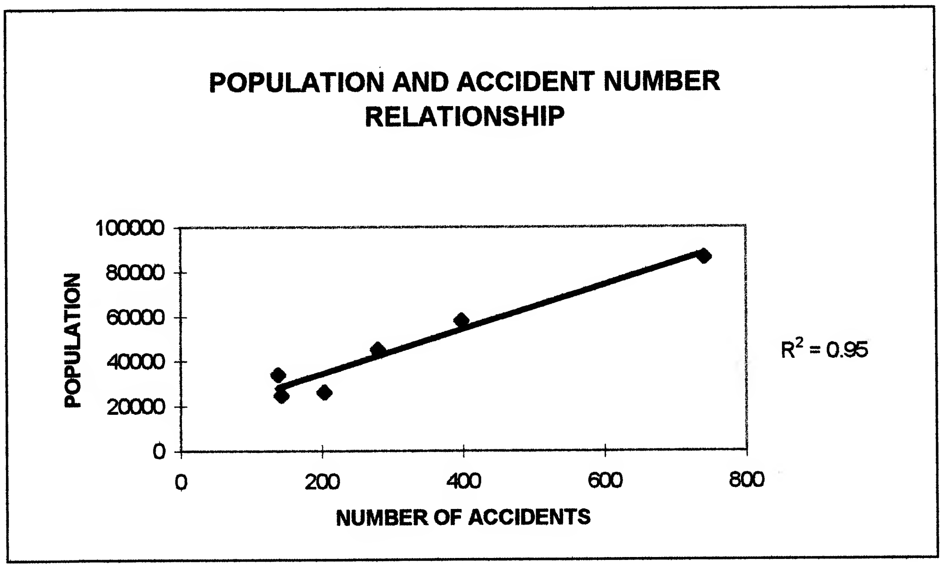


Figure 10. Population And Accident Number Relationship

Table 9. Population And Signal Number Relationship

CITY	# SIGNALS	POPULATION	PEOPLE/SIGNAL
BILLINGS	130	86578	666
GREAT FALLS	57	58202	1021
MISSOULA	49	45364	926
BUTTE	37	34190	924
HELENA	26	26339	1013
BOZEMAN	24	25067	1044

MEAN	932
STD DEV	140

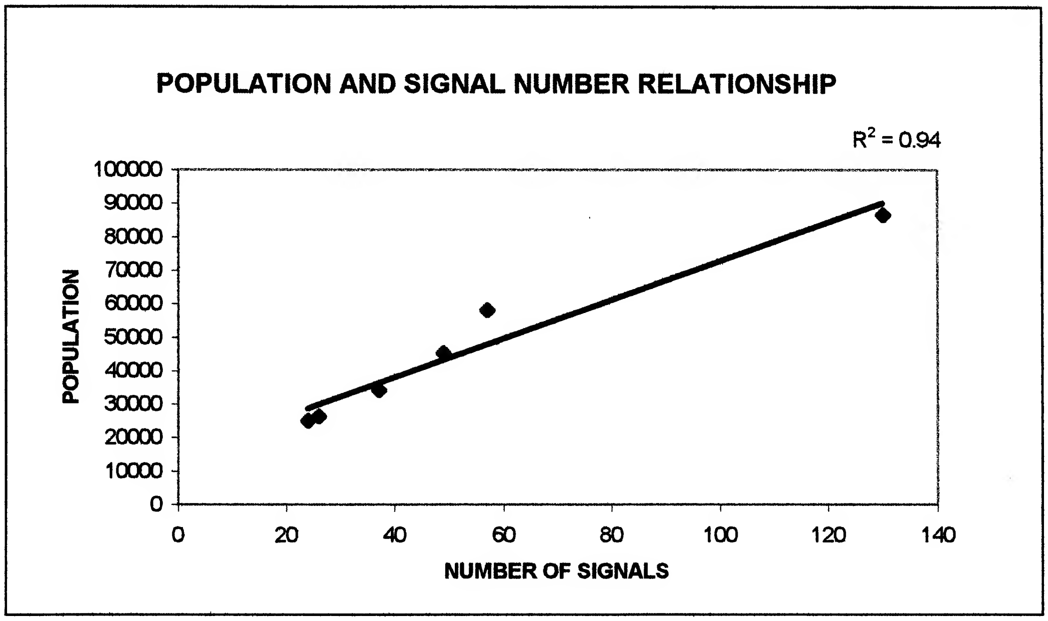


Figure 11. Population And Signal Number Relationship

The angle accidents were subdivided by the drivers' intent to more specifically identify the type of accident that occurred. All of these situations are shown in the charts on pages B-1 and B-2. These accidents were then regrouped into the following categories: right-angle, left-turn, right-turn and other. Accidents that reported both drivers going straight were placed in the right-angle category. The left-turn accidents included any accident in which at least one of the vehicles was making a left-turn, including the left-turn/right-turn category. Right-turn accidents included accidents where at least one vehicle was turning right. The remaining accidents were placed in the "other" category.

Accidents that occurred at signalized intersections versus unsignalized intersections and mid-block locations were investigated, as well. Accident data for all reportable accidents on the State Primary Routes within the city limits of each city for 1993 and 1994 were divided into signalized intersection locations and unsignalized locations (all other locations) for each route. It should be noted that the type of traffic control device at the accident location is reported based upon the officer's opinion. Then accident percentages for signalized and unsignalized locations were calculated. When data for the six cities were combined, the unsignalized accident locations accounted for an average of 54.4 percent of the intersection accidents and the signalized accident locations accounted for 45.6 percent of the intersection accidents. The standard deviation was 7.7 percent. The standard deviation may be high because of the variability of the routes, such as the length of the route and the number of signals along the route. Additionally, a high standard deviation is characteristic of a small sample size. (See Appendix B page B-5.)

Another approach to determining the percentage of signalized accidents was to divide the number of accidents at signalized intersections within the city limits into the total number of accidents within the city limits. The mean number of accidents that occurred at these signalized intersections for the cities was 22.4 percent. (See Appendix B page B-6.) One possible reason for the difference in percentages for the State Primary Routes and the cities is the number of unsignalized intersections compared to signalized intersections.

The next step was to look at the State Primary Routes individually. The number and type of accidents were determined for the signalized intersections along each route. Some of the accident locations could not be clearly identified and were placed in the "Unidentifiable Intersections" category. The two major accident categories were rear-end and angle-type accidents. Rear-end and angle accidents varied from route to route as to which accident type had a greater percentage of accidents. (See Appendix C.)

Additionally, the involvement of elderly drivers in accidents at signalized intersections was examined. Along each State Primary Route, the number of accidents involving drivers age 65 or older was determined for 1994 accident data. The number of accidents per mile and the percentage of accidents with a driver age 65 or older were calculated. The accidents per mile ranged from 0.3 accidents per mile on State Primary Route 86 (Rouse Avenue in Bozeman) to 6.2 accidents per mile on State Primary Route 60 (10th Avenue South in Great Falls). This variability may be due to the number of signals along the routes. Additional variables such as traffic volume may also be contributing to this variability. The accident percentages ranged from 8.3 percent to 25.4 percent on State Primary Route 86 and State Primary Route 60, respectively. (See Appendix D pages D-1 to D-6.)

The types of accidents involving elderly drivers were also determined. When data for the six cities were combined, drivers age 65 and older were involved in 162 accidents. This total was broken down by accident type and city, with percentages reported on page D-7 in Appendix D. In general, angle accidents represented the largest percentage. Angle accidents were further broken down into the categories of right-angle, right-turn, left-turn, and other, as described previously. (See Appendix D page D-8.)

The types of accidents involving elderly drivers were calculated for the individual cities, as well. Angle accidents accounted for the largest percentage of accidents in each city except Bozeman, where there were more rear-end accidents. (See pages D-9 to D-12 in Appendix D.) Again, when the angle accidents were categorized into smaller classifications, right-angle and left-turn accidents generally represented the largest percentages of angle accidents. (See Appendix D pages D-13 to D-16.)

A study entitled "Accident Analysis of Older Drivers at Intersections" presented in a Highway Safety Information System Summary Report compared a "young elderly" group (ages 65 to 74), and an "old elderly" group (age 75 and older), to a middle-aged comparison group (ages 30 to 50) in Illinois and Minnesota. The report stated that elderly drivers were less likely to be involved in rear-end collisions than their middle-aged counterparts, but more likely to be involved in left-turn and angle collisions at both urban and rural signalized intersections (16).

Additionally, the pre-accident driver maneuvers were investigated. For turning collisions at urban and rural signalized intersections, middle-aged drivers tended to be going straight, while older drivers were more likely to have been turning left, and were slightly more likely to be turning right and turning right on red. The study also reported that both the "young elderly" and the "old elderly" appear to have problems at intersections, specifically left-turning maneuvers at signalized intersections. These problems may relate to the difficulties in distinguishing target vehicles from surrounding clutter, judging closing speeds of target vehicles, and/or an inability to use the acceleration capabilities of the cars they are driving in order to utilize what would be considered "safe gaps" for younger drivers (16).

Task C and Task D - Establish Variables of Influence and Determine Significant Causal Patterns

Task C, Establishing Variables of Influence, and Task D, Determining Significant Causal Patterns, were combined into a single task. Signalized intersections on the State Primary Routes were selected from each city for further study. Total accident rates and angle accident rates were calculated for each intersection. For each route, a mean and standard deviation were calculated for the accident rates using 1994 data. The intersection selection criteria were based upon the following:

1. If the intersection accident rate exceeded the mean accident rate plus one standard deviation for the route, the intersection was selected.

2. If the intersection angle accident rate exceeded the mean angle accident rate plus one standard deviation for the route, the intersection was selected.

Intersection selection was based upon individual routes to keep more variables consistent, such as functional classification. For approximately 10 percent of the intersections, there was limited data for the minor street approach volumes. Table 10 shows the intersections selected for further study. For each State Primary Route, the mean plus one standard deviation selection criteria are listed. The total accident rates and angle accident rates with asterisks indicate intersections that met the selection criterion. Some intersections met one of the two criterion and some intersections met both selection criteria.

Table 10. Intersection Selection Criteria

City	Route	Intersection	Total Acc. Rate (acc/mev)	Mean Total Acc. Rate (acc/mev)	Std. Dev. Total Acc. (acc/mev)	Mean + Std. Dev. (acc/mev)	Angle Acc. Rate (acc/mev)	Mean Angle Acc. Rate (acc/mev)	Std. Dev. Total Acc. (acc/mev)	Mean + Std. Dev. (acc/mev)
Billings	FAP 16	Main St. & Hwy. 318	1.36*	0.71	0.35	1.06	0.45*	0.30	0.18	0.48
	FAP 53	27th St. & 1st Ave. N.	2.32*	1.13	0.56	1.69	1.7	0.77	0.44	1.21
Great Falls	FAP 10	14th St. & Central Ave.	3.51*	1.24	0.89	2.13	2.70*	0.86	0.70	1.56
	FAP 60	10th Ave. S. & 32nd St.	0.82	0.67	0.26	0.93	0.41*	0.24	0.15	0.39
		10th Ave. S. & 26th St.	1.04*				0.32			
		10th Ave. S. & 25th St.	0.96*				0.27			
		10th Ave. S. & 20th St.	0.67				0.40*			
		10th Ave. S. & 9th St.	1.01*				0.57*			
		10th Ave. S. & 5th St.	0.63				0.39*			
Missoula	FAP 7	Brooks St. & Reserve St.	1.14*	0.58	0.35	0.93	0.38	0.35	0.22	0.57
		Higgins Ave. & S. 6th St.	1.12*				0.92*			
	FAP 71	Broadway St. & Orange St.	1.60*	0.87	0.53	1.40	1.43*	0.66	0.40	1.06
		Broadway St. & Higgins Ave.	1.64*				0.87			
Butte	FAP 29	Harrison Ave. & Roosevelt Ave.	1.16*	0.76	0.34	1.10	0.72*	0.45	0.25	0.70
		Harrison Ave. & Civic Center Rd.	1.01				0.84*			
		Arizona St. & Mercury St.	0.80				0.80*			
		Montana St. & Platinum St.	1.11				0.83*			
Helena	FAP 8	Euclid Ave./Lyndale Ave. & Benton Ave.	1.41*	0.70	0.41	1.11	0.56	0.38	0.30	0.68
		Montana Ave. & Prospect Ave.	1.31*				0.75*			
		Prospect Ave. & Lamborn St.	0.86				0.69*			
		Prospect Ave. & Fee St.	1.19*				0.86*			
		11th Ave. & Fee St.	1.14*				0.91*			
Bozeman	FAP 50	Main St. & 19th Ave.	1.58*	0.87	0.30	1.17	0.75*	0.41	0.23	0.64
		Main St. & Bozeman Ave.	1.27*				0.86*			
	FAP 86	Rouse Ave. & Tamarack St.	1.58*	0.89	0.63	1.52	0.45*	0.27	0.24	0.51

The selection procedures yielded a total of 25 intersections for further study. For each of these intersections, accident report files were obtained for 1993 and 1994. From these reports, collision diagrams were prepared. Summaries of the collision diagrams are in Appendix E. The summaries include information on the signal phasing (left turns permissive or protected), yellow and all-red clearance interval timing and flashing operation. If the intersection involves one-way streets, the description is included. Major accident type percentages and descriptions are discussed. Additionally, the percentages of accidents occurring when the weather was clear and the roads were dry are reported.

The intersections selected were all four-leg intersections. Most of the intersections crossed at a right angle. However, three intersections had skews on the minor street approach. These geometric differences did not seem to have an affect on accidents.

The intersections selected have varying signal phasings. Some intersections have no protective or permissive left turn phasing. Other intersections have permissive or protective phasing for the major approach and none for the minor approach. Some of the intersections have protected and/or permissive left turn phasing for all approaches. (See Appendix E.)

The Institute of Transportation Engineers (ITE) formulas were used to calculate yellow clearance intervals and all-red clearance intervals for the study intersections, except for four intersections where the necessary data were not available (17). The formula for the yellow clearance interval is

$$y = t + v/(2a + 2Gg)$$

where:

y = length of yellow interval, seconds;

t = driver perception and reaction time, seconds;

v = velocity of the approaching vehicle, meters per second (feet per second);

a = deceleration rate, meters per second squared (feet per second squared);

G = acceleration due to gravity, meters per second squared (feet per second squared); and

g = grade of the approach, percent divided by 100.

The following values were assumed :

t = 1.0 sec,

a = 3.048 m/ sec^2 (10 ft/sec^2),

G = 9.81 m/sec^2 (32.2 ft/sec^2),

g = 0, and

v = the posted speed limit.

The values assumed for the variables t, a, and G are the values recommended by Reference (17). Thus, the formula for the yellow clearance interval becomes

$$\mathbf{y = 1.0sec + v/6.096\ m/s^2}$$

$$\mathbf{(y= 1.0sec + v/20\ ft/s^2).}$$

The formula for the all red interval is

$$\mathbf{r = (w + L)/v}$$

where:

r = length of the all-red interval, seconds;

w = length of the vehicle path from the departure stop line to the far side of the furthest conflicting traffic lane, meters (feet);

L = length of vehicle, meters (feet); and

v = speed of the vehicle through the intersection, meters per second (feet per second) (17).

The following values were assumed:

L = 6.096 m (20 feet) (17) and

v = posted speed limit.

Therefore, the formula for the all-red interval is

$$\mathbf{r = (w + 6.096\ m)/v}$$

$$\mathbf{(r = (w + 20\ ft)/v).}$$

The actual yellow clearance interval and all-red interval timings were compared to the calculated values for the through movements for twenty-one of the twenty-five intersections. In most cases, the calculated yellow clearance intervals were less than or equal to the actual value used at the signal. (See Table 11.) However, the calculated all-red clearance intervals were higher than the values used at the signals, except in two cases where the calculated value was equal to or less than the actual value. According to Montana Department of Transportation personnel (18), until recently, a rule of thumb of approximately 1.0 to 1.5 seconds of all-red was used at signalized intersections. New signals will use the ITE formula for the all-red clearance intervals. Most of the intersections in this study have been in place for some time and the timings may not have been updated. The differences between the calculated and actual all-red clearance interval lengths may not be related to the accidents.

For the subject intersections, accident frequencies were plotted against traffic volumes for the intersections. The total traffic volumes ranged from about 10,000 to 48,500 annual average daily traffic (AADT). The total number of accidents was plotted against the total AADT, the major street approach AADT, and the minor street approach street AADT. (See Figure 12.) The total intersection AADT showed the best linear relationship with the number of accidents. The regression coefficient was $r^2 = 0.46$. If more data points are used, a better relationship may be found.

Table 11. Yellow and All-Red Clearance Intervals

City	Intersection	Yellow Actual (sec)	Yellow Calculated (sec)	All-Red Actual (sec)	All-Red Calculated (sec)
Billings	N 27th xing 1st Ave N	3.0	2.8	1.5	1.5
	1st Ave N xing N 27th	3.0	2.8	1.5	2.4
	Main St xing Hwy 318	3.6	3.6	1.3	3.7
	Hwy 318 xing Main St	3.0	3.6	1.5	3.4
Great Falls	10th Ave S xing 32nd St	4.0	3.6	1.0	2.0
	32nd St xing 10th Ave S	4.0	3.6	1.0	2.3
	10th Ave S xing 26th St	4.0	3.6	1.0	1.7
	26th St xing 10th Ave S	4.0	3.6	1.0	2.0
	10th Ave S xing 25th St	4.0	3.6	1.0	1.8
	25th St xing 10th Ave S	4.0	3.6	1.0	2.0
	10th Ave S xing 20th St	4.0	3.6	1.0	1.7
	20th St xing 10th Ave S	4.0	3.6	1.0	2.0
	10th Ave S xing 9th St	4.0	3.6	1.0	1.7
	9th St xing 10th Ave S	4.0	3.6	1.0	2.1
	10th Ave S xing 5th St	4.0	3.6	1.0	1.4
	5th St xing 10th Ave S	4.0	3.6	1.0	2.0
Missoula	Brooks St xing Reserve St	4.0	4.3	2.0	1.9
	Reserve St xing Brooks St	4.3	4.3	2.0	2.7
	Higgins Ave xing S 6th St	3.0	2.8	1.0	2.0
	S 6th St xing Higgins Ave	3.0	2.8	1.0	2.3
	Broadway St xing Orange St	4.0	2.8	1.0	2.6
	Orange St xing Broadway St	3.0	2.8	1.0	2.9
Butte	Harrison Ave xing Roosevelt St	3.0	3.6	1.0	1.6
	Roosevelt St xing Harrison Ave	3.5	3.6	1.0	2.1
	Harrison Ave xing Civic Center Rd	3.0	3.6	1.0	1.7
	Civic Center Rd xing Harrison Ave	3.0	3.6	1.0	2.0
	Arizona St xing Mercury St	3.0	2.8	1.0	2.5
	Mercury St xing Arizona St	3.0	2.8	1.0	2.0
	Montana St. xing Platinum St	3.0	2.8	1.0	2.0
	Platinum St xing Montana St	3.0	2.8	1.0	2.6
Helena	Euclid/Lyndale Ave xing Benton Ave	4.0	3.2	1.0	2.5
	Benton Ave xing Euclid/Lyndale Ave	3.0	3.2	1.0	2.8
	Prospect Ave xing Lamborn St	4.0	3.6	1.0	1.6
	Lamborn St xing Prospect Ave	3.0	3.6	1.0	1.5
	Prospect Ave xing Fee St	4.0	2.8	1.0	2.2
	Fee St xing Prospect Ave	4.0	2.8	1.0	2.0
	11th ave xing Fee St	4.0	3.6	1.0	2.0
	Fee St xing 11th Ave	4.0	3.6	1.0	1.7
Bozeman	Main St xing 19th Ave	3.0	3.6	1.0	2.0
	19th Ave xing Main St	3.0	3.6	1.0	2.3
	Rouse Ave xing Tamarack St	3.0	2.8	1.0	2.0
	Tamarack St xing Rouse Ave	3.0	2.8	1.0	2.0

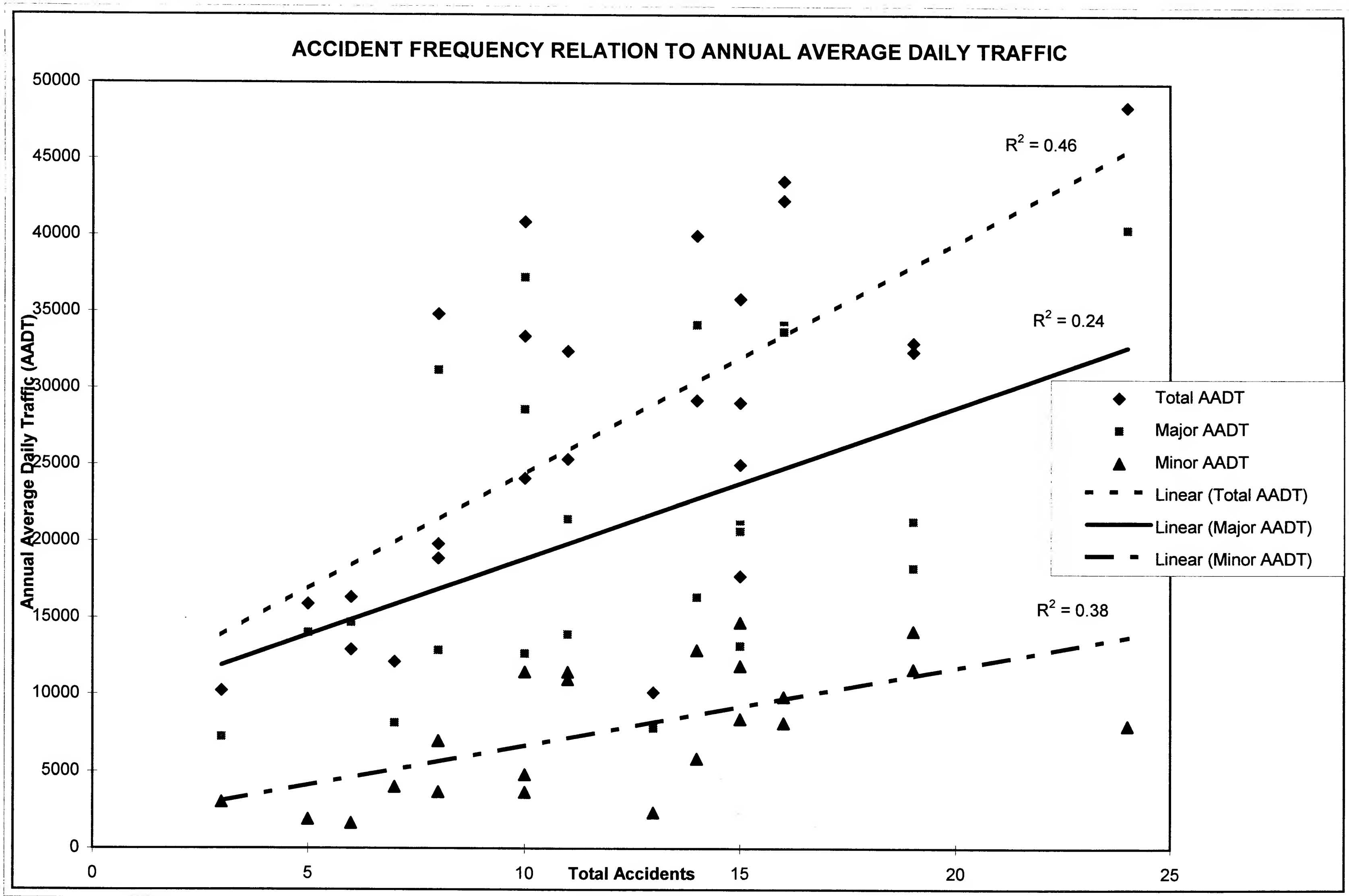


Figure 12. Accident Frequency Relation to Annual Average Daily Traffic

The accident rates were also plotted against the traffic volumes for the intersections along the State Primary Routes. Linear, logarithmic and polynomial regressions were used to determine a relationship between these variables. The linear regression exhibits a correlation of $r^2 = 0.0012$ and is shown in Figure 13.

The functional classification of the roadways intersecting the State Primary Routes was also investigated for the six major urban areas. The intersection roadways were categorized as a principal arterial, minor arterial, or collector. The State Primary Routes are principal arterials. Functional classification and accident rate did not seem to show any relationship. However, as the functional classification decreased, so did the accident frequency at those intersections. (See Table 12.)

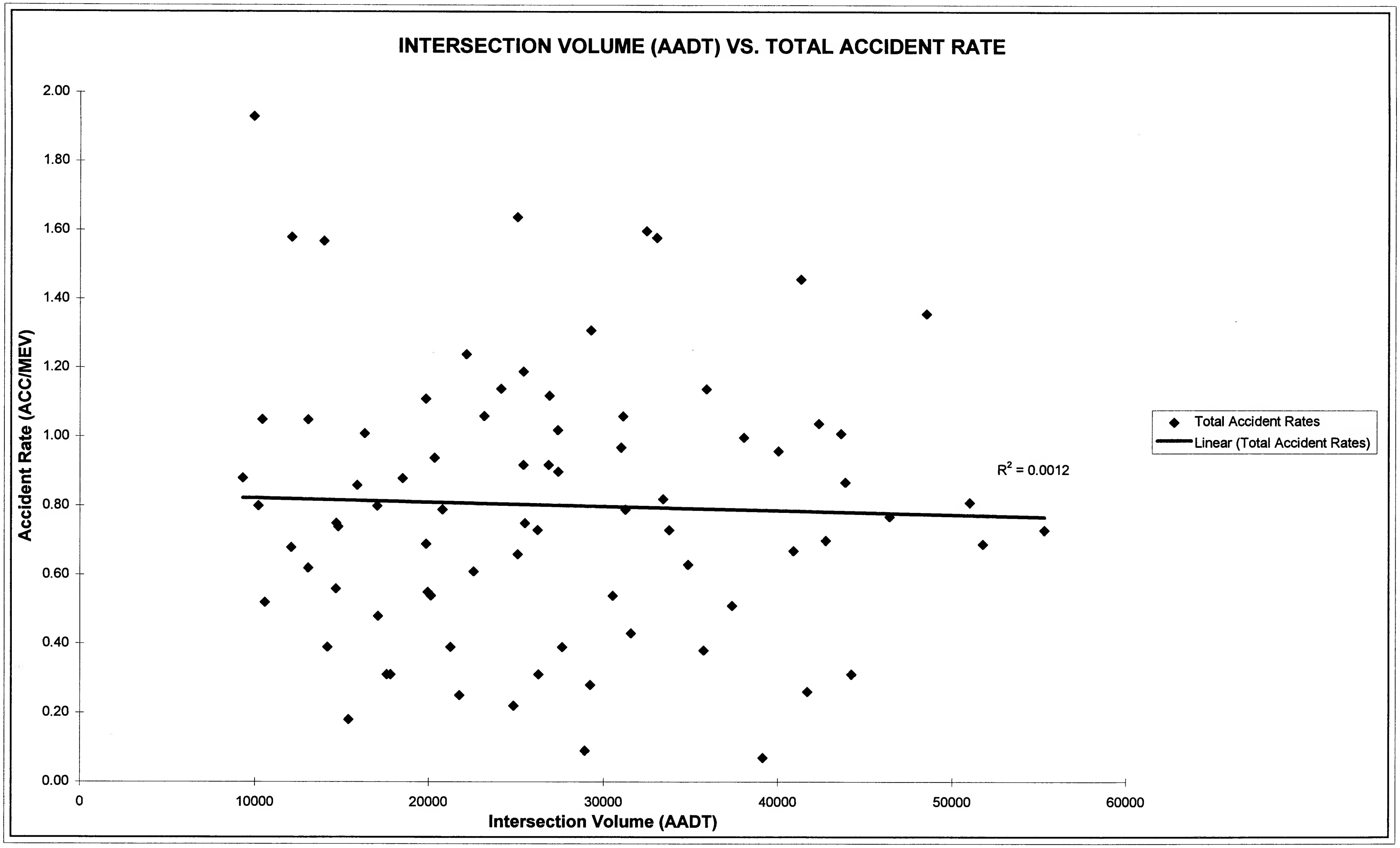


Figure 13. Intersection Volume (AADT) vs. Total Accident Rate

Table 12. Functional Classification of Intersecting Roadways*

		Total Accident Rate / Million Entering Vehicles			Total Accident Frequency		
City	Intersection	Principal Arterial	Minor Arterial	Collector	Principal Arterial	Minor Arterial	Collector
Billings	Main St. & Ist Ave. N.	0.73			16		
	Main St. & 4th Ave. N.	0.91			12		
	Main St. & 6th Ave. N.	0.38			5		
	Main St. & Hwy 318	1.36			24		
	Main St. & Lake Elmo Dr.			0.81			15
	Main St. & Hilltop Rd.	0.26			2		
	Main St. & Wicks Ln.	0.79			9		
	Main St. & Pemberton Ln.			0.48			3
	27th St. & 1st Ave. S.	1.46			8		
	27th St. & Montana Ave.	0.97			10		
	27th St. & 1st Ave. N.	2.32			15		
	27th St. & 4th Ave. N.	1.46			19		
	27th St. & 6th Ave. N.	1.00			14		
	27th St. & 9th Ave. N.			0.73			6
	27th St. & Poly Dr.		0.39			3	
Great Falls	15th St. & Central Ave.			1.93			7
	15th St. & 1st Ave. N.		0.18			1	
	15th St. & 2nd Ave. N.		0.56			3	
	15th St. & 8th Ave. N.			0.68			3
	14th St. & 8th Ave. N.			0.52			2
	14th St. & 2nd Ave. N.	1.57			8		
	14th St. & 1st Ave N.	0.75			4		
	14th St. & Central Ave.			3.51			13
	15th St. & River Dr.	1.24			10		
	15th St. & River Rd.		1.05			5	
	10th Ave. S. & 38th St.		0.28			3	
	10th Ave. S. & 32nd St.			0.82			10
	10th Ave. S. & 26th St.		1.04			16	
	10th Ave. S. & 25th St.		0.96			14	
	10th Ave. S. & 20th St.			0.67			10
	10th Ave. S. & 15th St.	0.87			14		
	10th Ave. S. & 14th St.	0.31			5		
	10th Ave. S. & 9th St.	1.01			16		
	10th Ave. S. & 7th St.			0.49			6
	10th Ave. S. & 5th St.		0.63			8	
	10th Ave. S. & River (FAU 5205)		0.38			5	
	10th Ave. S. & 6th St. SW.	0.90			9		

*All state highways are classified as principal arterials.

Table 12. Functional Classification of Intersecting Roadways*

		Total Accident Rate / Million Entering Vehicles			Total Accident Frequency		
City	Intersection	Principal Arterial	Minor Arterial	Collector	Principal Arterial	Minor Arterial	Collector
Missoula	Brooks St. & 39th St.	0.31			3		
	Brooks St. & Reserve St.	1.14			15		
	Brooks St. & Paxon St.			0.47			4
	Brooks St., South Ave. & Russell St.	0.69			13		
	Brooks St. & Stephens St.	0.07			1		
	Brooks St. & Mount Ave.		0.75			7	
	Brooks St. & Beckwith Ave.		0.31			2	
	Brooks St. & Higgins Ave.	0.66			6		
	Higgins Ave. & 6th St.	1.12			11		
	Higgins Ave. & 5th St.	0.92			9		
	Broadway & N. Russell	0.73			9		
	Broadway & Scott			0.25			2
	Broadway & N. Orange	1.60			19		
	Broadway & Ryman			0.31			2
	Broadway & Higgins	1.64			15		
	Broadway & Pattee			0.80			5
	Broadway & Madison	1.06			9		
	Broadway & Van Buren		0.54			6	
Butte	Harrison Ave. & Elizabeth Warren		0.61			5	
	Harrison Ave. & Holmes Ave.		0.22			2	
	Harrison Ave. & Amherst St.		0.09			1	
	Harrison Ave & Cobban St.			1.23			7
	Harrison Ave & Grand Ave.			0.54			4
	Harrison Ave. & Civic Center Rd.			1.01			6
	Utah St. & Front	0.55			4		
	Utah St. & Second St.			0.88			3
	Utah St. & Platinum St.			0.39			2
	Arizona St. & Mercury St.			0.80			3
	Arizona St. & Park St.	1.05			4		
	Montana St. & Mercury St.	0.62			3		
	Montana St. & Platinum St.			1.11			8

*All state highways are classified as principal arterials.

Table 12. Functional Classification of Intersecting Roadways*

		Total Accident Rate / Million Entering Vehicles			Total Accident Frequency		
City	Intersection	Principal Arterial	Minor Arterial	Collector	Principal Arterial	Minor Arterial	Collector
Helena	Euclid Ave. & Henderson St.		0.79			6	
	Euclid Ave. & Benton Ave.	1.41			15		
	Lyndale Ave. & Last Chance Gulch	0.43			5		
	Lyndale Ave., Helena Ave. & Montana Ave.				27		
	Montana Ave. & Billings Ave.	0.38			3		
	Montana Ave. & 11th Ave.	0.39			4		
	11th Ave. & Roberts St.			0.14			1
	11th Ave. & Sanders St.			0.65			3
	11th Ave. & Lamborn St.			0.88			6
	11th Ave. & Fee St.		1.14			10	
	Prospect Ave. & Fee St.		1.19			11	
	Prospect Ave. & Lamborn St.			0.86			5
Bozeman	Main St. & College St.		0.79			6	
	Main St. & 19th Ave.		1.58			19	
	Main St. & 15th Ave.			0.86			7
	Main St. & 11th Ave.			1.06			12
	Main St. & 8th Ave.		0.54			6	
	Main St. & 7th Ave.	0.51			7		
	Main St. & Willson Ave.		0.94			7	
	Main St. & Rouse Ave.		0.69			5	
	Mean	0.91	0.68	0.85	10.1	6.6	5.7
	Standard Deviation	0.48	0.37	0.64	6.2	4.7	3.7

*All state highways are classified as principal arterials.

Task E - Summary of Findings

To accomplish the study objective of identifying accident patterns and trends amenable to correction at signalized intersections, several major tasks were undertaken. The first was to review relevant literature regarding accidents at signalized intersections. In particular, studies that analyzed factors such as accident type and severity, traffic control devices, delay, fuel consumption, and signal coordination, among others, were examined and pertinent findings discussed in detail.

The volume of entering intersection traffic, for example, affects both accident frequency and accident rates. Statistically, the *frequency* of accidents is directly related to the number of entering intersection vehicles, but accident *rates* do not necessarily increase as the number of entering intersection vehicles increase. The frequency of accidents at signalized intersections was also found to be related to the type of signal control. Another factor of influence on accidents is signal coordination. Inadequate clearance interval durations can lead to an increase in accidents. Based on the previously cited research (9), the use of the all-red clearance interval may show a reduction in accident rates initially, but the long-term effects do not show an appreciable reduction when compared to similar intersections that have not been installed with an all-red clearance interval. It was also noted that recent use of photo enforcement has shown promising results in the reduction of violations and accidents at the treated intersections.

Flashing signal operation has many common uses, such as during low-volume periods, as the result of a signal malfunction, and prior to removal of a traffic signal or following the installation of a new signal. Although flashing operation of traffic signals has been widely used over the years as an alternative to operating signals in normal mode (green-yellow-red), there are no comprehensive guidelines for its utilization. The use of flashing operation during low-volume conditions has the potential to reduce stops and delays to major street traffic, as well as reduce delays to minor street traffic. However, accidents during flashing operation appear to be more numerous than accidents during normal operation, especially right-angle accidents. Suggested guidelines for flashing signal operation were outlined in the literature review.

The second task of the study analyzed statewide accident statistics from 1992 through 1994 to identify apparent trends in the data. Specifically, the data were broken down by accident type, severity, alcohol involvement, roadway surface conditions, light conditions, age of drivers, and contributing factors for purposes of analysis. When appropriate, findings from the examination of Montana data were compared to the results of other studies to determine the extent to which the accident experience at signalized intersections in this state differed from that in other locations.

In an initial review, it appeared that Montana had a larger than average percentage of angle accidents. However, upon further examination, the difference was found to be the result of variations in the way angle accidents were coded. Montana's definition of angle accidents includes right-angle, left-turn, right-turn and other types of accidents where the vehicles collide at an angle. A more restrictive definition is sometimes used for data collection or analysis purposes in other locations. Once coding discrepancies were controlled, Montana's right-angle accident percentages were found to be more comparable to those reported in other studies. Angle accidents and rear-end accidents represented the largest percentages of accident types.

Accidents on Montana's State Primary Routes were subsequently plotted against MOVITE plots which were based on accident number, traffic volume, intersection geometry and signal phasing. In each comparison, Montana's accident frequencies were equal to or below the average of the other nine states that were represented in the MOVITE plots. When variables such as accident severity, roadway surface conditions, light conditions and contributing factors were introduced into the analysis, Montana's accident experience remained comparable to those of the other locations, as well.

Accident trends at signalized intersections were then analyzed and compared across Montana's six largest cities: Billings, Great Falls, Missoula, Butte, Helena, and Bozeman. Accident frequencies from 1994 were used as the basis for this phase of the analysis. The breakdown of crashes by accident type did not reveal any noteworthy variations across the six cities. In addition, the total number of accidents was found to be directly related to the population of the study sites, as was the number of signals in each city.

Additional analyses of the accident experience in each city were conducted, such as the involvement of elderly drivers in intersection collisions, and a comparison of signalized intersection accidents versus accidents at unsignalized intersections and mid-block intersections. Results of these analyses are shown in tabular and graphic form in the appendices to this report. Overall, the results of the examination of accidents at signalized intersections appeared to be fairly comparable across the cities with no consistent or noteworthy variations reported for any one location. The authors believe, however, that the findings from these detailed analyses should prove useful to MDT personnel or other transportation officials in the respective study sites for planning or evaluating accident countermeasures.

The final two tasks in this study involved establishing variables of influence and determining significant causal patterns with regard to signalized intersection accidents. In order to identify appropriate locations for further study, selection criteria were developed that were based upon both intersection accident rates and intersection angle accident rates. A sample of twenty-five intersections on State Primary Routes were ultimately selected for this phase of analysis. No unusual situations or atypical findings were noted across study sites in terms of either total accident rates or angle accident rates.

In the subsequent analysis, clearance interval values were compared to recommended yellow and all-red clearance interval values that were calculated using established ITE formulas. It should be noted that for most of the 25 intersections in the sample, the calculated yellow clearance value was less than or equal to the respective values currently being used for the signals. However, the calculated all-red intervals were generally longer than the comparable values currently in use for the signals. According to Montana Department of Transportation personnel (18), 1.0 to 1.5 seconds had generally been used as a rule of thumb for the all-red signal phase. Now, the ITE formula is being used for new signal installations, which will increase the length of time of the all-red signal phase.

The relationships between intersection volume and accident frequency and accident rates were examined. The linear relationship of annual average daily traffic and accident frequency showed that as the volume increases, the accident frequency increases also. However, a linear regression showed little significance in the relationship of volume and accident rates.

In conclusion, it is the opinion of the authors that Montana does not exhibit any unusual accident characteristics or trends at signalized intersections based upon available Montana data for the variables of influence. This research determined the following results for Montana:

- Angle accidents and rear-end accidents accounted for the largest percentages of accident types.

- As traffic volume increased, accident frequencies also increased.

- The relationship between intersection traffic volume and accident rates was not found to be statistical significant.

- As population within the city limits increased, the accident frequencies also increased.

- Accident frequencies decreased as the functional classification of the intersecting roadways decreased.

- Accidents at such locations in this state seem to occur in similar proportions and for the same reasons as they do in other states and jurisdictions.

References

1. Essam Radwan and Daniel Wing, "Safety Effects of Traffic Signal Installations," Center for Advanced Research in Transportation, College of Engineering & Applied Sciences, Arizona State University, July 1987. FHWA-AZ87-809.

2. *Highway Capacity Manual*, Transportation Research Board Special Report 209, 1985.

3. Hall and M. Polanco de Hurtado, "Urban Intersection Accident Rates and Congestion," Traffic Safety Bureau Transportation Programs Division NMSHTD, November 1990. FHWA-NMTSB-90-01.

4. Zador, H. Stein, S. Shapiro and P. Tarnoff, "Effect of Clearance Interval Timing on Traffic and Crashes at Signalized Intersections," *ITE Journal*, November 1985.

5. Gazis, D.; Heiman, R.; and Marududin, A. "The Problem of the Amber Signal Light in Traffic Flow," *Traffic Engineering*, July 1960.

6. Rach, L. "Traffic Signals," *Transportation and Traffic Engineering Handbook.* 2nd ed., Institute of Transportation Engineers, 1982.

7. *Transportation and Traffic Engineering Handbook.* 1st ed., Institute of Transportation Engineers, 1976.

8. Zador, H. Stein, S. Shapiro and P. Tarnoff, "Effect of Signal Timing on Traffic Flow and Crashes at Signalized Intersections," Insurance Institute for Highway Safety, May 1984.

9. Brian A. Roper, Jon D. Fricker and Kumares C. Sinha, "The Effects of the All-Red Clearance Interval on Intersection Accident Rates in Indiana," Purdue University, School of Engineering, Indiana Department of Transportation, Joint Highway Research Project, April 26, 1996. FHWA/IN/JHRP-90/7.

10. Dr. T. Makinen and Oei Hway-liem, "Automatic Enforcement of Speed and Red Light Violations: Applications, experiences and developments," SWOV Institute for Road Safety Research, The Netherlands, 1992. R-92-58.

11. Thomas Mericle and Nazir Lalani, "Transportation Tips: A Review of Photo Enforcement," *WesternITE*, May-June 1996.

12. James C. Barbaresso, "Flashing Signal Accident Evaluation," *Transportation Research Record 956,* Transportation Research Record, 1984.

13. Kent C. Kacir, H. Gene Hawkins, Jr., Robert J. Benz, Mike E. Obermeyer, and Richard T. Bartoskewitz, "Evaluation of Flashing Traffic Signal Operation," Research Report 1297-2F, Texas Transportation Institute, Texas A&M University, Texas, November 1993.

14. MOVITE Technical Committee 83-6, "MOVITE Area Accident Rate Comparison," October, 1984.

15. Estimates of Montana's Resident Population: Incorporated Places, 1994.

16. Federal Highway Administration, Highway Safety Information System Summary Report, "Accident Analysis of Older Drivers at Intersections," February 1995.

17. McShane, W.R. and Roess, R.P., "Traffic Engineering," 1990.

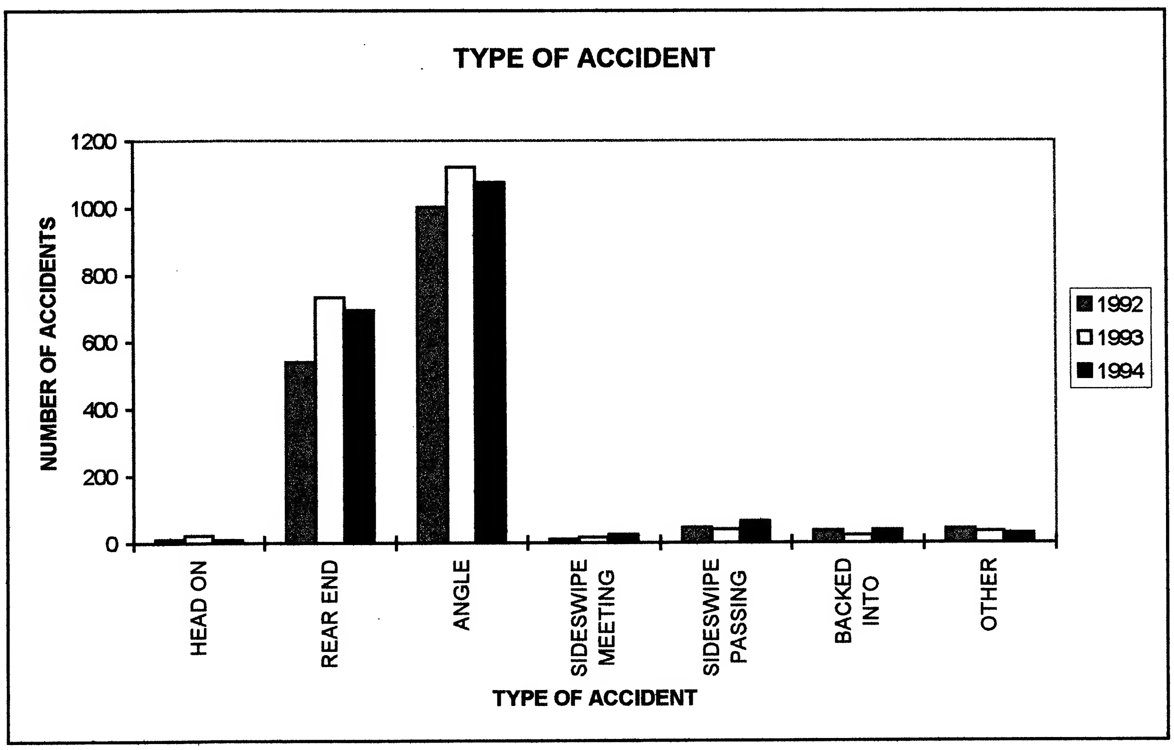
18. Dusek, Don, Technical Panel Discussions, Traffic Section, Montana Department of Transportation, 1996.

APPENDIX A - THREE-YEAR SUMMARY STATISTICS

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS

MANNER OF TWO MOTOR VEHICLE COLLISION
NUMBER OF ACCIDENTS

TYPE OF ACCIDENT	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
HEAD ON	11	23	10	0.7	1.2	0.5	0.8
REAR END	539	733	694	32.0	36.8	35.9	34.9
ANGLE	1002	1122	1076	59.4	56.3	55.6	57.1
SIDESWIPE MEETING	11	17	24	0.7	0.9	1.2	0.9
SIDESWIPE PASSING	46	41	64	2.7	2.1	3.3	2.7
BACKED INTO	36	23	38	2.1	1.2	2.0	1.8
OTHER	42	34	29	2.5	1.7	1.5	1.9
TOTAL	1687	1993	1935	100	100	100	100

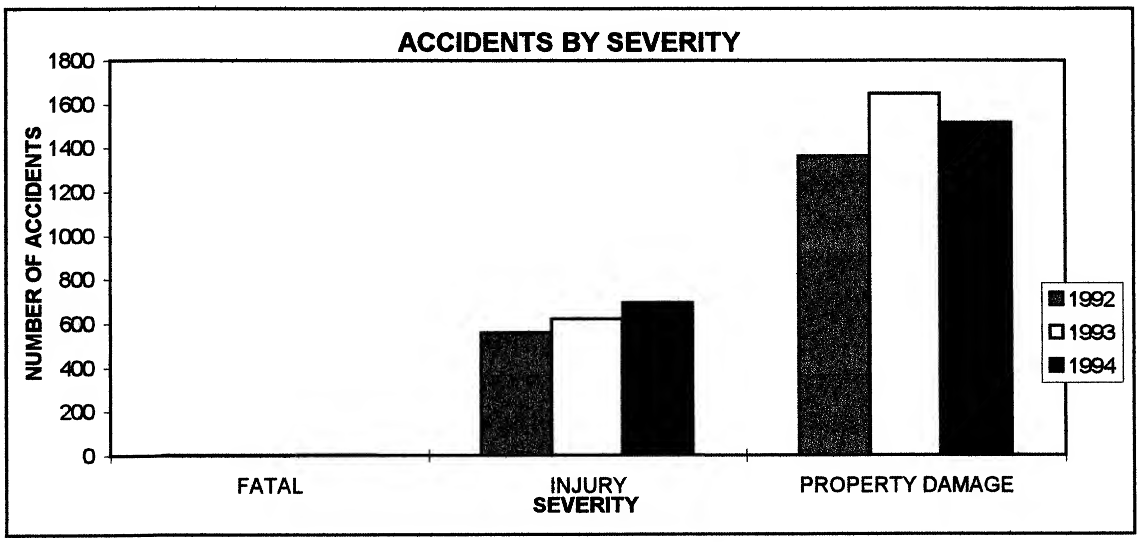


APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS

ACCIDENTS BY SEVERITY
NUMBER OF ACCIDENTS

SEVERITY OF ACCIDENT	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
FATAL	2	2	2	0.1	0.1	0.1	0.1
INJURY	560	621	693	29.1	27.3	31.4	29.3
PROPERTY DAMAGE	1364	1650	1514	70.8	72.6	68.5	70.6
TOTAL	1926	2273	2209	100	100	100	100

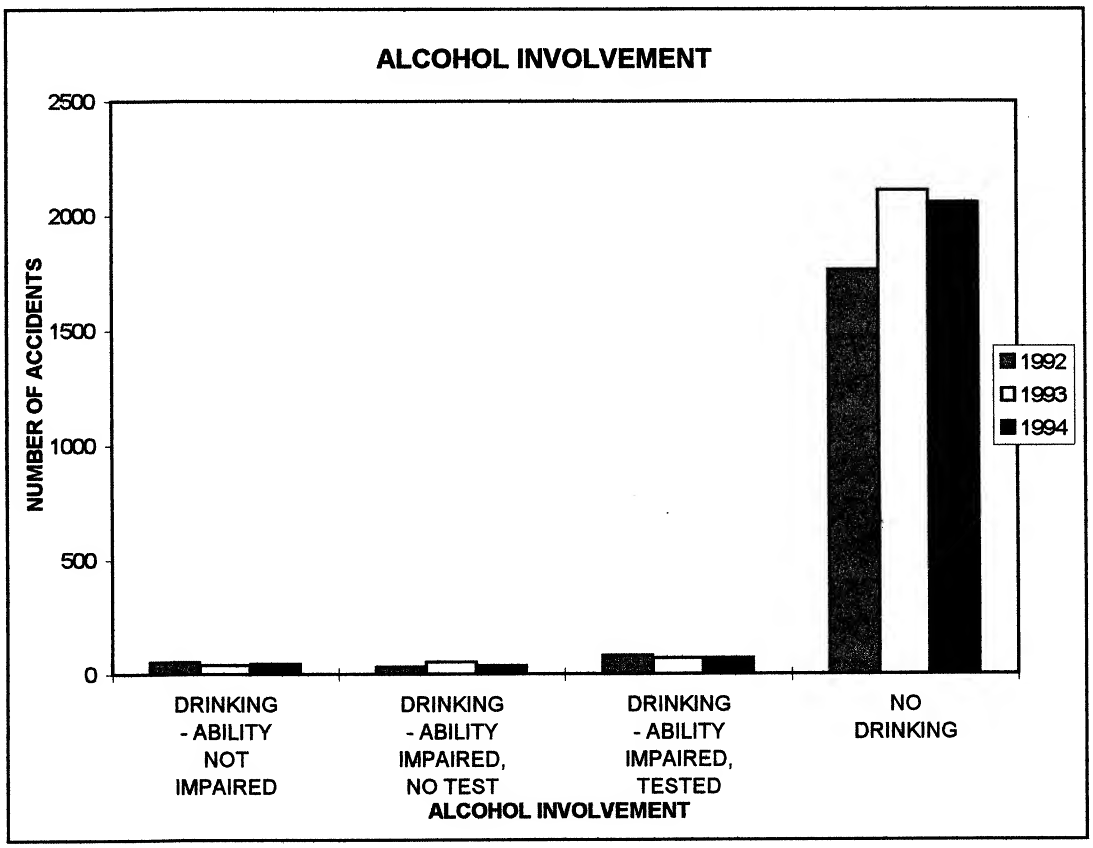


APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS

ALCOHOL INVOLVEMENT
NUMBER OF ACCIDENTS

ALCOHOL INVOLVEMENT	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
DRINKING - ABILITY NOT IMPAIRED	54	40	46	2.8	1.8	2.1	2.2
DRINKING - ABILITY IMPAIRED, NO TEST	30	54	37	1.6	2.4	1.7	1.9
DRINKING - ABILITY IMPAIRED, TESTED	80	69	69	4.2	3.0	3.1	3.4
NO DRINKING	1762	2110	2057	91.5	92.8	93.1	92.5
TOTAL	1926	2273	2209	100	100	100	100

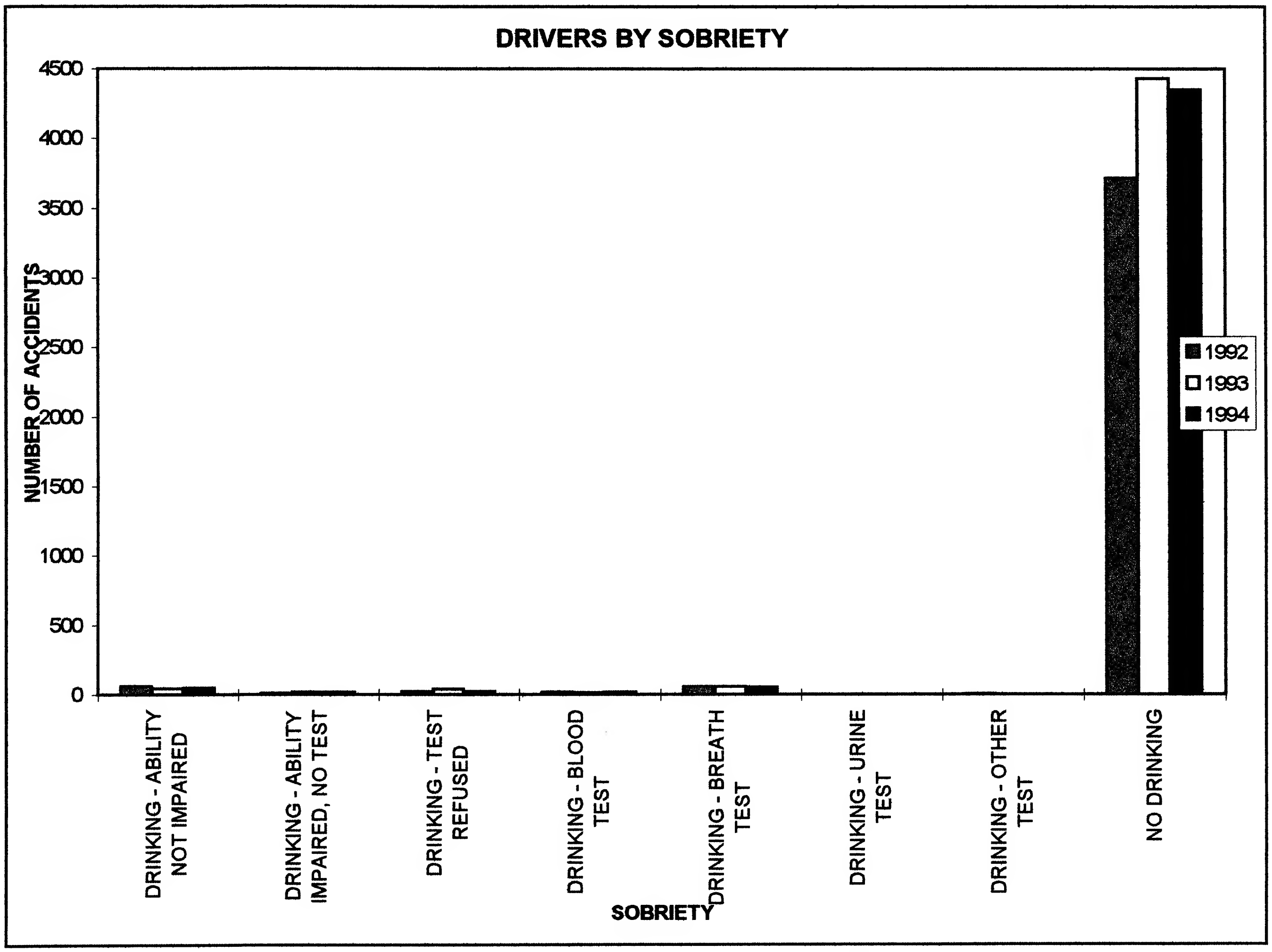


APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS

DRIVERS BY SOBRIETY
NUMBER OF DRIVERS

DRIVERS BY SOBRIETY	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
DRINKING - ABILITY NOT IMPAIRED	62	43	48	1.6	0.9	1.1	1.2
DRINKING - ABILITY IMPAIRED, NO TEST	10	16	17	0.3	0.3	0.4	0.3
DRINKING - TEST REFUSED	21	40	20	0.5	0.9	0.4	0.6
DRINKING - BLOOD TEST	16	13	18	0.4	0.3	0.4	0.4
DRINKING - BREATH TEST	58	55	50	1.5	1.2	1.1	1.3
DRINKING - URINE TEST	1	0	0	0.0	0.0	0.0	0.0
DRINKING - OTHER TEST	6	2	1	0.2	0.0	0.0	0.1
NO DRINKING	3714	4432	4347	95.5	96.3	96.6	96.1
TOTAL	3888	4601	4501	100	100	100	100

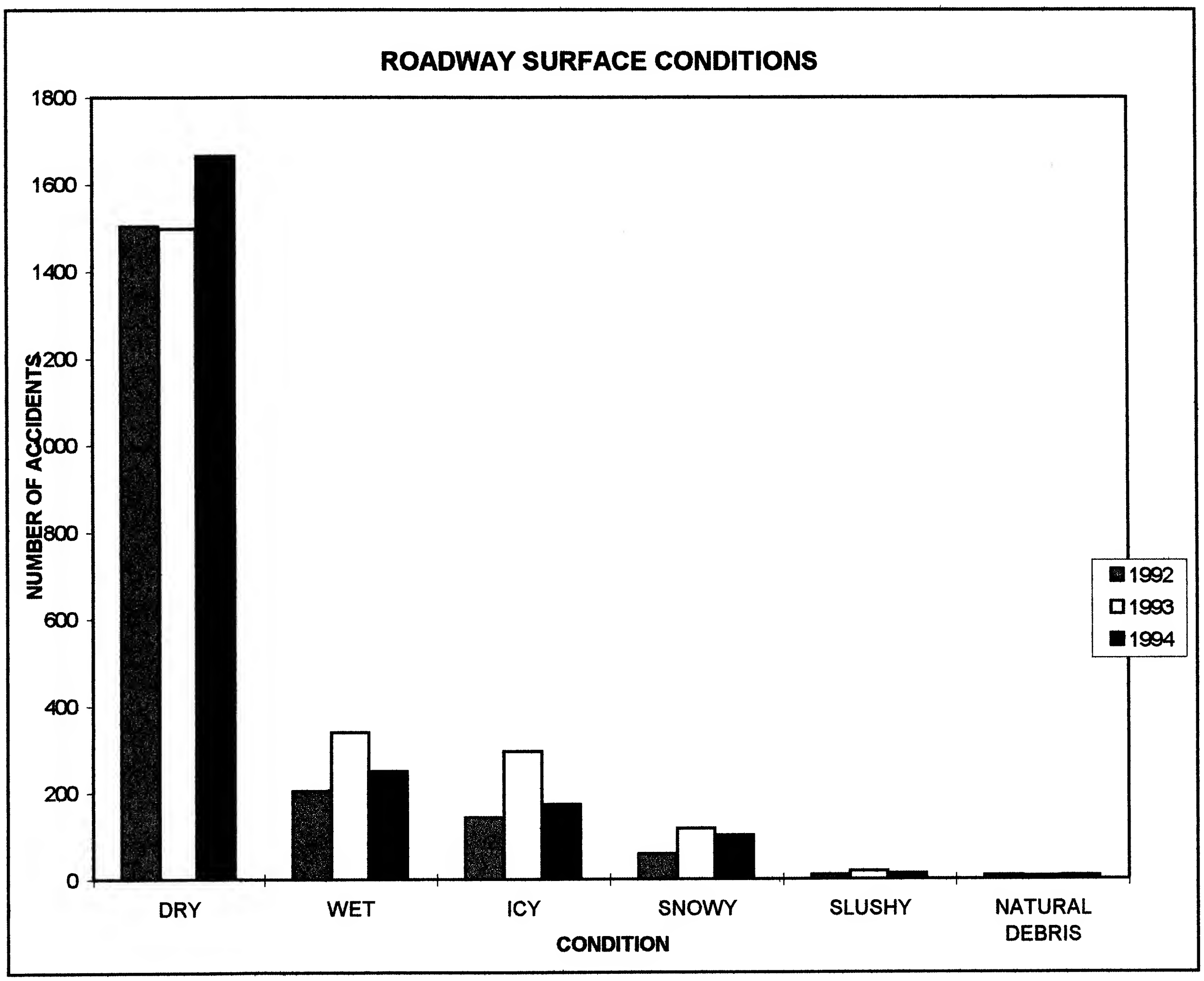


APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS

ROADWAY SURFACE CONDITIONS
NUMBER OF ACCIDENTS

ROADWAY SURFACE CONDITIONS	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
DRY	1503	1497	1665	78.0	65.9	75.4	73.1
WET	204	339	249	10.6	14.9	11.3	12.3
ICY	143	295	172	7.4	13.0	7.8	9.4
SNOWY	58	116	101	3.0	5.1	4.6	4.2
SLUSHY	10	19	13	0.5	0.8	0.6	0.6
NATURAL DEBRIS	8	7	9	0.4	0.3	0.4	0.4
TOTAL	1926	2273	2209	100	100	100	100

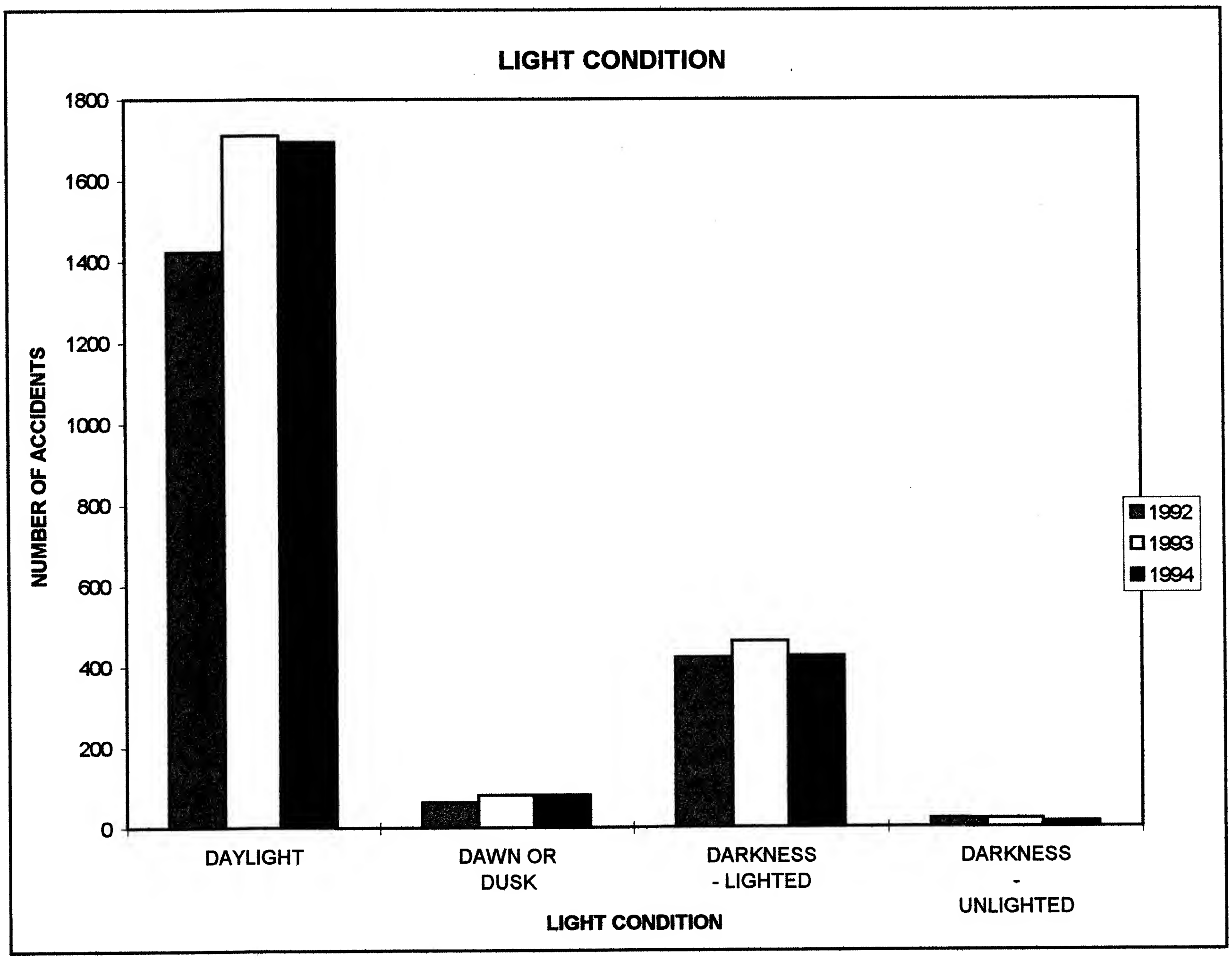


APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS

LIGHT CONDITION
NUMBER OF ACCIDENTS

LIGHT CONDITION	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
DAYLIGHT	1423	1711	1694	73.9	75.3	76.7	75.3
DAWN OR DUSK	63	81	80	3.3	3.6	3.6	3.5
DARKNESS - LIGHTED	419	460	422	21.8	20.2	19.1	20.4
DARKNESS - UNLIGHTED	21	21	13	1.1	0.9	0.6	0.9
TOTAL	1926	2273	2209	100	100	100	100

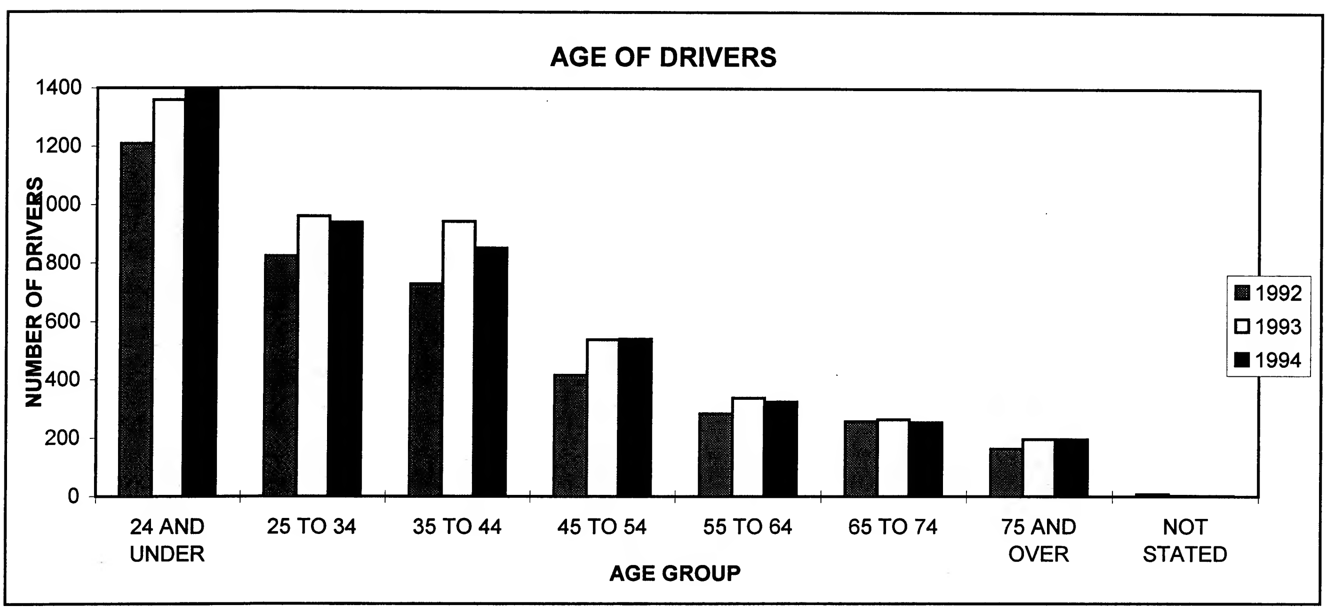


APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

AGE OF DRIVER
NUMBER OF DRIVERS

AGE	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
24 AND UNDER	1209	1359	1392	31.1	29.5	30.9	30.5
25 TO 34	824	961	940	21.2	20.9	20.9	21.0
35 TO 44	728	943	852	18.7	20.5	18.9	19.4
45 TO 54	415	538	540	10.7	11.7	12.0	11.5
55 TO 64	283	337	324	7.3	7.3	7.2	7.3
65 TO 74	257	264	254	6.6	5.7	5.6	6.0
75 AND OVER	164	197	197	4.2	4.3	4.4	4.3
NOT STATED	8	2	2	0.2	0.0	0.0	0.1
TOTAL	5880	6594	6495	100	100	100	100

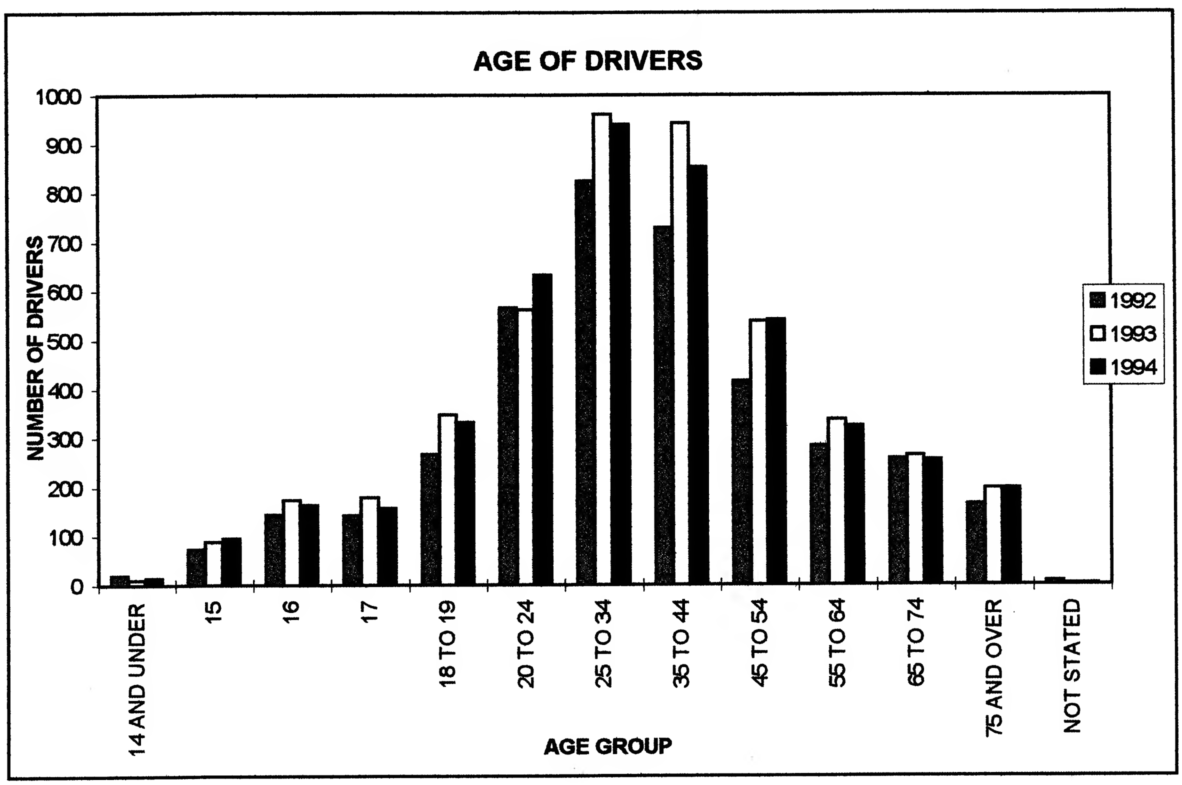


APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS

AGE OF DRIVER
NUMBER OF DRIVERS

AGE	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
14 AND UNDER	20	10	14	0.5	0.2	0.3	0.3
15	73	89	95	1.9	1.9	2.1	2.0
16	143	173	163	3.7	3.8	3.6	3.7
17	142	179	157	3.7	3.9	3.5	3.7
18 TO 19	266	347	331	6.8	7.5	7.4	7.2
20 TO 24	565	561	632	14.5	12.2	14.0	13.6
25 TO 34	824	961	940	21.2	20.9	20.9	21
35 TO 44	728	943	852	18.7	20.5	18.9	19.4
45 TO 54	415	538	540	10.7	11.7	12.0	11.5
55 TO 64	283	337	324	7.3	7.3	7.2	7.3
65 TO 74	257	264	254	6.6	5.7	5.6	6.0
75 AND OVER	164	197	197	4.2	4.3	4.4	4.3
NOT STATED	8	2	2	0.2	0.0	0.0	0.1
TOTAL	3888	4601	4501	100	100	100	100



APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

CONTRIBUTING FACTORS

VISION OBSTRUCTION	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
PRIVATE STRUCTURE	3	7	2	0.1	0.1	0	0.1
HIGHWAY RELATED STRUCTURE	0	0	0	0	0	0	0
TREES, OTHER VEGETATION	0	1	0	0	0	0	0
OTHER VEHICLE	71	72	78	1.8	1.5	1.7	1.7
SNOW BANK	0	0	0	0	0	0	0
SIGN / SIGN POST	1	0	0	0	0	0	0
HILL / CURVE	0	1	1	0	0	0	0
UNKNOWN	28	28	22	0.7	0.6	0.5	0.6
NOT OBSCURED	3878	4588	4501	97.4	97.7	97.8	97.6
TOTAL	3981	4697	4604	100	100	100	100

ROAD DEFECTS	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
HOLES	1	1	0	0	0	0	0
SHOULDERS	0	0	0	0	0	0	0
LOOSE MATERIAL	3	16	15	0.1	0.3	0.3	0.2
CONSTRUCTION	5	9	4	0.1	0.2	0.1	0.1
RUTTED/GROOVED	0	0	1	0	0	0	0
BLEEDING PAVEMENT	1	0	1	0	0	0	0
WASHBOARD	0	0	0	0	0	0	0
NO DEFECTS	3971	4671	4583	99.7	99.4	99.5	99.5
TOTAL	3981	4697	4604	100	100	100	100

MECHANICAL DEFECTS	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
LIGHTS/SIGNALS	6	1	8	0.2	0	0.2	0.1
EXHAUST SYSTEM	0	0	0	0	0	0	0
WINDSHIELD/WINDOWS/WIPERS	0	2	4	0	0	0.1	0.0
TIRES/WHEELS	2	4	2	0.1	0.1	0	0.1
BRAKES	21	23	21	0.5	0.5	0.5	0.5
POWER TRAIN/FUEL SYSTEM	5	6	2	0.1	0.1	0	0.1
TRUCK COUPLING/TRAILER HITCH	2	0	1	0.1	0	0	0.0
SUSPENSION	0	2	1	0	0	0	0
STEERING	1	2	2	0	0	0	0
NO APPARENT DEFECTS	3944	4657	4563	99.1	99.1	99.1	99.1
TOTAL	3981	4697	4604	100	100	100	100

APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

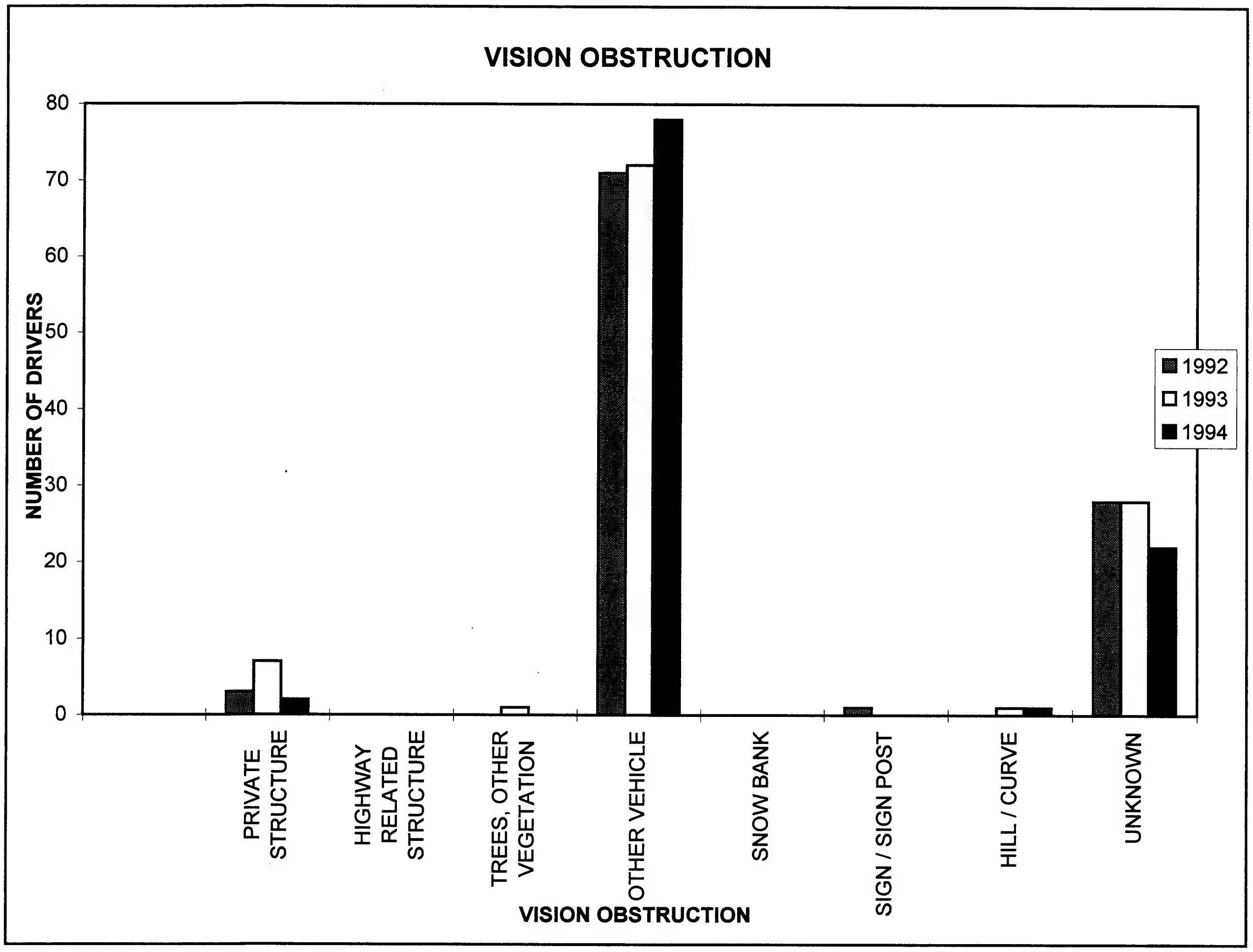
CONTRIBUTING FACTORS

DRIVER RELATED	1992 NUMBER	1993 NUMBER	1994 NUMBER	1992 %	1993 %	1994 %	AVERAGE %
HAS BEEN DRINKING	99	101	85	2.5	2.2	1.8	2.2
RECKLESS DRIVING	50	57	51	1.3	1.2	1.1	1.2
SPEED TOO FAST FOR CONDITIONS	121	241	183	3	5.1	4	4.0
FAILED TO YIELD RIGHT OF WAY	463	563	580	11.6	12	12.6	12.1
IMPROPER PASSING	17	16	12	0.4	0.3	0.3	0.3
IMPROPER BACKING	27	20	26	0.7	0.4	0.6	0.6
IMPROPER TURN	104	89	92	2.6	1.9	2	2.2
FAIL TO SIGNAL	8	4	5	0.2	0.1	0.1	0.1
CARELESS DRIVING	432	509	549	10.9	10.8	11.9	11.2
FAIL TO DRIVE TO THE RIGHT OF ROAD	3	6	2	0.1	0.1	0	0.1
IMPROPER PARKING	3	1	1	0.1	0	0	0.0
IMPROPER LANE CHANGE	46	42	40	1.2	0.9	0.9	1.0
EXCEEDED POSTED SPEED	4	2	5	0.1	0	0.1	0.1
OTHER	450	462	428	11.3	9.8	9.3	10.1
NO APPARENT VIOLATION	2154	2584	2545	54.1	55	55.3	54.8
TOTAL	3981	4697	4604	100	100	100	100

APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

VISION OBSTRUCTION



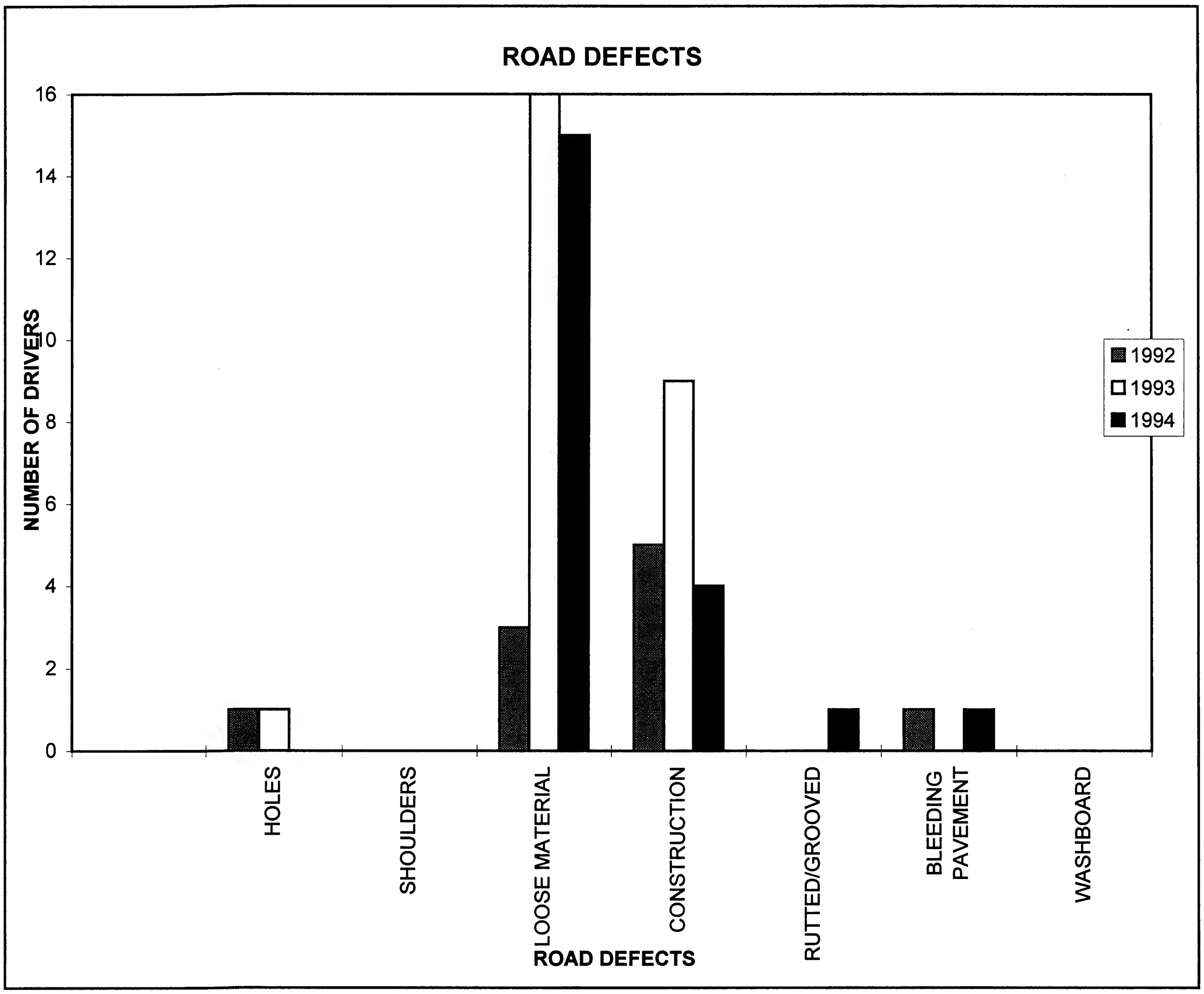
VISION NOT OBSCURED

YEAR	NUMBER OF DRIVERS
1992	3878
1993	4588
1994	4501

APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

ROAD DEFECTS



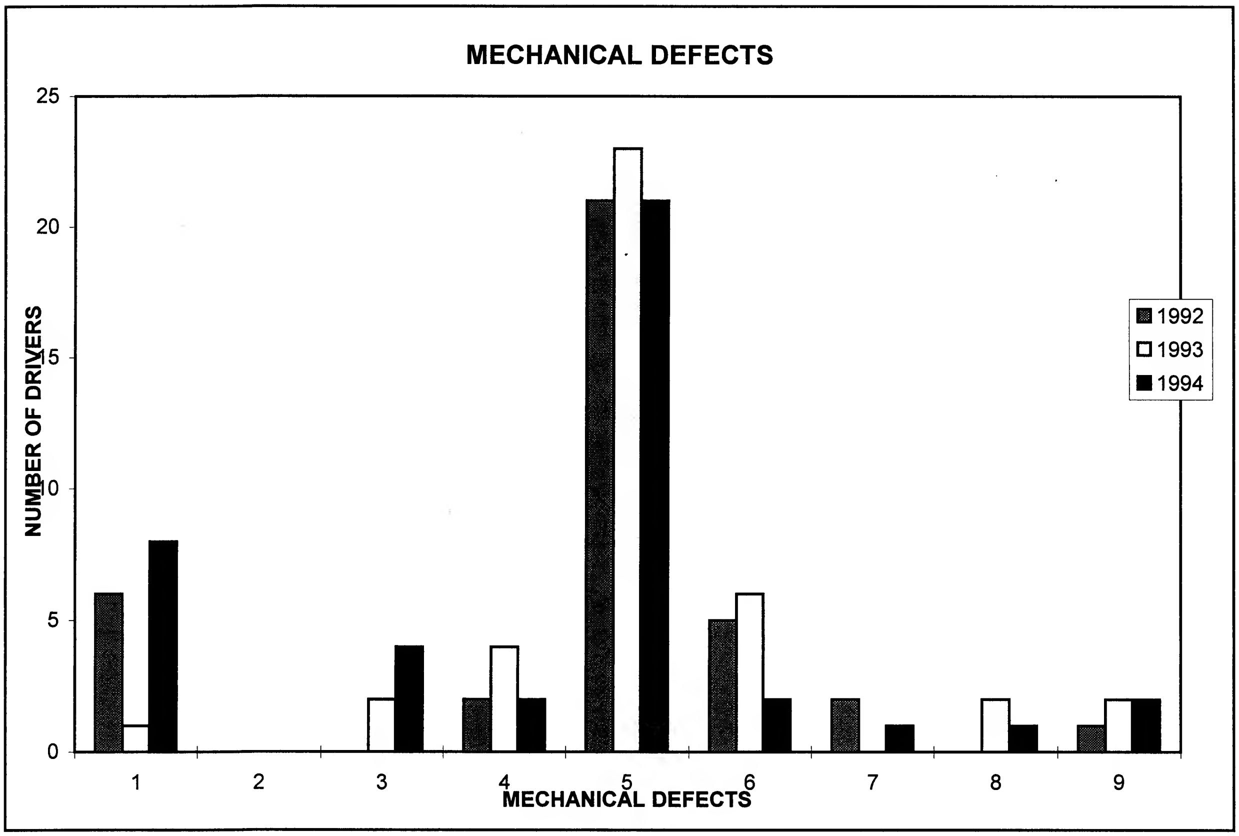
NO ROAD DEFECTS

YEAR	NUMBER OF DRIVERS
1992	3971
1993	4671
1994	4583

APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

MECHANICAL DEFECTS



NO MECHANICAL DEFECTS

YEAR	NUMBER OF DRIVERS
1992	3944
1993	4657
1994	4563

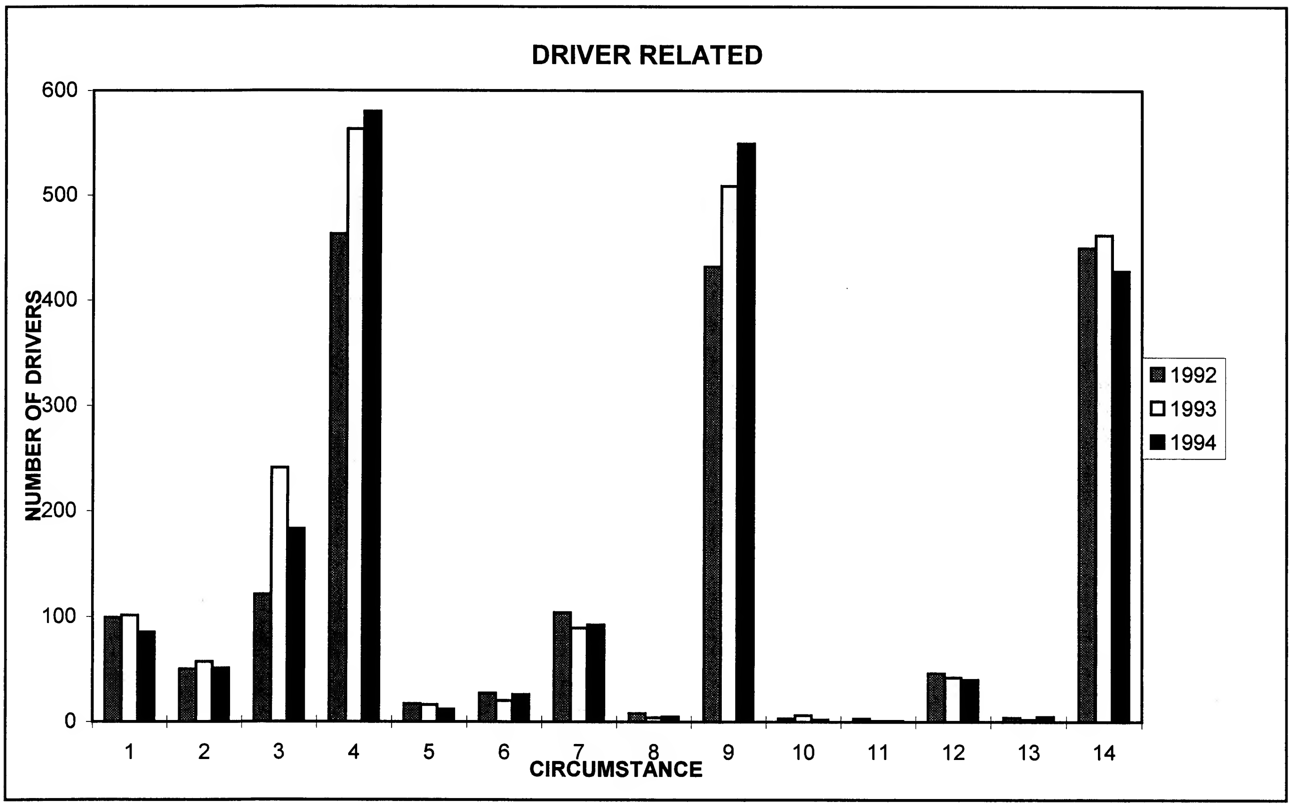
MECHANICAL DEFECTS

1. LIGHTS / SIGNALS
2. EXHAUST SYSTEM
3. WINDSHIELDS / WINDOWS / WIPERS
4. TIRES / WHEELS
5. BRAKES
6. POWER TRAIN / FUEL SYSTEM
7. TRUCK COUPLING / TRAILER HITCH
8. SUSPENSION
9. STEERING

APPENDIX A

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

DRIVER RELATED



NO APPARENT VIOLATION

YEAR	NUMBER OF DRIVERS
1992	2154
1993	2584
1994	2545

DRIVER RELATED CIRCUMSTANCE

0. NO APPARENT VIOLATION (SEE DATA ON LEFT)
1. HAS BEEN DRINKING
2. RECKLESS DRIVING
3. SPEED TOO FAST FOR CONDITIONS
4. FAILED TO YIELD RIGHT OF WAY
5. IMPROPER PASSING
6. IMPROPER BACKING
7. IMPROPER TURN
8. FAIL TO SIGNAL
9. CARELESS DRIVING
10. FAIL TO DRIVE TO THE RIGHT OF ROAD
11. IMPROPER PARKING
12. IMPROPER LANE CHANGE
13. EXCEEDED POSTED SPEED
14. OTHER

APPENDIX A

ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

TYPE OF ACCIDENT
HSIS 1994 MINNESOTA STATE DATA

ACCIDENT FILE - ACCDIGM

TYPE OF ACCIDENT	FREQUENCY	PERCENT
REAR END	4509	32.1
SIDESWIPE PASSING	691	4.9
LEFT TURN	1858	13.2
RAN OFF ROAD LEFT	81	0.6
RIGHT ANGLE	4858	34.6
RIGHT TURN	132	0.9
RAN OFF ROAD RIGHT	156	1.1
HEAD ON	251	1.8
SIDESWIPE OPPOSING	124	0.9
OTHER	570	4.1
NOT STATED	494	3.5
UNKNOWN	301	2.1
TOTAL	14025	100

SEVERITY OF ACCIDENT
HSIS 1994 MINNESOTA STATE DATA

ACCIDENT FILE - SEVERITY

SEVERITY	FREQUENCY	PERCENT
INJURY	586	4.2
NON-INCAPACITATING INJURY	2054	14.6
POSSIBLE INJURY	3559	25.4
FATAL	36	0.3
PROPERTY DAMAGE	7789	55.5
TOTAL	14024	100

FREQUENCY MISSING = 1

APPENDIX A

ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

ROAD SURFACE CONDITIONS
HSIS 1994 MINNESOTA STATE DATA

ACCIDENT FILE - RDSURF

ROAD SURFACE CONDITION	FREQUENCY	PERCENT
DRY	8966	63.9
WET	3099	22.1
SNOW / SLUSH	780	5.6
ICE / SNOW PACK	1013	7.2
MUDDY	4	0.0
DEBRIS	31	0.2
OILY	14	0.1
OTHER	32	0.2
UNKNOWN	86	0.6
TOTAL	14025	100

LIGHT CONDITIONS
HSIS 1994 MINNESOTA STATE DATA

ACCIDENT FILE - LIGHT

LIGHT CONDITION	FREQUENCY	PERCENT
DAYLIGHT	10106	72.1
DAWN	209	1.5
DUSK	541	3.9
DARK - STREET LIGHT ON	3002	21.4
DARK - STREET LIGHT OFF	34	0.2
DARK - NO STREET LIGHT	59	0.4
OTHER	6	0.0
UNKNOWN	68	0.5
TOTAL	14025	100

APPENDIX A

ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

AGE OF DRIVERS
HSIS 1994 MINNESOTA STATE DATA

VEHICLE FILE - DRV_AGE

AGE OF DRIVER	FREQUENCY	PERCENT
24 AND UNDER	7777	26.8
25 TO 34	7309	25.2
35 TO 44	5629	19.4
45 TO 54	3250	11.2
55 TO 64	1782	6.1
65 TO 74	1398	4.8
75 AND OLDER	1887	6.5
TOTAL	29032	100

FREQUENCY MISSING = 527

WEATHER CONDITIONS
HSIS 1994 MINNESOTA STATE DATA

ACCIDENT FILE - WEATHER

WEATHER CONDITION	FREQUENCY	PERCENT
CLEAR	7382	52.6
CLOUDY	4272	30.5
RAIN	1393	9.9
SNOW	745	5.3
SLEET, HAIL, FREEZING RAIN	39	0.3
FOG, SMOG, DUST	59	0.4
BLOWING SAND, DUST OR SNOW	57	0.4
SEVERE CROSS WINDS	6	0.0
OTHER	4	0.0
UNKNOWN	68	0.5
TOTAL	14025	100

APPENDIX A

ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

CONTRIBUTING FACTORS
HSIS 1994 MINNESOTA STATE DATA

VEHICLE FILE - CONTRIB1 AND CONTRIB2

CONTRIBUTING FACTOR	FACTOR 1		FACTOR 2	
	FREQUENCY	PERCENT	FREQUENCY	PERCENT
NO IMPROPER DRIVING	14055	47.5	8035	27.2
FAILURE TO YIELD R.O.W.	3705	12.5	690	2.3
ILLEGAL OR UNSAFE SPEED	1212	4.1	391	1.3
FOLLOWING TOO CLOSELY	1434	4.9	436	1.5
DISREGARD TRAFFIC CONTROL	2422	8.2	580	2.0
DRIVER LEFT OF CENTER	31	0.1	33	0.1
IMPROPER PASSING	137	0.5	68	0.2
IMPROPER LANE USE	572	1.9	278	0.9
IMPROPER PARK, STOP,START	177	0.6	82	0.3
IMPROPER TURN	541	1.8	405	1.4
NO SIGNAL / IMPROPER SIGNAL	29	0.1	21	0.1
IMPEDING TRAFFIC	29	0.1	27	0.1
DRIVER INATTENTION OR DISTRACTION	2523	8.5	2921	9.9
DRIVER INEXPERIENCE	101	0.3	294	1.0
PEDESTRIAN VIOLATION	146	0.5	11	0.0
PHYSICAL IMPAIRMENT	247	0.8	281	1.0
VISION OBSCURED-WINDSHIELD GLASS	8	0.0	14	0.0
VISION OBSCURED-SUN OR HEADLIGHTS	39	0.1	86	0.3
VISION OBSCURED-OTHER	139	0.5	180	0.6
OTHER HUMAN VIOLATION OR FACTOR	64	0.2	61	0.2
DEFECTIVE BREAKS	126	0.4	78	0.3
DEFECTIVE TIRE OR TIRE FAILURE	4	0.0	5	0.0
DEFECTIVE LIGHTS	8	0.0	4	0.0
INADEQUATE WINDSHIELD OR GLASS	1	0.0	0	0.0
OVERSIZE OR OVERWEIGHT VEHICLE	4	0.0	3	0.0
SKIDDING	242	0.8	308	1.0
OTHER VEHICLE DEFECTS OR FACTORS	51	0.2	23	0.1
WEATHER	248	0.8	363	1.2
ROAD DEFECT	355	1.2	192	0.6
UNKNOWN	909	3.0	13689	46.2
TOTAL	29559	100.0	29559	100.0

If more that one factor contributed to the accident, a second contributing factor was reported.

APPENDIX A

ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

HOUR OF ACCIDENT
HSIS 1994 MINNESOTA STATE DATA

ACCIDENT FILE - HOUR

HOUR	FREQUENCY	PERCENT
0:00 TO 0:59	152	1.1
1:00 TO 1:59	208	1.5
2:00 TO 2:59	68	0.5
3:00 TO 3:59	27	0.2
4:00 TO 4:59	27	0.2
5:00 TO 5:59	57	0.4
6:00 TO 6:59	228	1.6
7:00 TO 7:59	547	3.9
8:00 TO 8:59	583	4.2
9:00 TO 9:59	605	4.3
10:00 TO 10:59	667	4.8
11:00 TO 11:59	757	5.4
12:00 TO 12:59	1003	7.2
13:00 TO 13:59	969	6.9
14:00 TO 14:59	1068	7.6
15:00 TO 15:59	1237	8.8
16:00 TO 16:59	1235	8.8
17:00 TO 17:59	1196	8.5
18:00 TO 18 :59	832	5.9
19:00 TO 19:59	679	4.8
20:00 TO 20:59	489	3.5
21:00 TO 21:59	495	3.5
22:00 TO 22:59	369	2.6
23:00 TO 23:59	283	2.0
UNKNOWN	244	1.7
TOTAL	14025	100

APPENDIX A

ACCIDENTS AT SIGNALIZED INTERSECTIONS IN MONTANA

FIXED OBJECT STRUCK
HSIS 1994 MINNESOTA STATE DATA

ACCIDENT FILE - OBJECT1

FIXED OBJECT STRUCK	FREQUENCY	PERCENT
NO OBJECT STRUCK	12608	89.9
CONSTRUCTION EQUIPMENT	35	0.2
TRAFFIC SIGNAL	328	2.3
RAILROAD CROSSING DEVICE	1	0.0
LIGHT POLE	38	0.3
UTILITY POLE	21	0.1
SIGN STRUCTURE OR POST	174	1.2
MAILBOX	5	0.0
OTHER POLE	23	0.2
FIRE HYDRANT	34	0.2
TREE OR SHRUBBERY	41	0.3
CRASH CUSHION	1	0.0
MEDIAN SAFETY BARRIER	17	0.1
BRIDGE PIERS AND GUARDRAIL	11	0.1
OTHER GUARDRAIL	6	0.0
FENCING (NOT MEDIAN BARRIER)	29	0.2
CULVERT OR HEADWALL	1	0.0
EMBANKMENT, DITCH OR CURB	43	0.3
BUILDING OR WALL	47	0.3
ROCK OUTCROPS	1	0.0
PARKING METER	510	3.6
OTHER FIXED OBJECT	51	0.3
TOTAL	14025	100

APPENDIX B - CITY SUMMARIES

Study of Accidents at Signalized Intersections
Accident Types
1994 Data

Accident Type	Billings		Great Falls		Missoula	
	# of Acc.	% of Total	# of Acc.	% of Total	# of Acc.	% of Total
Head On	3	0.4	3	0.8	3	1.1
Rear End	249	33.7	159	40.0	89	31.9
Angle						
Right-Angle	159	21.5	84	21.1	56	20.1
Left-Turn	189	25.5	78	19.6	80	28.7
Right-Turn	29	3.9	4	1.0	16	5.7
Right-Turn/Slow or Stop	1	0.1	1	0.3		
Right-Turn/Remain Stopped	2	0.3	2	0.5	3	1.1
2 Right-Turns	2	0.3	8	2.0	1	0.4
Right-Turn/Lane Change	1	0.1				
Left-Turn/Right-Turn	7	1.0	1	0.3	3	1.1
Left-Turn/Slow or Stop			2	0.5		
Left-Turn/ Remain Stopped	4	0.5			1	0.4
2 Left-Turns	2	0.3	1	0.3		
Left-Turn/Lane Change						
Left-Turn/Parking Maneuver					1	0.4
Slow or Stop/Remain Stopped	1	0.1	2	0.5	1	0.4
Straight/Slow or Stop	2	0.3	14	3.5		
Straight/Remain Stopped	7	1.0	2	0.5	3	1.1
Lane Change/Straight	9	1.2	2	0.5	1	0.4
Lane Change/Remain Stopped	1	0.1				
2 Lane Changes					1	0.4
U-Turn/Straight	3	0.4	1	0.3	1	0.4
U-Turn/Right-Turn			1	0.3		
2 U-Turns	1	0.1				
Overtake/Straight					1	0.4
Slow or Stop/Slow or Stop			1	0.3	1	0.4
Start in Traffic Lane	3	0.4				
Start from Parked Position	1	0.1				
Unknown						
Total	424	57.3	204	51.3	170	60.9
Sideswipe Meeting	12	1.6	1	0.3	1	0.4
Sideswipe Passing	26	3.5	11	2.8	7	2.5
Backed Into	7	1.0	6	1.5	3	1.1
Other	19	2.6	14	3.5	6	2.2
Totals	740	100	398	100	279	100

APPENDIX B

Study of Accidents at Signalized Intersections
Accident Types
1994 Data

Accident Type	Butte		Helena		Bozeman	
	# of Acc.	% of Total	# of Acc.	% of Total	# of Acc.	% of Total
Head On	0	0.0	2	1.0	0	0.0
Rear End	44	31.9	73	36.0	65	45.8
Angle						
Right-Angle	27	19.6	35	17.2	18	12.7
Left-Turn	31	22.5	47	23.2	34	23.9
Right-Turn	5	3.6	6	3.0	4	2.8
Right-Turn/Slow or Stop					1	0.7
Right-Turn/Remain Stopped	1	0.7			2	1.4
2 Right-Turns			2	1.0		
Right-Turn/Lane Change						
Left-Turn/Right-Turn						
Left-Turn/Slow or Stop	1	0.7	2	1.0		
Left-Turn/ Remain Stopped						
2 Left-Turns			1	0.5	2	1.4
Left-Turn/Lane Change					1	0.7
Left-Turn/Parking Maneuver						
Slow or Stop/Remain Stopped						
Straight/Slow or Stop	2	1.5	1	0.5	1	0.7
Straight/Remain Stopped	3	2.2				
Lane Change/Straight			2	1.0		
Lane Change/Remain Stopped						
2 Lane Changes						
U-Turn/Straight	1	0.7				
U-Turn/Right-Turn						
2 U-Turns						
Overtake/Straight					2	1.4
Slow or Stop/Slow or Stop	1	0.7				
Start in Traffic Lane	1	0.7				
Start from Parked Position	1	0.7				
Unknown			2	1.0		
Total	74	53.6	98	48.3	65	45.8
Sideswipe Meeting	7	5.1	1	0.5	0	0.0
Sideswipe Passing	5	3.6	2	5.4	3	2.1
Backed Into	1	0.7	9	4.4	3	2.1
Other	7	5.1	9	4.4	6	4.2
Totals	138	100	203	100	142	100

APPENDIX B

Study of Accident at Signalized Intersections
Accident Types by City
1994 Data

	Percent of Total Accidents						
Accident Type	Billings	Great Falls	Missoula	Butte	Helena	Bozeman	3 Yr State Ave
Head On	0.41	0.75	1.08	0	0.99	0	0.77
Rear End	33.65	39.95	31.90	31.88	35.96	45.77	34.86
Angle	57.30	51.26	60.93	53.62	48.28	45.77	57.10
Sideswipe Meeting	1.62	0.25	0.36	5.07	0.49	0	0.92
Sideswipe Passing	3.51	2.76	2.51	3.62	5.42	2.11	2.70
Backed Into	0.95	1.51	1.08	0.72	4.43	2.11	1.75
Other	2.56	3.52	2.15	5.07	4.43	4.23	1.90

Accident Type	Mean for Cities	Standard Deviation
Head On	0.57	0.44
Rear End	36.52	5.45
Angle	52.86	5.64
Sideswipe Meeting	1.30	1.93
Sideswipe Passing	3.32	1.18
Backed Into	1.80	1.38
Other	3.66	1.13

APPENDIX B

Study of Accident at Signalized Intersections
Angle Accident Types
1994 Data

Angle Acc. Type	Percentages of Total Accidents						Mean	Std. Dev.
	Billings	Great Falls	Missoula	Butte	Helena	Bozeman		
Right-Angle	21.5	21.1	20.1	19.6	17.2	12.7	18.7	3.3
Left-Turn	25.5	19.6	28.7	22.5	23.2	23.9	23.9	3.1
Right-Turn	3.9	1.0	5.7	3.6	3.0	2.8	3.3	1.5
Other	6.4	9.6	6.4	7.9	4.9	6.4	6.9	1.6

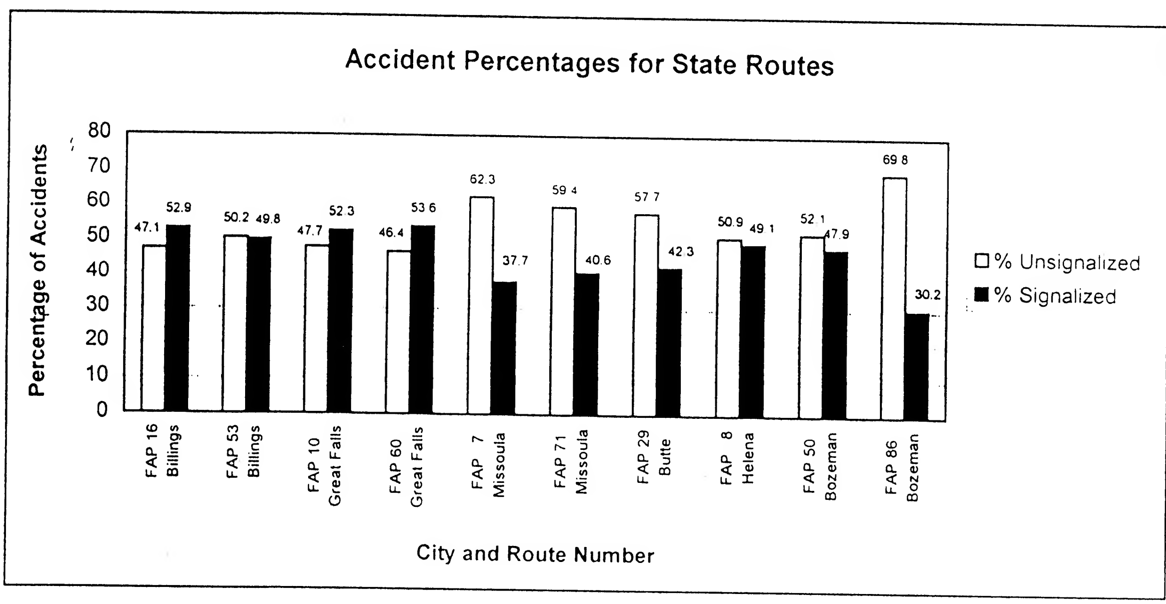
APPENDIX B

Study of Accidents at Signalized Intersections
Percentage of Accidents that Occured at Signalized Intersections on State Routes
1993 - 1994 Accident Data

City	Route	Street Name	Total # Acc.	% Unsignalized	% Signalized	Miles
Billings	FAP 16	Main St.	522	47.1	52.9	4.722
Billings	FAP 53	27th St.	323	50.2	49.8	5.629
Great Falls	FAP 10	14th, 15th St.	222	47.7	52.3	4.800
Great Falls	FAP 60	10th Ave. So.	617	46.4	53.6	5.351
Missoula	FAP 7	Brooks St.	422	62.3	37.7	4.722
Missoula	FAP 71	Broadway St.	342	59.4	40.6	5.167
Butte	FAP 29	Harrison Ave.	437	57.7	42.3	6.820
Helena	FAP 8	Highway 12	532	50.9	49.1	6.039
Bozeman	FAP 50	Main St.	357	52.1	47.9	4.497
Bozeman	FAP 86	Rouse Ave.	43	69.8	30.2	3.003

Unsignalized Accident Locations
Mean = 54.4
Standard Deviation = 7.7

Signalized Intersection Accidents
Mean = 45.6
Standard Deviation = 7.7



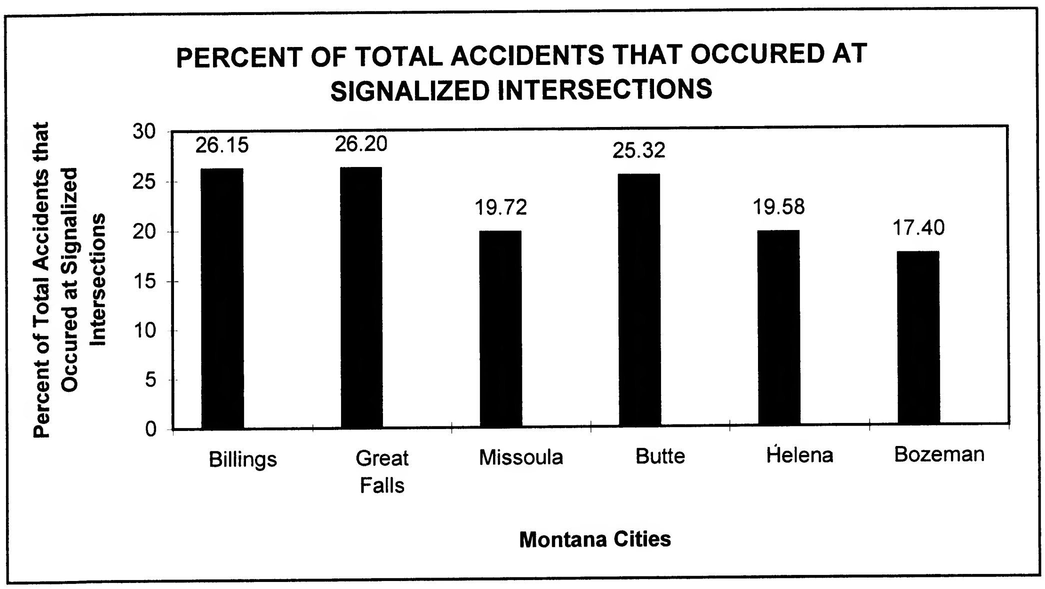
APPENDIX B

Study of Accidents at Signalized Intersections
Percent of Total Accidents that Occured at a Signalized Intersection
1994 Accident Data

City	# Sig. Acc.	Total # Acc.	% of Acc. at Sig. Intersections
Billings	740	2830	26.15
Great Falls	398	1519	26.20
Missoula	279	1415	19.72
Butte	138	545	25.32
Helena	203	1037	19.58
Bozeman	142	816	17.40

Mean = 22.40 %

Standard Deviation = 3.93 %

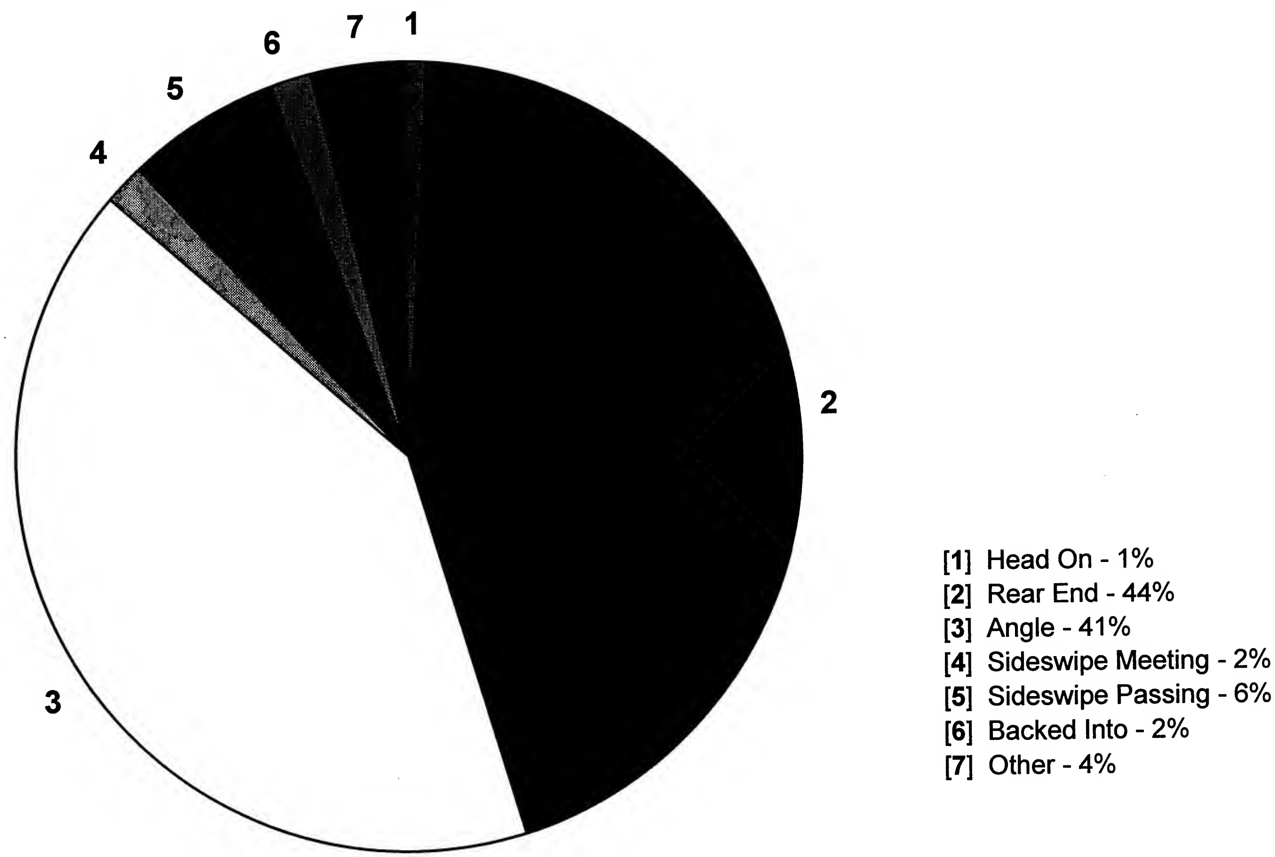


APPENDIX C - STATE PRIMARY ROUTE SUMMARIES

Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Billings ~ FAP 16									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
FAP 16 & I-90		1	1					2		
FAP 16 & Lockwood Rd.		3	7				2	12		
Main St. & Ist Ave. N.	1	5	4		3	1	2	16	0.73	0.20
Main St. & 4th Ave. N.		5	4		3			12	0.91	0.30
Main St. & 6th Ave. N.		2	2				1	5	0.38	0.15
Main St. & Hwy 318		14	8	1		1		24	1.36	0.45
Main St. & Lake Elmo Dr.		8	6	1				15	0.81	0.32
Main St. & Hilltop Rd.		1	1					2	0.26	0.07
Main St. & Milton Rd.		5	9					14	1.06	0.68
Main St. & Logan Ln.		2	2					4	0.30	0.15
Main St. & Wicks Ln.		5	4					9	0.79	0.35
Main St. & Pemberton Ln.		1	2					3	0.48	0.32
Unidentifiable Intersections		4	2		2			8		
TOTAL	1	56	52	2	8	2	5	126		
PERCENT OF TOTAL	1	44	41	2	6	2	4	100		

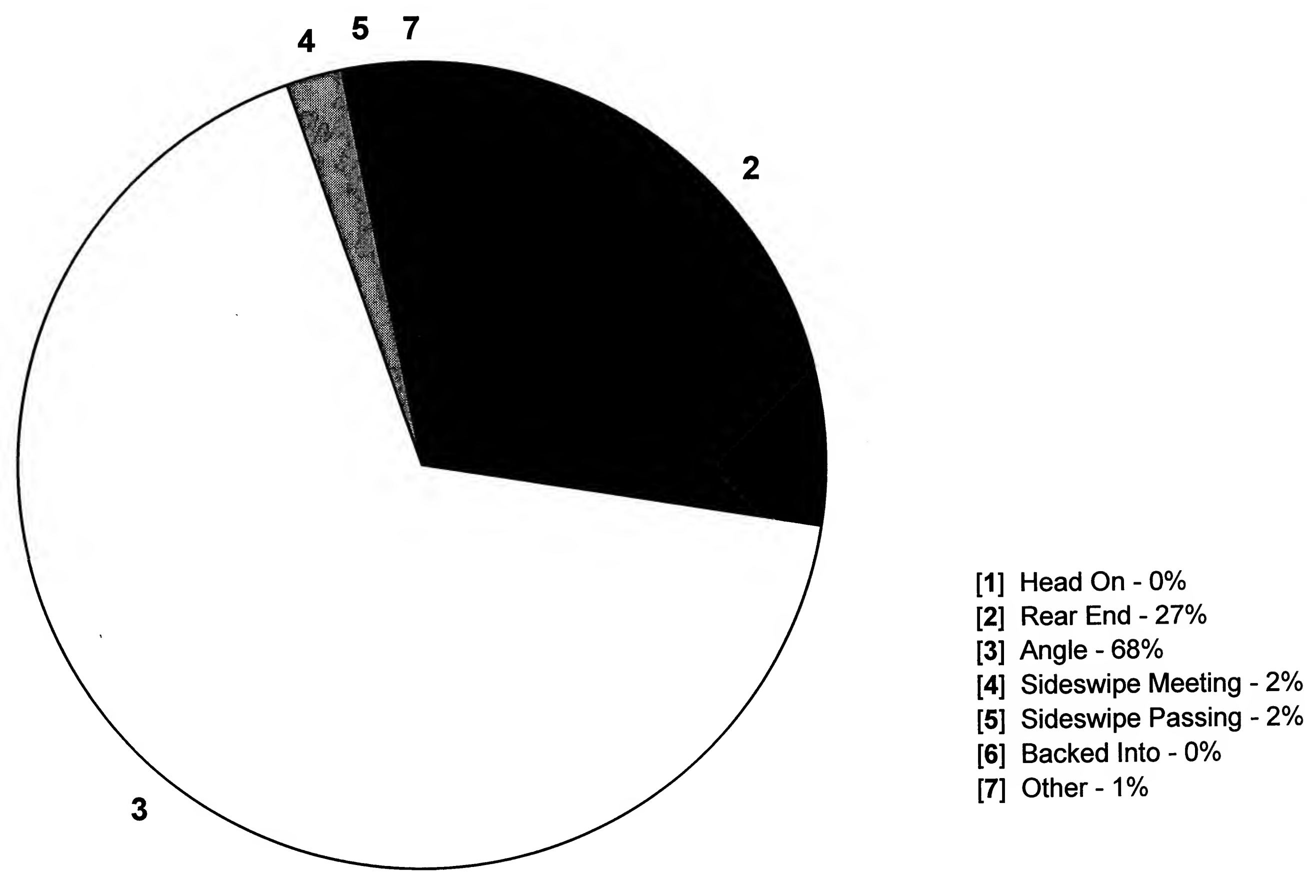
PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR BILLINGS - FAP 16



Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Billings ~ FAP 53									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
27th St. & 1st Ave. S.		2	6					8	1.46	1.10
27th St. & Montana Ave.		1	8	1				10	0.97	0.71
27th St. & 1st Ave. N.		3	11	1				15	2.32	1.70
27th St. & 2nd Ave. N.		2	2		1			5	0.77	0.31
27th St. & 3rd Ave. N.		2	5					7	1.08	0.77
27th St. & 4th Ave. N.		6	12		1			19	1.46	0.86
27th St. & 6th Ave. N.		4	10					14	1.00	0.72
27th St. & 9th Ave. N.		1	5					6	0.73	0.52
27th St. & Poly Dr.			2				1	3	0.39	0.26
Unidentifiable Intersections		5	3					8		
TOTAL	0	26	64	2	2	0	1	95		
PERCENT OF TOTAL	0	27	67	2	2	0	1	100		

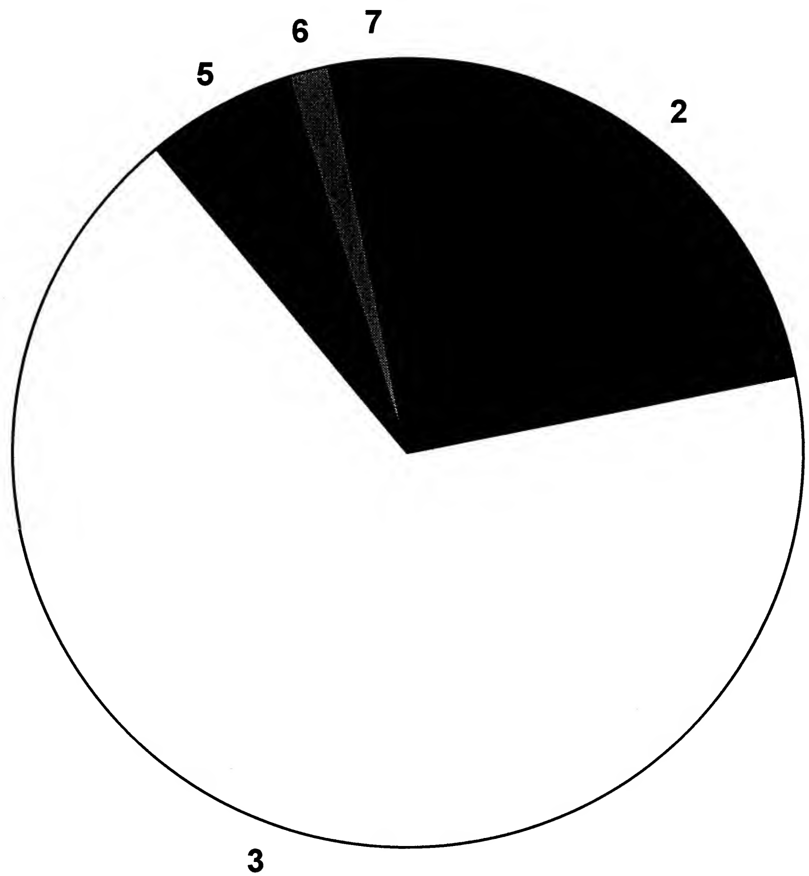
PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR BILLINGS - FAP 53



Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Great Falls ~ FAP 10									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
15th St. & 6th Ave. S.			3					3	1.08	1.08
15th St. & Central Ave.		2	4				1	7	1.93	1.10
15th St. & 1st Ave. N.			1					1	0.18	0.18
15th St. & 2nd Ave. N.			2		1			3	0.56	0.37
15th St. & 8th Ave. N.		1	2					3	0.68	0.45
14th St. & 8th Ave. N.		1	1					2	0.52	0.26
14th St. & 2nd Ave. N.		2	6					8	1.57	1.18
14th St. & 1st Ave N.		1	3					4	0.75	0.56
14th St. & Central Ave.		2	10				1	13	3.51	2.70
14th St. & 6th Ave. S.			4		1			5	1.75	1.40
15th St. & River Dr.		4	5			1		10	1.24	0.62
15th St. & River Rd.		1	2		2			5	1.05	0.42
TOTAL	0	14	43	0	4	1	2	64		
PERCENT OF TOTAL	0	22	67	0	6	2	3	100		

PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR GREAT FALLS - FAP 10

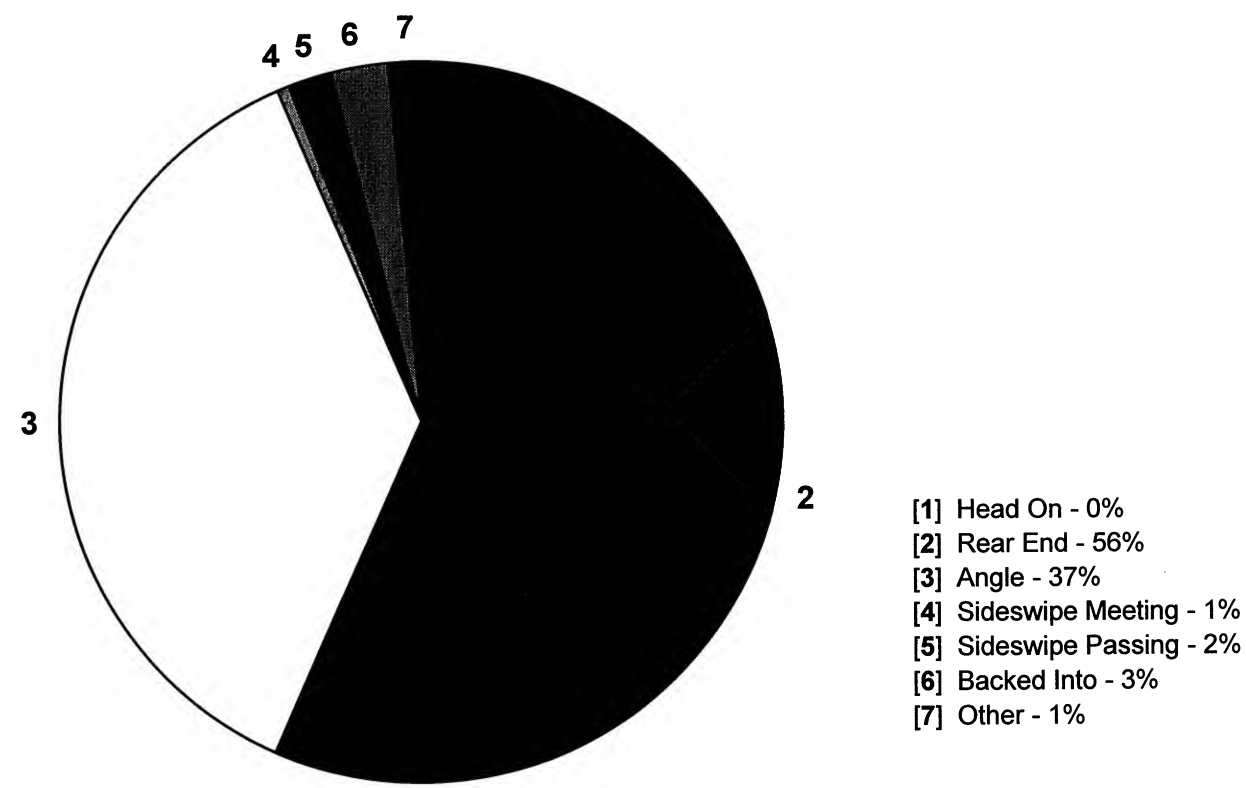


[1] Head On - 0%
[2] Rear End - 22%
[3] Angle - 67%
[4] Sideswipe Meeting - 0%
[5] Sideswipe Passing - 6%
[6] Backed Into - 2%
[7] Other - 3%

Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Great Falls ~ FAP 60									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
10th Ave. S. & 49th St.		4						4	0.49	0.00
10th Ave. S. & 43rd St.		1	1					2	0.24	0.12
10th Ave. S. & 38th St.		1	1				1	3	0.28	0.09
10th Ave. S. & 32nd St.		3	5		1	1		10	0.82	0.41
10th Ave. S. & 26th St.		11	5					16	1.04	0.32
10th Ave. S. & 25th St.		9	4		1			14	0.96	0.27
10th Ave. S. & 23rd St.		5	5			1		11	0.70	0.32
10th Ave. S. & 20th St.		4	6					10	0.67	0.40
10th Ave. S. & 15th St.		11	2			1		14	0.87	0.12
10th Ave. S. & 14th St.		2	3					5	0.31	0.19
10th Ave. S. & 13th St.		11	2					13	0.77	0.12
10th Ave. S. & 11th St.		7	4					11	0.86	0.31
10th Ave. S. & 9th St.		5	9	1	1			16	1.01	0.57
10th Ave. S. & 7th St.		3	2			1		6	0.49	0.16
10th Ave. S. & 5th St.		2	5				1	8	0.63	0.39
10th Ave. S. & River (FAU 5205)		3	2					5	0.38	0.15
10th Ave. S. & 6th St. SW.		7	2					9	0.90	0.20
TOTAL	0	89	58	1	3	4	2	157		
PERCENT OF TOTAL	0	57	37	1	2	3	1	100		

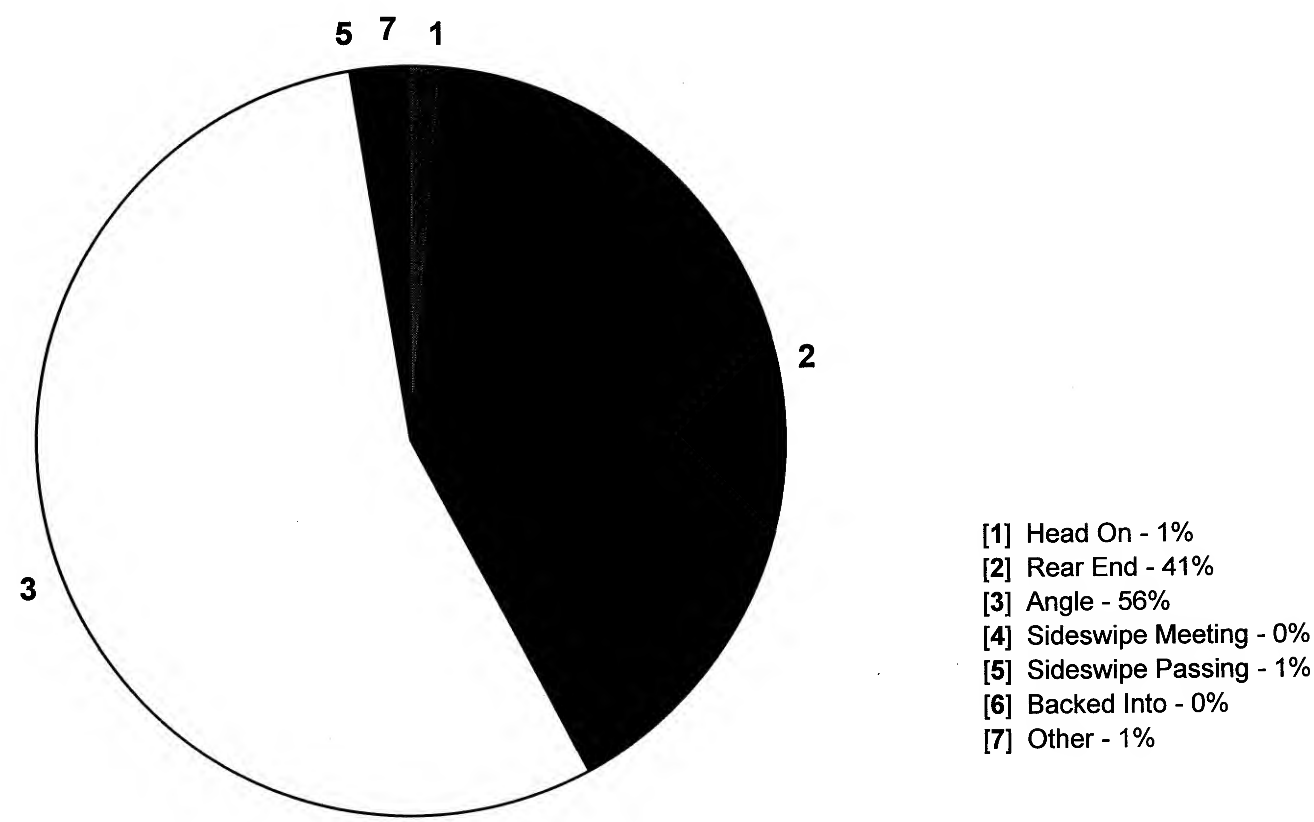
PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR GREAT FALLS - FAP 60



Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Missoula ~ FAP 7									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
Brooks St. & 39th St.			2		1			3	0.31	0.21
Brooks St. & Reserve St.		11	4					15	1.14	0.38
Brooks St. & Paxon St.			4					4	0.47	0.47
Brooks St. & Grant St.			2					2	0.24	0.24
Brooks St. & Fairview		1	2					3	0.30	0.20
Brooks St., South Ave. & Russell St.		7	6					13	0.69	0.32
Brooks St. & Stephens St.		1						1	0.07	0.00
Brooks St. & Mount Ave.	1	3	3					7	0.75	0.32
Brooks St. & Beckwith Ave.			2					2	0.31	0.31
Brooks St. & Higgins Ave.		2	3				1	6	0.66	0.33
Higgins Ave. & 6th St.		2	9					11	1.12	0.92
Higgins Ave. & 5th St.		4	5					9	0.92	0.51
TOTAL	1	31	42	0	1	0	1	76		
PERCENT OF TOTAL	1	41	55	0	1	0	1	100		

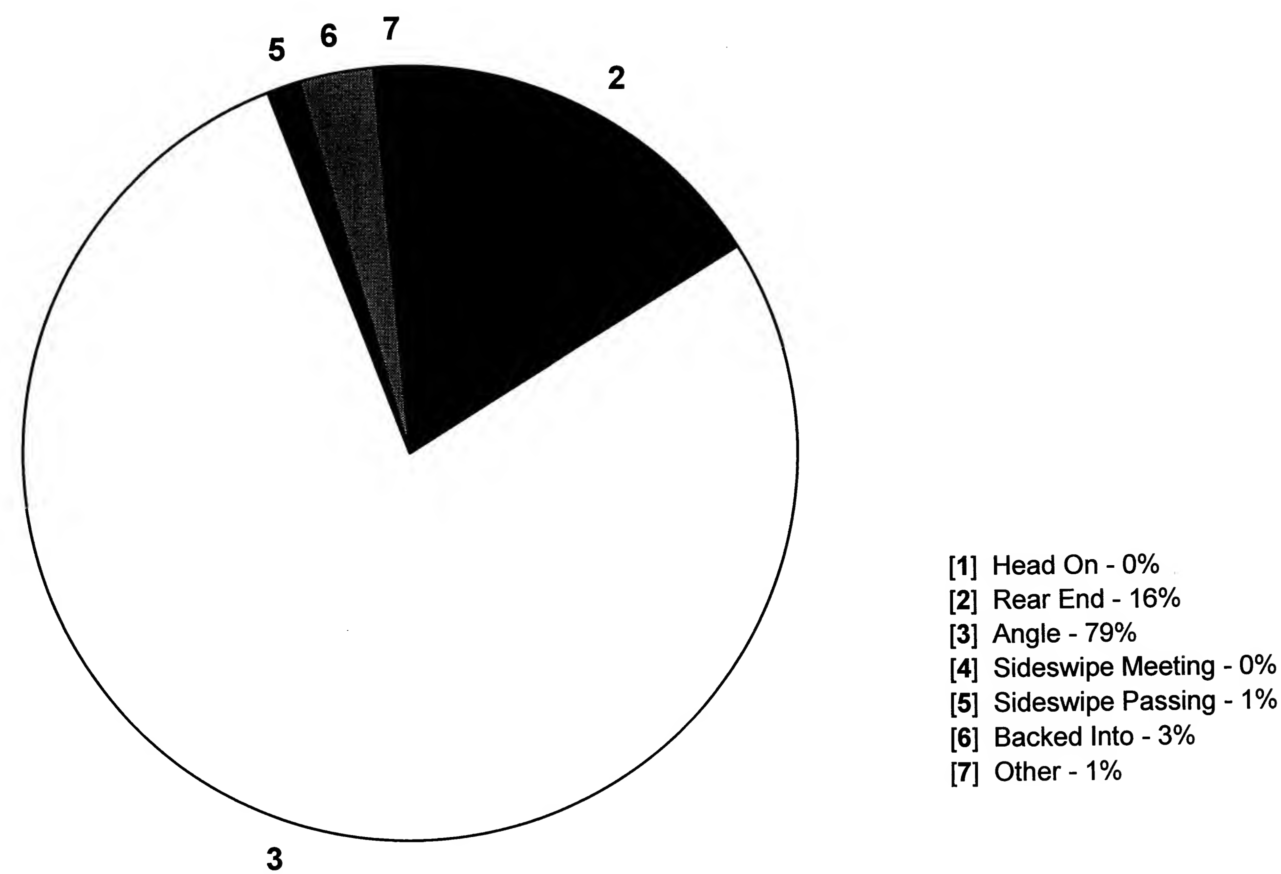
PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR MISSOULA - FAP 7



Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Missoula ~ FAP 71									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
Broadway & N. Russell		1	8					9	0.73	0.65
Broadway & Scott			1				1	2	0.25	0.13
Broadway & N. Orange		1	17		1			19	1.60	1.43
Broadway & Ryman			2					2	0.31	0.31
Broadway & Higgins		5	8			2		15	1.64	0.87
Broadway & Pattee		2	3					5	0.80	0.48
Broadway & Madison		2	7					9	1.06	0.83
Broadway & Van Buren			6					6	0.54	0.54
Unidentifiable Intersections			1					1		
TOTAL	0	11	53	0	1	2	1	68		
PERCENT OF TOTAL	0	16	78	0	1	3	1	100		

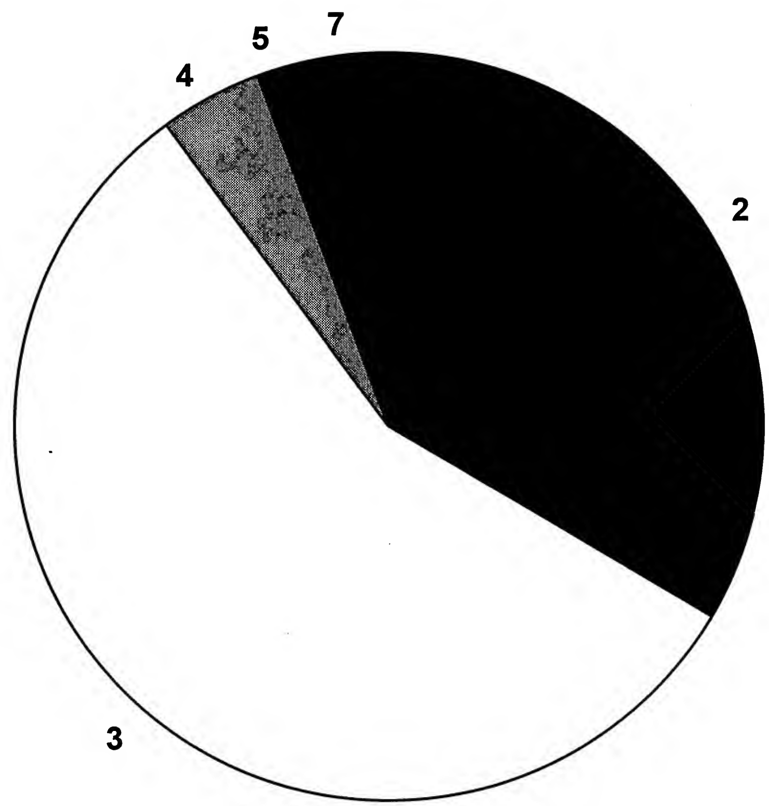
PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR MISSOULA - FAP 71



Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Butte ~ FAP 29									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
Harrison Ave. & Elizabeth Warren		1	3		1			5	0.61	0.36
Harrison Ave. & Holmes Ave.		1	1					2	0.22	0.11
Harrison Ave. & Roosevelt Ave.		1	5	1			1	8	1.16	0.72
Harrison Ave. & Dewey Blvd.		5	3				1	9	0.92	0.31
Harrison Ave. & Westbound										
Interchange Ramps		7	4					11	1.02	0.40
Harrison Ave. & Amherst St.		1						1	0.09	0.00
Harrison Ave & Cobban St.		5	2					7	1.23	0.35
Harrison Ave & Grand Ave.		2	2					4	0.54	0.27
Harrison Ave. & Civic Center Rd.		1	5					6	1.01	0.84
Utah St. & Front			2				2	4	0.55	0.27
Utah St. & Second St.			2	1				3	0.88	0.59
Utah St. & Platinum St.			2					2	0.39	0.39
Arizona St. & Mercury St.			3					3	0.80	0.80
Arizona St. & Park St.			2	2				4	1.05	0.53
Montana St. & Mercury St.		1	2					3	0.62	0.42
Montana St. & Platinum St.		2	6					8	1.11	0.83
Unidentifiable Intersections		3	6					9		
TOTAL	0	30	50	4	1	0	4	89		
PERCENT OF TOTAL	0	34	56	4	1	0	4	100		

PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR BUTTE - FAP 29



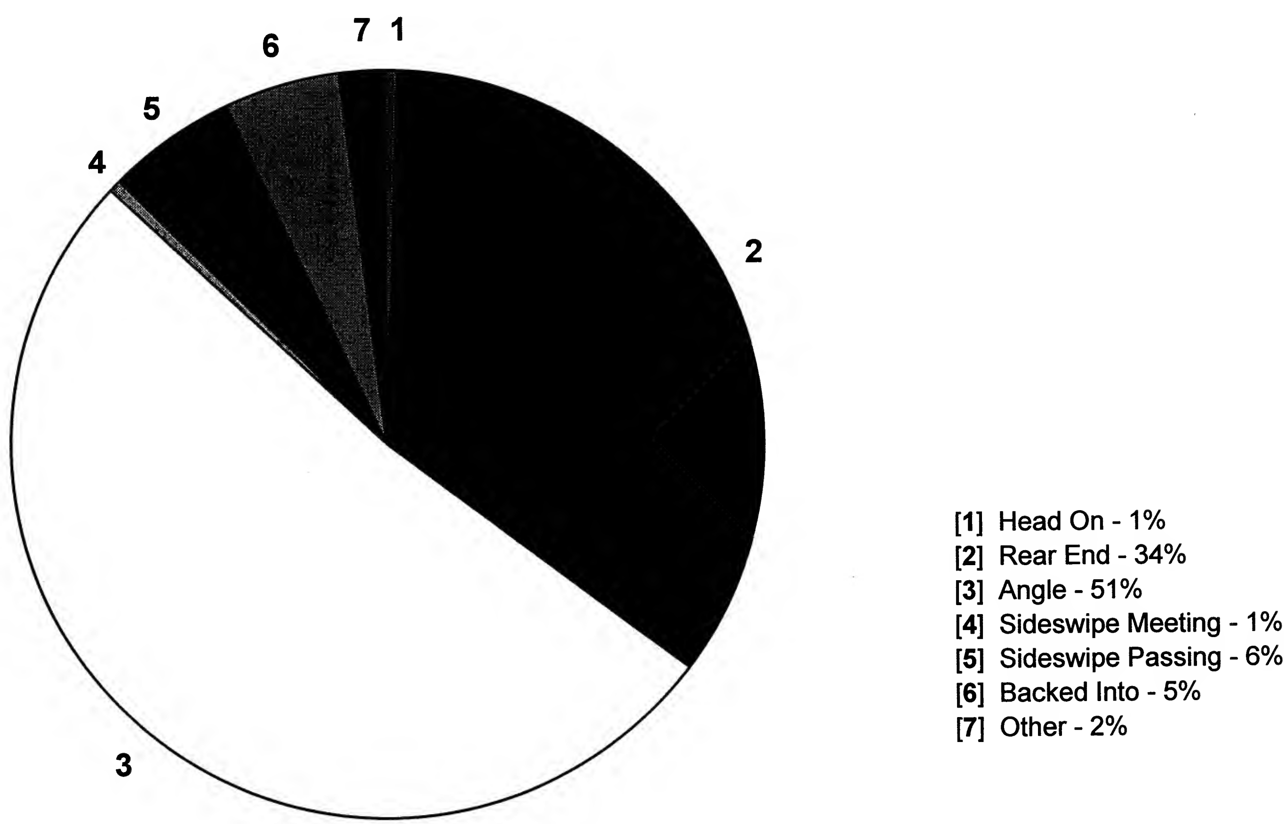
[1] Head On - 0%
[2] Rear End - 34%
[3] Angle - 57%
[4] Sideswipe Meeting - 4%
[5] Sideswipe Passing - 1%
[6] Backed Into - 0%
[7] Other - 4%

APPENDIX C

Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Helena ~ FAP 8									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
Euclid Ave. & Joslyn St.	1	1	2					4	0.69	0.35
Euclid Ave. & Henderson St.		1	2		1	2		6	0.79	0.26
Euclid Ave. & Benton Ave.		4	6		2	2	1	15	1.41	0.56
Lyndale Ave. & Last Chance Gulch		4	1					5	0.43	0.09
Lyndale Ave., Helena Ave. & Montana Ave.		6	18	1	2			27		
Montana Ave. & Billings Ave.		1	1			1		3	0.38	0.13
Montana Ave. & Butte Ave.		1						1	0.13	0.00
Montana Ave. & Prospect Ave.		6	8					14	1.31	0.75
Montana Ave. & 11th Ave.		1	1		2			4	0.39	0.10
11th Ave. & Roberts St.			1					1	0.14	0.14
11th Ave. & Sanders St.		1	2					3	0.65	0.43
11th Ave. & Oakes St.					1			1	0.22	0.00
11th Ave. & Lamborn St.		2	3			1		6	0.88	0.44
11th Ave. & Fee St.		2	8					10	1.14	0.91
West Interchange I-15		3						3		
Prospect Ave. & Washington		1	2					3	0.59	0.39
Prospect Ave. & Fee St.		2	8			1		11	1.19	0.86
Prospect Ave. & Lamborn St.			4				1	5	0.86	0.69
FAP 8 & East Interchange I-15		1						1		
FAP 8 & 18th St.		2	2					4		
Unidentifiable Intersections		11	6				1	18		
TOTAL	1	50	75	1	8	7	3	145		
PERCENT OF TOTAL	1	34	52	1	6	5	2	100		

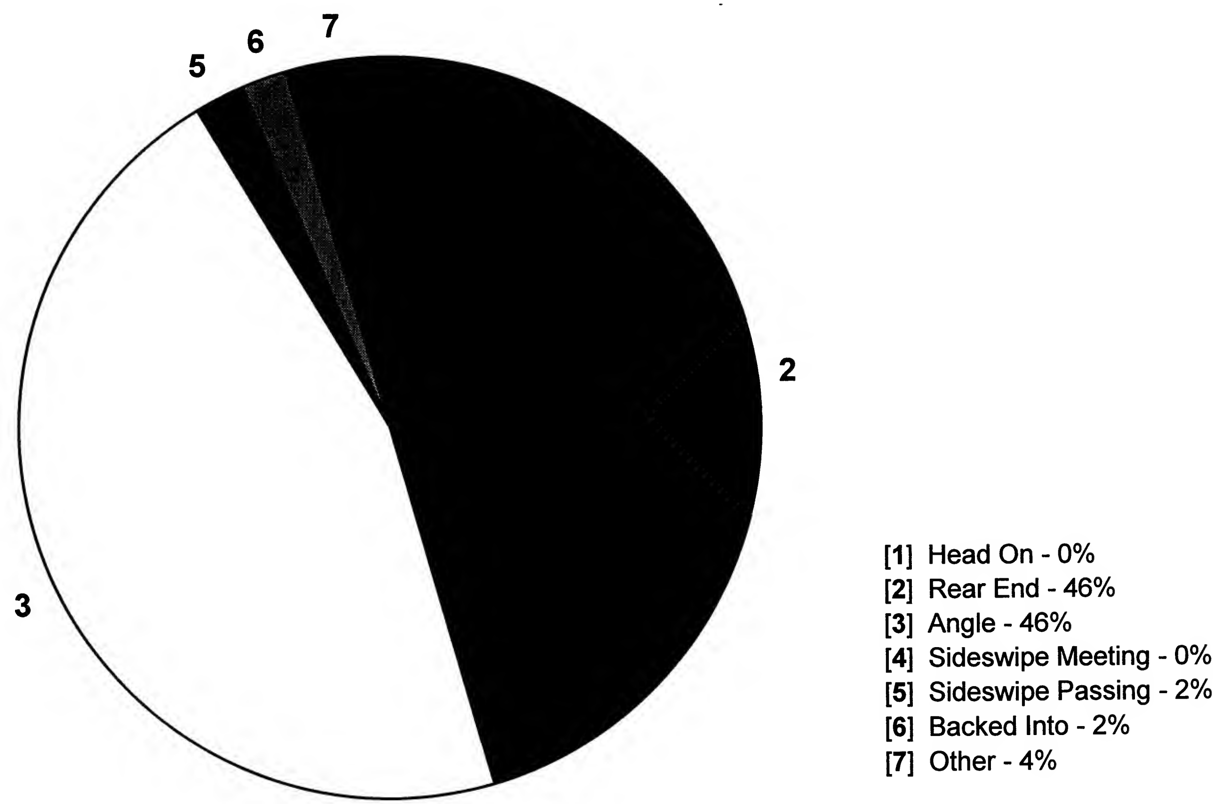
PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR HELENA - FAP 8



Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Bozeman ~ FAP 50									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
Main St. & College St.		3	1		1		1	6	0.79	0.13
Main St. & 19th Ave.		9	9				1	19	1.58	0.75
Main St. & 15th Ave.		6	1					7	0.86	0.12
Main St. & 11th Ave.		6	5		1			12	1.06	0.44
Main St. & 8th Ave.		4	2					6	0.54	0.18
Main St. & 7th Ave.		3	4					7	0.51	0.29
Main St. & 5th Ave.		1	3					4	0.65	0.49
Main St. & Grand Ave.		1	2			1		4	0.65	0.33
Main St. & Willson Ave.		2	3				2	7	0.94	0.40
Main St. & Tracy Ave.			3			1		4	0.76	0.57
Main St. & Black Ave.		4	1					5	0.95	0.19
Main St. & Bozeman Ave.		2	4					6	1.27	0.86
Main St. & Rouse Ave.		1	4					5	0.69	0.55
TOTAL	0	42	42	0	2	2	4	92		
PERCENT OF TOTAL	0	46	46	0	2	2	4	100		

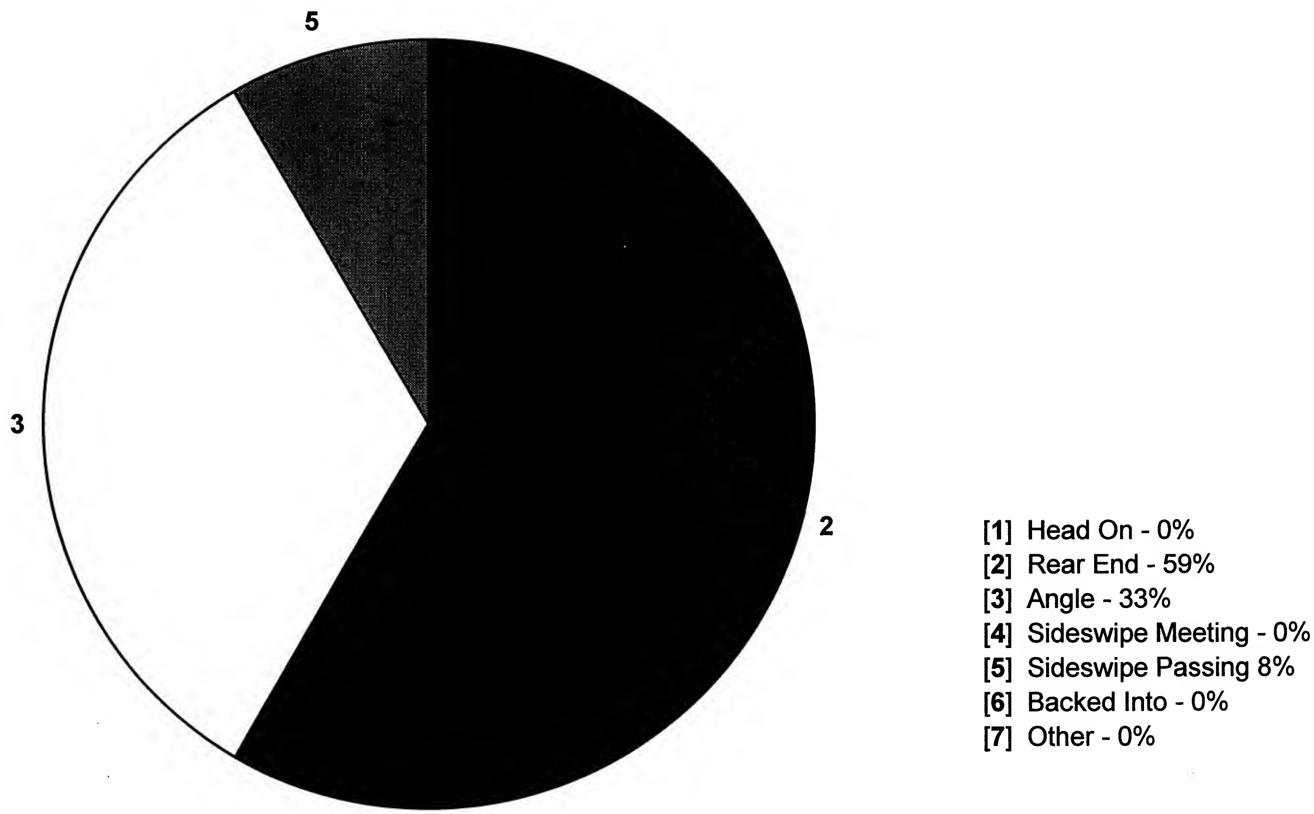
PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR BOZEMAN - FAP 50



Study of Accidents at Signalized Intersections
State Route Accident Locations and Numbers
1994 Data

	Number of accidents ~ Bozeman ~ FAP 86									
	Accident Type									
Intersection	Head On	Rear End	Angle	Meeting Sideswipe	Passing Sideswipe	Into Backed	Other	Total	Accident Rate ACC/MEV	Angle Accident Rate ACC/MEV
Rouse Ave. & Mendenhall St.		2	2					4	0.74	0.37
Rouse Ave. & Tamarack St.		4	2		1			7	1.58	0.45
Rouse Ave. & Birch St.		1						1	0.34	0.00
TOTAL	0	7	4	0	1	0	0	12		
PERCENT OF TOTAL	0	58	33	0	8	0	0	100		

PERCENT OF TOTAL ACCIDENTS AT SIGNALIZED INTERSECTIONS FOR BOZEMAN - FAP 86



APPENDIX D - ELDERLY DRIVER SUMMARIES

Study of Accidents at Signalized Intersections
Elderly Driver Information
1994 Data

CITY OF BILLINGS

Calculating the number of accidents with a driver age 65 or older per mile for P53 (27th St.) from milepost 0+0.000 to 5+0.629 for 1994 data.

Total Miles = 5.629

Total Number of Accidents = 82

Total Number of Accidents With a Driver Age 65 or Older = 16

Accidents With a Driver Age 65 or Older Per Mile = <u>2.84 Accidents per Mile</u>

Percentage of Accidents With a Driver Age 65 or Older = <u>19.51%</u>

Calculating the number of accidents with a driver age 65 or older per mile for P16 (Main St.) from milepost 0+0.000 to 4+0.722 for 1994 data.

Total Miles = 4.722

Total Number of Accidents = 125

Total Number of Accidents With a Driver Age 65 or Older = 16

Accidents With a Driver Age 65 or Older Per Mile = <u>3.39 Accidents per Mile</u>

Percentage of Accidents With a Driver Age 65 or Older = <u>12.80%</u>

APPENDIX D

Study of Accidents at Signalized Intersections
Elderly Driver Information
1994 Data

CITY OF GREAT FALLS

Calculating the number of accidents with a driver age 65 or older per mile for P60 (10th Ave S.) from milepost 90+0.366 to 95+0.717 for 1994 data.

Total Miles = 5.351

Total Number of Accidents = 153

Total Number of Accidents With a Driver Age 65 or Older = 33

Accidents With a Driver Age 65 or Older Per Mile = 6.17 Accidents per Mile

Percentage of Accidents With a Driver Age 65 or Older = 21.57%

Calculating the number of accidents with a driver age 65 or older per mile for P10 (14th St., 15th St.) fro milepost 0+0.000 to 4+0.800 for 1994 data.

Total Miles = 4.800

Total Number of Accidents = 63

Total Number of Accidents With a Driver Age 65 or Older = 16

Accidents With a Driver Age 65 or Older Per Mile = 3.33 Accidents per Mile

Percentage of Accidents With a Driver Age 65 or Older = 25.39%

APPENDIX D

Study of Accidents at Signalized Intersections
Elderly Driver Information
1994 Data

CITY OF MISSOULA

Calculating the number of accidents with a driver age 65 or older per mile for P7 (Brooks) from milepost 90+0.152 to 95+0.276 for 1994 data.

Total Miles = 5.124

Total Number of Accidents = 63

Total Number of Accidents With a Driver Age 65 or Older = 8

Accidents With a Driver Age 65 or Over Per Mile = 1.56 Accidents per Mile

Percentage of Accidents With a Driver Age 65 or Older = 12.70%

Calculating the number of accidents with a driver age 65 or older per mile for P71 (Broadway) from milepost 0+0.000 to 5+0.167 for 1994 Data.

Total Miles = 5.167

Total Number of Accidents = 68

Total Number of Accidents With a Driver Age 65 or Older = 10

Accidents With a Driver Age 65 or Older Per Mile = 1.94 Accidents per Mile

Percentage of Accidents With a Driver Age 65 or Older = 14.71%

APPENDIX D

Study of Accidents at Signalized Intersections
Elderly Driver Information
1994 Data

CITY OF BUTTE

Calculating the number of accidents with a driver age 65 or over per mile for P29 (Harrison Ave, Utah St., Arizona St., Park St., Montana St.) from milepost 83+0.790 to 90+0.610 for 1994 data.

Total Miles = 6.820

Total Number of Accidents = 86

Total Number of Accidents With a Driver Age 65 or Older = 18

Accidents With a Driver Age 65 or Older Per Mile = 2.64 Accidents per Mile

Percentage of Accidents With a Driver Age 65 or Older = 20.93%

APPENDIX D

Study of Accidents at Signalized Intersections
Elderly Driver Information
1994 Data

CITY OF HELENA

Calculating the number of accidents with a driver age 65 or older per mile for P8 (Euclid Ave, Lindale Ave, Montana Ave, Prospect Ave, 11th Ave) from milepost 39+0.831 to 47+0.480 for 1994 data.

Total Miles = 6.039

Total Number of Accidents = 133

Total Number of Accidents With a Driver Age 65 or Over = 30

Accidents With a Driver Age 65 or Over Per Mile = 4.97 Accidents per Mile

Percentage of Accidents With a Driver Age 65 or Older = 22.56%

APPENDIX D

Study of Accidents at Signalized Intersections
Elderly Driver Information
1994 Data

CITY OF BOZEMAN

Calculating the number of accidents with a driver age 65 or older per mile for P50 (Main) from milepost 86+0.327 to 90+0.824 for 1994 data.

Total Miles = 4.497

Total Number of Accidents = 89

Total Number of Accidents With a Driver Age 65 or Older = 14

Accidents With Driver Age 65 or Over Per Mile = 3.11 Accidents per Mile

Percentage of Accidents With a Driver Age 65 or older = 15.73%

Calculating the number of accidents with a driver age 65 or older per mile for P86 (Rouse) from milepost 0+0.000 to 3+0.003 for 1994 data.

Total Miles = 3.003

Total Number of Accidents = 12

Total Number of Accidents With a Driver Age 65 or Older = 1

Accidents With a Driver Age 65 or Older Per Mile = 0.33 Accidents per Mile

Percentage of Accidents With a Driver Age 65 or Older = 8.33%

APPENDIX D

Study of Accidents at Signalized Intersections
Accidents With a Driver Age 65 or Older
Accident Types by City on State Routes Only
1994 Data

	Percent of Total Accidents With a Driver Age 65 or Older					
ACCIDENT TYPE	BILLINGS	GREAT FALLS	MISSOULA	BUTTE	HELENA	BOZEMAN
Head On	0	0	0	0	0.6	0
Rear End	6.2	10.5	3.1	2.5	3.1	4.9
Angle	12.3	18.5	8.0	7.4	12.3	4.3
Sideswipe Meeting	0	0	0	1.2	0	0
Sideswipe Passing	1.2	0.6	0	0	2.5	0
Backed Into	0	0.6	0	0	0	0
Other	0	0	0	0	0	0

Totals Accidents = 162

APPENDIX D

Study of Accidents at Signalized Intersections
Accidents With a Driver Age 65 or Older
Types of Angle Accidents by City on State Routes Only
1994 Data

	Percent of Total Angle Accidents With a Driver Age 65 or Older					
ANGLE ACC. TYPES	BILLINGS	GREAT FALLS	MISSOULA	BUTTE	HELENA	BOZEMAN
Right-Angle	7.8	9.8	2.9	4.9	7.8	0
Right-Turn	1.0	1.0	2.9	0	1.0	0
Left-Turn	8.8	8.8	4.9	4.9	9.8	0
Other	2.0	9.8	2.0	2.0	1.0	6.9

Total Accidents = 102

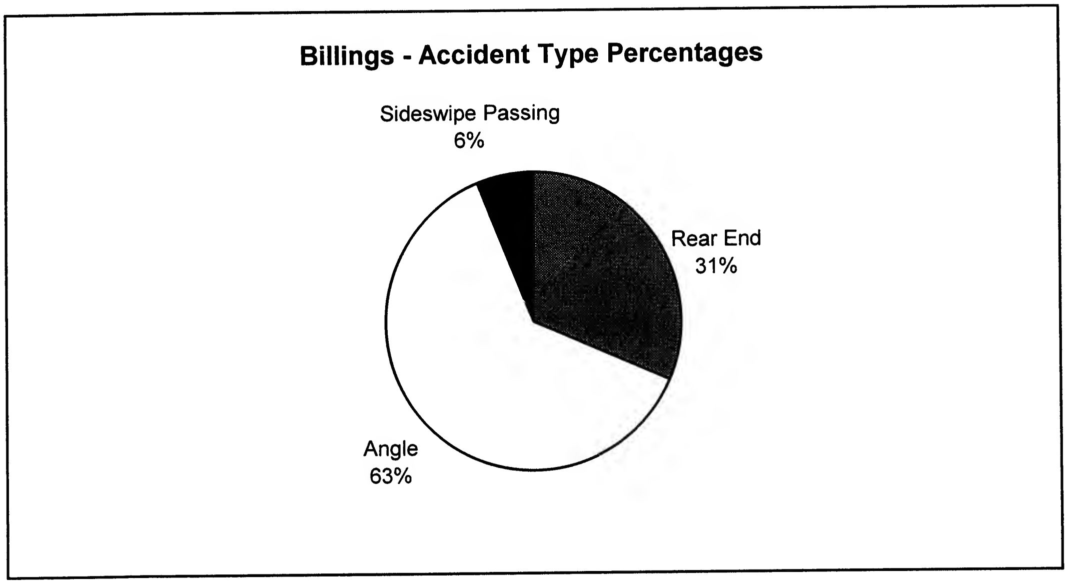
APPENDIX D

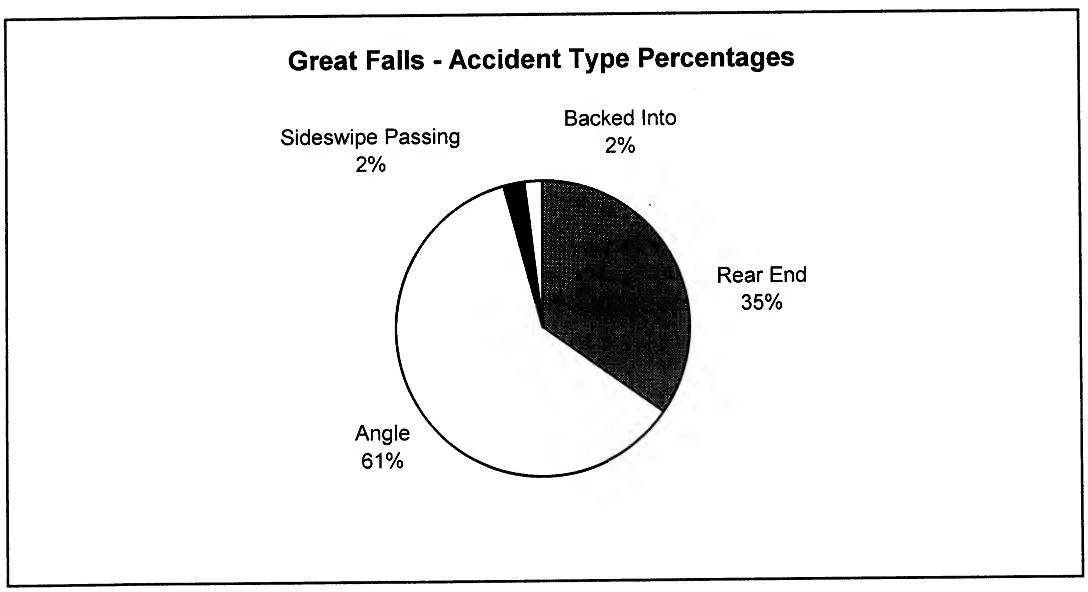
Study of Accidents at Signalized Intersections
Accidents With a Driver Age 65 or Older
Accident Types by City on State Routes Only
1994 Data

	Percent of Total Accidents Per City With a Driver Age 65 or Older					
ACCIDENT TYPE	BILLINGS	GREAT FALLS	MISSOULA	HELENA	BUTTE	BOZEMAN
Head On	0	0	0	3.3	0	0
Rear End	31.3	34.7	27.8	16.7	22.2	53.3
Angle	62.5	61.2	72.2	66.7	66.7	46.7
Sideswipe Meeting	0	0	0	0	11.1	0
Sideswipe Passing	6.3	2.0	0	13.3	0	0
Backed Into	0	2.0	0	0	0	0
Other	0	0	0	0	0	0
Total Accidents Per City	32	49	18	30	18	15

APPENDIX D

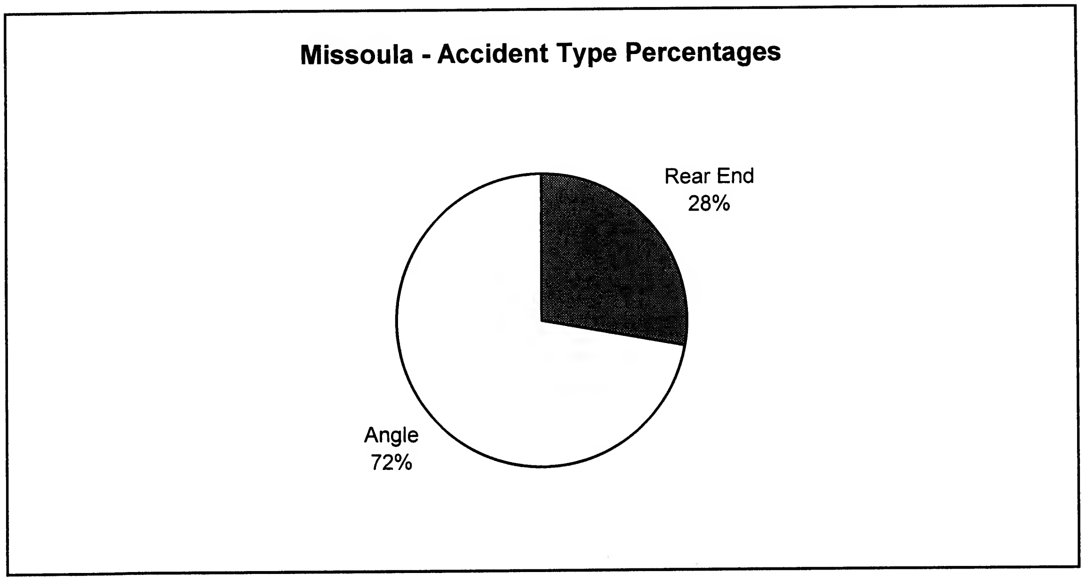
Study of Accidents at Signalized Intersections
Accidents With a Driver Age 65 or Older
1994 Data

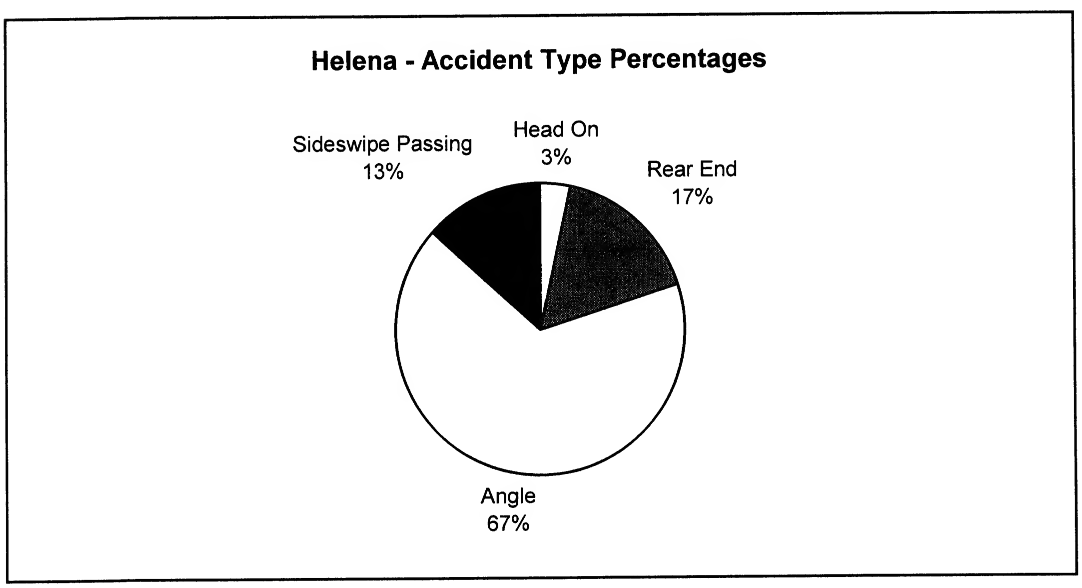




APPENDIX D

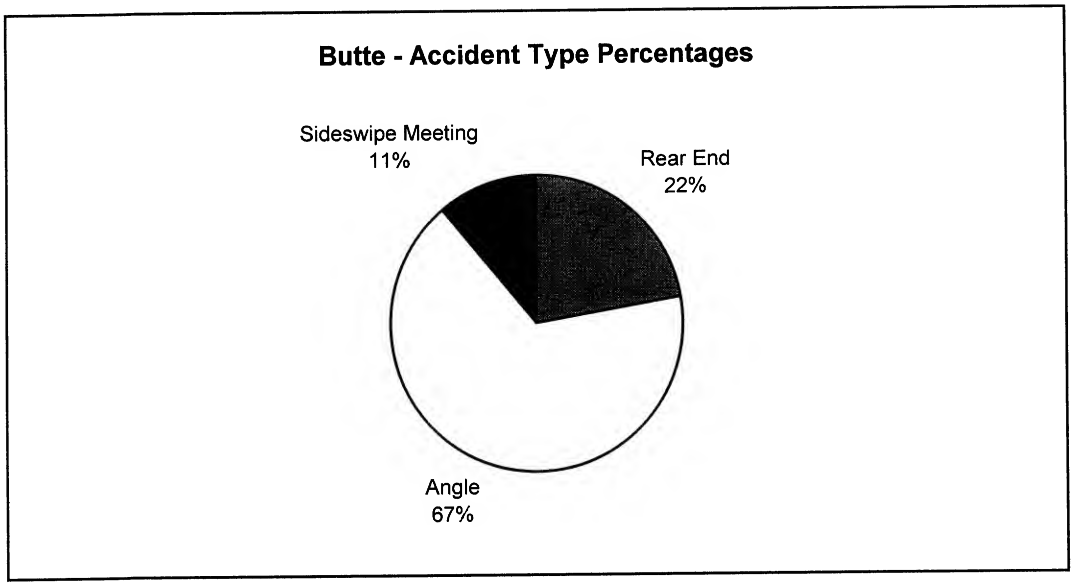
Study of Accidents at Signalized Intersections
Accidents With a Driver Age 65 or Older
1994 Data

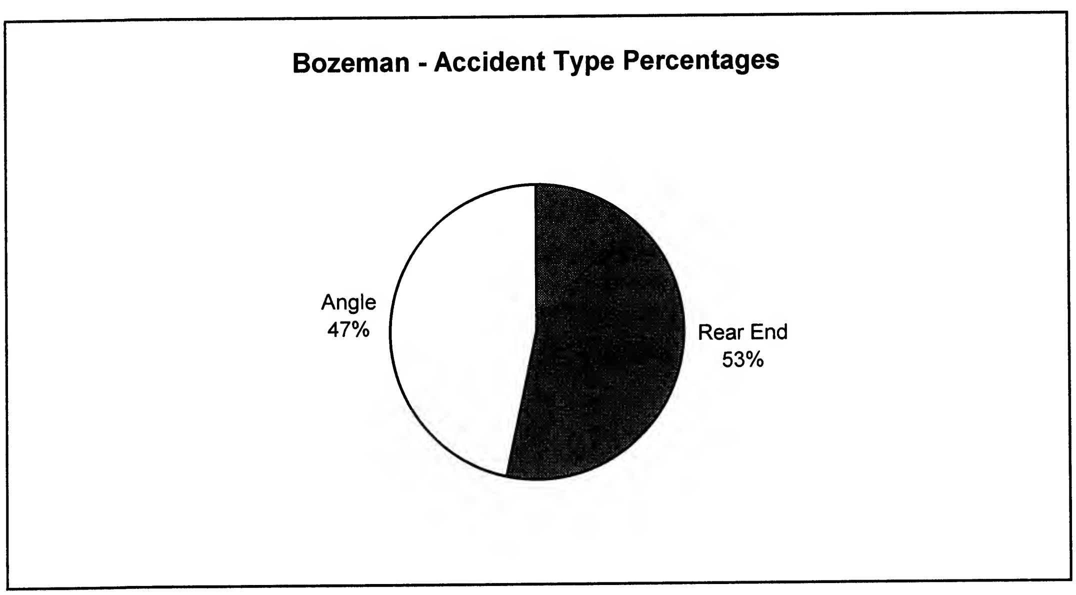




APPENDIX D

Study of Accidents at Signalized Intersection
Accidents With a Driver Age 65 or Older
1994 Data



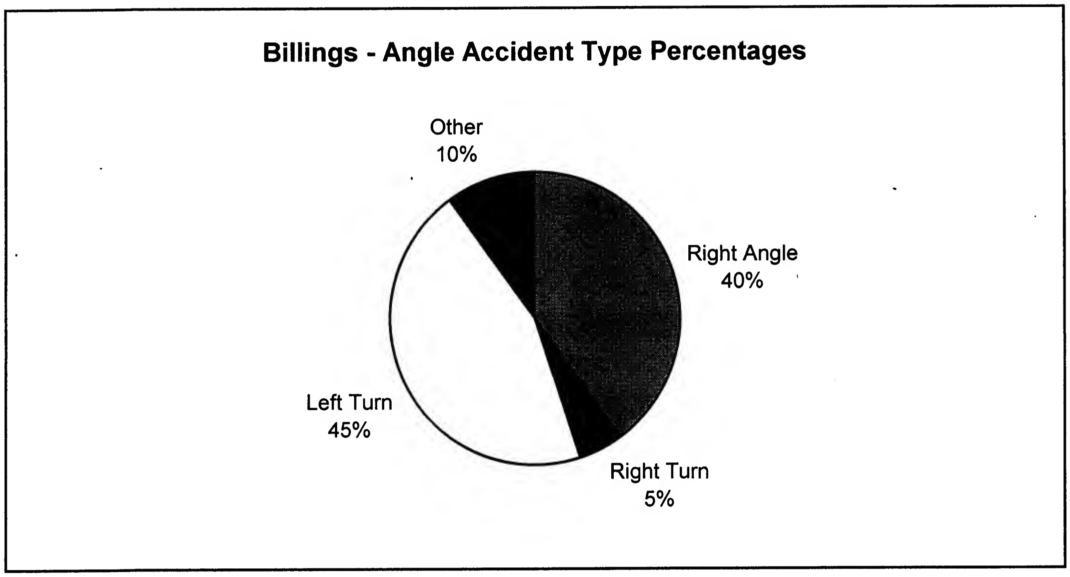


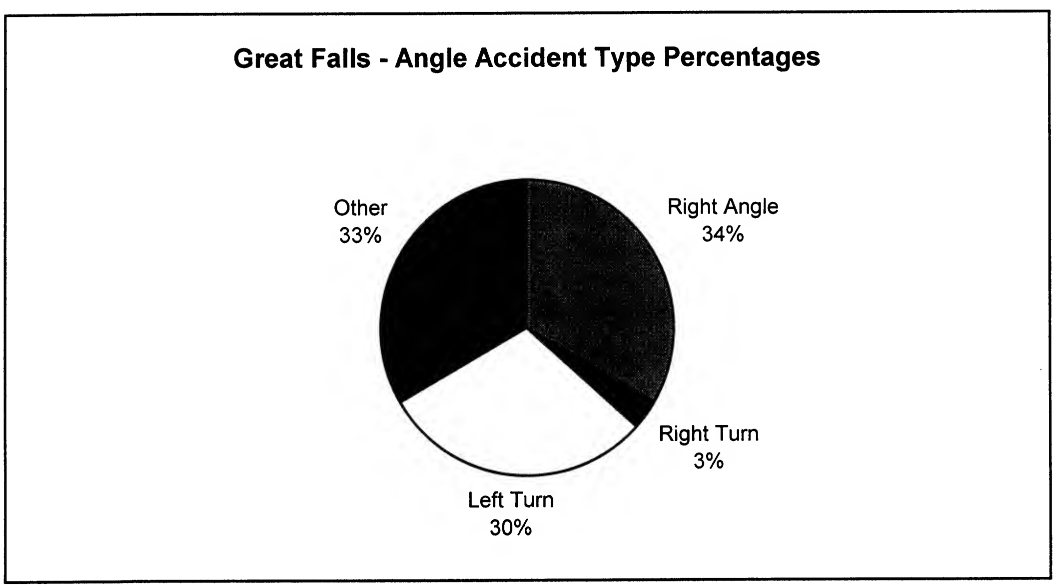
APPENDIX D

Study of Accidents at Signalized Intersections
Accidents With a Driver Age 65 or Older
Angle Accident Types by City on State Routes Only
1994 Data

	Percent of Total Angle Accidents Per City With a Driver Age 65 or Older					
ANGLE ACC. TYPE	BILLINGS	GREAT FALLS	MISSOULA	HELENA	BUTTE	BOZEMAN
Right Angle	40.0	33.3	23.1	40.0	41.7	0
Right Turn	5.0	3.3	23.1	5.0	0	0
Left Turn	45.0	30.0	38.5	50.0	41.7	0
Other	10.0	33.3	15.4	5.0	16.7	100
Total Angle Accidents Per City	20	30	13	20	12	7

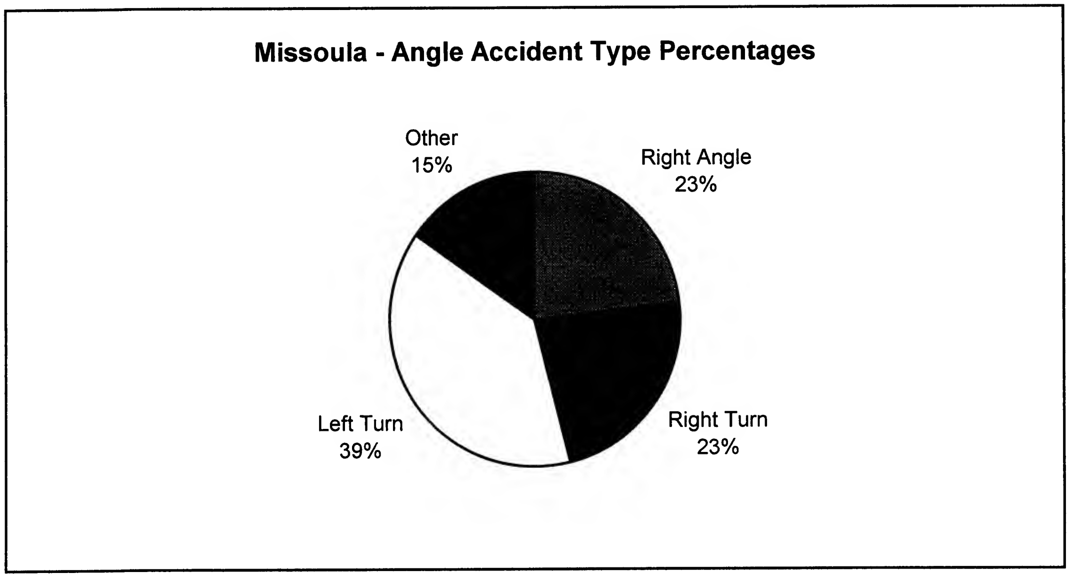
Study of Accidents at Signalized Intersections
Angle Accidents With a Driver Age 65 or Older
1994 Data

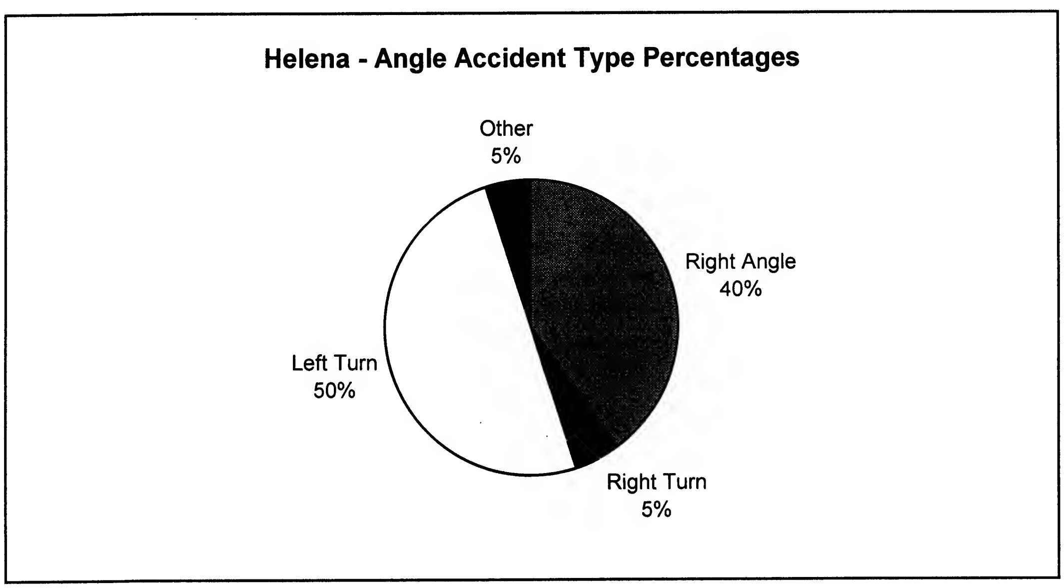




APPENDIX D

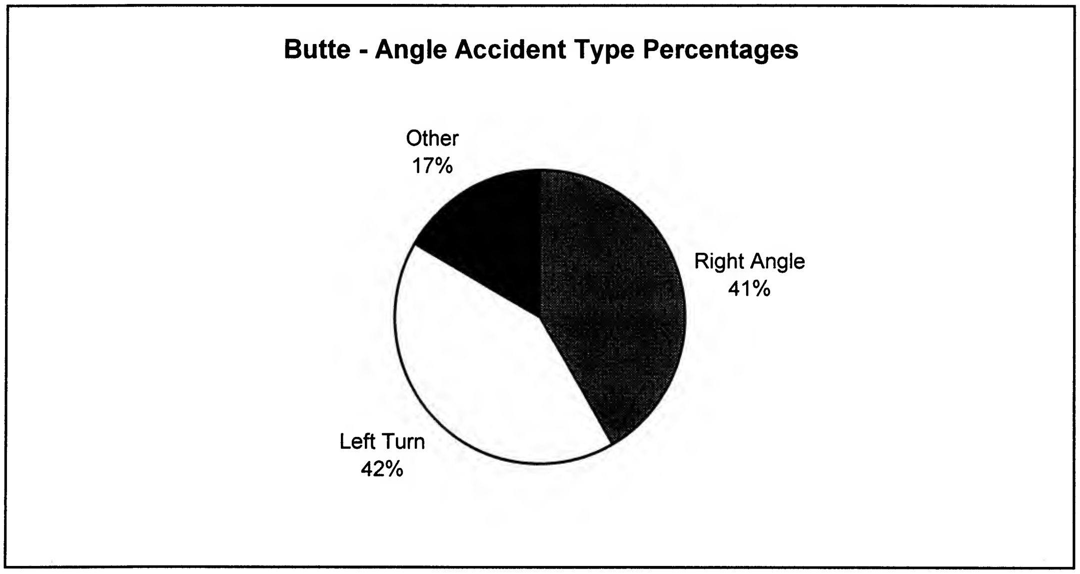
Study of Accidents at Signalized Intersections
Angle Accidents With a Driver Age 65 or Older
1994 Data

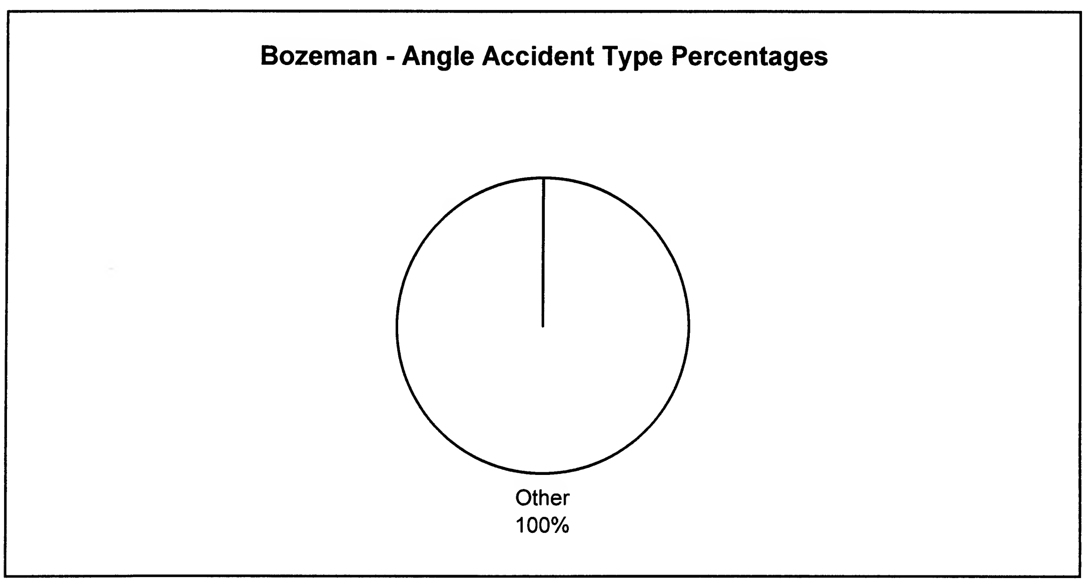




APPENDIX D

Study of Accidents at Signalized Intersections
Accidents With a Driver Age 65 or Older
1994 Data





APPENDIX E - COLLISION DIAGRAM SUMMARIES

STUDY OF ACCIDENTS AT SIGNALIZED INTERSECTIONS

Billings

North 27th Street and 1st Avenue North

- No protective/permissive left turns
- Yellow clearance interval 3.0 seconds
- All-Red 1.5 seconds
- No flashing operation
- 1st Avenue is a one-way Westbound
- Right Angle accidents (34.5 % of total) :
    - 5 Northbound vehicles ran red light
    - 2 Southbound vehicles failed to stop
- 12 of 29 (41.4 %) of accidents occurred in darkness
- 21 of 29 (72.4%) of accidents occurred when the weather was clear
- 23 of 29 (79.3%) of accidents occurred when the roads were dry

Main Street and Highway 318

- Main Left protective, Yellow clearance 3.0 sec, All-Red 1.5 sec
- Main permissive, Yellow clearance 3.6 sec, All-Red 1.3 sec
- Metra (Westbound) Single Phase Protected, Yellow clearance 3.0 sec, All-red 1.5 sec
- Highway 318 (Eastbound) Single Phase protected, Yellow clearance 3.0 sec, All-red 1.5 sec
- No flashing operation
- 20 Rear End accidents (58.8% of total)
- Left Turn Accidents (17.6% of total):
    - 2 Southbound vehicles turned in front of Northbound vehicles
    - 1 Southbound vehicle lost control and hit Eastbound vehicle
    - 3 Northbound vehicles turned in front of Southbound vehicles
- 27 of 34 (79.4%) of accidents occurred when the weather was clear
- 29 of 34 (85.3%) of accidents occurred when the roads were dry

Great Falls

14th Street and Central Avenue

- No protected/ permissive left turns
- 14th Street, Yellow clearance 3.3 sec, All-Red 1.0 sec
- Central Avenue, Yellow clearance 3.0 sec, All-Red 1.0 sec
- No flashing operation
- 14th Street is a one-way Southbound
- Right Angle accidents (72.2 % of total) :
  - 2 Southbound violators
  - 8 Eastbound violations
  - 3 Westbound violations
- Left Turn accidents (16.7% of total):
  - 3 Southbound vehicles made left turns from improper lane causing accidents
- 11 of 18 (61.1%) of accidents occurred when the weather was clear
- 11 of 18 (61.1%) of accidents occurred when the roads were dry

10th Avenue South and 32nd Street

- 10th Avenue South Protected left, Yellow clearance 3.5 sec, All-red 1.0 sec
- 10th Avenue South Permissive left, Yellow clearance 4.0 sec, All-red 1.0 sec
- 32nd Street no protected/permissive left turns, Yellow clearance 4.0, All-red 1.0 sec
- Flashing operation begins at 12:05 a.m. and ends at 6:30 a.m. on weekdays and begins at 3:30 a.m. and ends at 7:00 a.m. on weekends
  - 10th Avenue South flashes yellow
  - 32nd Street flashes red
  - 1 Right Angle accident during flashing operation
- 7 Rear End accidents (36.8% of total)
- Left Turn accidents (42.1% of total):
  - 5 Eastbound vehicles turned in front of Westbound vehicles
  - 2 Westbound vehicles hit Eastbound vehicles turning left
  - 1 Eastbound vehicle failed to stop for red, hitting Northbound vehicle turning left
- 13 of 19 (68.4%) of accidents occurred when the weather was clear
- 13 of 19 (68.4%) of accidents occurred when the roads were dry

10th Avenue South and 26th Street

- 10th Avenue South Protected, Yellow clearance 3.1 sec, All-red 1.0 sec
- 10th Avenue South Permissive, Yellow clearance 4.0 sec, All-red 1.0 sec
- 26th Street no protected/ permissive left turns, Yellow clearance 4.0 sec, All-red 1.0 sec
- Flashing operation begins at 12:05 a.m. on weekdays, 03:30 a.m. on weekends, end flash 06:30 a.m.
    - 10th Avenue South flashes yellow
    - 26th Street flashes red
    - 1 possible accident during flashing operation
- 26th Street is a one-way Northbound
- 16 Rear End accidents (48.5% of total)
- Left turn accidents (30.3% of total):
    - 1 Eastbound vehicle made left turns in front of Westbound vehicle
    - 7 Westbound vehicles made left turns in front of Eastbound vehicles
    - 1 Westbound vehicle ran red light and hit Eastbound vehicle turning left
    - 1 Eastbound vehicle unable to make left turn due to excessive speed (DUI)
- 29 of 33 (87.9%) of accidents occurred when the weather was clear
- 26 of 33 (78.8%) of accidents occurred when the roads were dry

10th Avenue South and 25th Street

- No protected/ permissive left turns, Yellow clearance 4.0 sec, All-red 1.0 sec
- Flashing operation begins at 12:05 a.m. on weekdays, 03:30 a.m. on weekends, end flash 06:30 a.m.
    - 10th Avenue South flashes yellow
    - 25th Street flashes red
    - No accidents during flashing operation
- 25th Street is a one-way Southbound
- 15 Rear End accidents (53.6% of total)
- 19 of 28 (67.9%) of accidents occurred when the weather was clear
- 19 of 28 (67.9%) of accidents occurred when the roads were dry

10th Avenue South and 20th Street

- 10th Avenue South Permissive, Yellow clearance 4.0 sec, All-red 1.0 sec
- 20th Street Permissive, Yellow clearance 4.0 sec, All-red 1.0 sec
- Flashing operation begins at 12:05 a.m. and ends at 6:30am on weekdays and begins at 3:30 a.m. and ends at 7:00 a.m. on weekends
    - 10th Avenue South flashes yellow
    - 20th Street flashes red
    - 1 possible accident during flashing operation
- 8 Rear End accidents (38.1% of total):
    - 2 icy conditions
- Right Angle accidents (38.1% of total):
    - 5 Eastbound violators
    - 2 Westbound violators
    - 1 Northbound violator
- Left Turn accidents (23.8% of total):
    - 2 Eastbound vehicles turned in front of Westbound vehicles
    - 2 Westbound vehicles turned in front of Eastbound vehicles
    - 1 Northbound vehicle turned in front of Southbound vehicle
- 14 of 21 (66.7%) of accidents occurred when the weather was clear
- 15 of 21 (71.4%) of accidents occurred when the roads were dry

10^{th} Avenue South and 9^{th} Street

- 10^{th} Avenue no protected/permissive left turns, Yellow clearance 4.0 sec, All-red 1.0 sec
- 9^{th} Street Left Protected, Yellow clearance 4.0 sec, All-red 1.0 sec
- 9^{th} Street permissive, Yellow clearance 4.0 sec, All-red 1.0 sec
- Flashing operation begins at 12:05 a.m. on weekdays, 03:30 a.m. on weekends, end flash 06:30 a.m.
    - 10^{th} Avenue flashes yellow
    - 9^{th} Street flashes red
    - No accidents during flashing operation
- 9 Rear End accidents (34.6% of total)
- Left turn accidents (26.9% of total):
    - 3 Southbound vehicles made left turns in front of Northbound vehicles
    - 1 Eastbound vehicle lost control after turning left striking Southbound vehicle
    - 1 Westbound vehicle made left turns in front of Eastbound vehicle
    - 1 Westbound vehicle make left turn and skidded out of control into 2 stopped vehicles
    - 1 Eastbound vehicle entered on yellow and started to turn left when Westbound vehicle ran red light and struck Southbound vehicle
- Right turn accidents (23.1% of total):
    - 4 Eastbound vehicles pulled into parking lane and were hit when vehicle turned right from proper lane
- 21 of 26 (80.8%) of accidents occurred when the weather was clear
- 18 of 26 (69.2%) of accidents occurred when the roads were dry

10^{th} Avenue South and 5^{th} Street

- 10^{th} Avenue South Permissive, Yellow clearance 4.0 sec, All-red 1.0 sec
- 10^{th} Avenue South Permissive, Yellow clearance 4.0 sec, All-red 1.0 sec
- Flashing operation begins at 12:05 a.m. and ends at 6:30am on weekdays and begins at 3:30 a.m. and ends at 7:00 a.m. on weekends
    - 10^{th} Avenue South flashes yellow
    - 32^{nd} Street flashes red
    - No accidents during flashing operation
- 5^{th} Street is a one-way Southbound north of 10^{th} Avenue South and two-way south of 10^{th} Avenue South
- Right Angle accidents (63.6% of total):
    - 5 Westbound violators
    - 1 Eastbound violator
    - 1 Northbound violator (DUI)
- 6 of 11 (54.5%) of accidents occurred when the weather was clear
- 7 of 11 (63.6%) of accidents occurred when the roads were dry

Missoula

Brooks Street and Reserve Street

- Brooks Street Westbound Left Protected only, Yellow clearance 3.5 sec, All-Red 2.0 sec
- Brooks Street Westbound Through, Yellow clearance 4.0 sec, All-Red 2.0 sec
- Brooks Street Eastbound Left Protected only, Yellow clearance 4.3 sec, All-Red 1.5 sec
- Brooks Street Eastbound Through, Yellow clearance 4.0 sec, All-Red 1.0 sec
- Reserve Street Northbound Left Protected only, Yellow clearance 4.0 sec, All-Red 0.0 sec
- Reserve Street Northbound Through, Yellow clearance 4.3 sec, All-Red 2.0 sec
- Reserve Street Southbound Left protected, Yellow clearance 4.0 sec, All-Red 0.0 sec
- Reserve Street Southbound permissive, Yellow clearance 4.3 sec, All-Red 1.0 sec
- No flashing operation
- 17 Rear End accidents (60.7% of total)
- 4 accidents related to private approaches (14.3% of total)
- 16 of 28 (57.1%) of accidents occurred when the weather was clear
- 17 of 28 (60.7%) of accidents occurred when the roads were dry

Higgins Avenue and South 6th Street

- No protective/permissive left turns for all approaches, Yellow clearance 3.0 sec, All-Red 1.0 sec
- Begin flashing operation at 02:30 a.m. and end at 06:00 a.m.
    - Higgins Avenue flashes red
    - South 6th Street flashes yellow
    - No accidents occurred during flashing operation
- Right Angle accidents (77.3 % of total) :
    - 6 Northbound violators
    - 9 Southbound violators
    - 2 Eastbound violators
    - Contributing factors
        - Looking for street name
        - Did not see traffic signal
        - Visibility
- 19 of 22 (86.4%) of accidents occurred when the weather was clear
- 15 of 22 (68.2%) of accidents occurred when the roads were dry

Broadway Street and Orange Street

- No protected/ permissive left turns
- Broadway, Yellow clearance 4.0 sec, All-Red 1.0 sec
- Orange Street, Yellow clearance 3.0 sec, All-red 1.0 sec
- No flashing operation
- Right Angle accidents (38.2 % of total) :
    - 3 Northbound violators
    - 4 Southbound violators
    - 3 Eastbound violators
    - 3 Westbound violators
- Left Turn Accidents (38.3% of total):
    - 3 Westbound vehicles turned in front Eastbound vehicles
    - 1 Eastbound vehicle turned in front of Westbound vehicle
    - 3 Northbound vehicles turned in front of Southbound vehicle
    - 4 Southbound vehicles turned in front of Northbound vehicle
    - 1 Westbound vehicle making left turn entered intersection on red light skidded on wet road into Southbound vehicle
    - 1 Northbound vehicle ran the red light striking Westbound vehicle turning left
- 16 of 34 (47.1%) of accidents occurred when the weather was clear
- 16 of 34 (47.1%) of accidents occurred when the weather was overcast
- 27 of 34 (79.4%) of accidents occurred when the roads were dry

Broadway Street and Higgins Avenue

- No protected/ permissive left turns
- Broadway and Higgins, Yellow clearance 3.0 sec, All-Red 1.0 sec
- No flashing operation
- Left Turn Accidents (42.3% of total):
    - 2 Westbound vehicles turned in front Eastbound vehicles
    - 4 Eastbound vehicle turned in front of Westbound vehicle
    - 1 Northbound vehicles turned in front of Southbound vehicle
    - 1 Westbound vehicle turned left and hit pedestrian crossing Higgins Avenue
    - 1 Westbound vehicle hit Southbound vehicle making left turn (temporarily blinded by setting sun)
    - 1 Northbound vehicle hit Southbound vehicle turning left
    - 1 Eastbound vehicle turning left was hit by Westbound vehicle
- 19 of 26 (73.1%) of accidents occurred when the weather was clear
- 23 of 26 (88.5%) of accidents occurred when the roads were dry

Butte

Harrison Avenue and Roosevelt Avenue

- Harrison Avenue protected left turns, Yellow clearance 3.0 sec, All-red 1.0 sec
- Harrison Avenue permissive left turns, Yellow clearance 3.5 sec, All-red 1.0 sec
- Roosevelt Avenue no protected/permissive left turns, Yellow clearance 3.0 sec, All-red 1.0 sec
- No flashing operation
- Left Turn accidents (70.0% of total):
  - 3 Southbound vehicles turned in front of Northbound vehicles
  - 1 Northbound vehicle attempted left on yellow and was hit by Southbound vehicles which did not stop for yellow
  - 1 Northbound vehicle turned in front of Southbound vehicle
  - 1 Eastbound vehicle attempted left turn and was hit by Southbound vehicle that slid through red light
  - First vehicle attempted left turn and was struck by another vehicle which could not stop due to icy conditions
- 5 of 10 (50.0%) of accidents occurred when the weather was clear
- 6 of 10 (60.0%) of accidents occurred when the roads were dry

Harrison Avenue and Civic Center Road

- Harrison Avenue Protected left, Yellow clearance 3.0 sec, All-red 1.0 sec
- Harrison Avenue Permissive left, Yellow clearance 3.0 sec, All-red 1.0 sec
- Civic Center Road Permissive left, Yellow clearance 3.0 sec, All-red 1.0 sec
- No flashing operation
- 4 Rear End accidents (33.3% of total)
- Left Turn accidents (41.7% of total):
  - 1 Northbound vehicle turned in front of Southbound vehicle
  - 3 Southbound vehicles turned in front of Northbound vehicles
  - 1 Westbound vehicle turned in front of Eastbound vehicle
- 5 of 12 (41.7%) of accidents occurred when the weather was clear
- 5 of 12 (41.7%) of accidents occurred when the weather was overcast
- 8 of 12 (66.7%) of accidents occurred when the roads were dry

Arizona Street and Mercury Street

- Arizona Street Permissive, Yellow interval 3.0 sec, All-red 1.0 sec
- Mercury Street Permissive, Yellow interval 3.0 sec, All-red 1.0 sec
- No flashing operation
- Right Angle accidents (71.4% of total):
    - 2 Northbound violators
    - 2 Southbound violators
    - 1 Eastbound violator
- 5 of 7 (71.4%) of accidents occurred when the weather was clear
- 6 of 7 (58.7%) of accidents occurred when the roads were dry

Montana Street and Platinum Street

- Montana Street protected left turns, Yellow clearance 3.0 sec, All-red 0.0 sec
- Montana Street permissive left turns, Yellow clearance 3.5 sec, All-red 1.0 sec
- Platinum Street no protected/permissive left turns, Yellow clearance 3.0 sec, All-red 1.0 sec
- No flashing operation
- Left turn accidents (36.4% of total):
    - 2 Southbound vehicles turned in front of Northbound vehicles
    - 1 Northbound vehicle turned in front of Southbound vehicle
    - 1 Northbound vehicle turned on green arrow and was hit by Southbound vehicle
- 7 of 11 (63.6%) of accidents occurred when the weather was clear
- 6 of 11 (54.4%) of accidents occurred when the roads were dry

Helena

Euclid Avenue/Lyndale Avenue and Benton Avenue

- Euclid Avenue/Lyndale Avenue no protected/permissive left turns, Yellow clearance 4.0 sec, All-Red 1.0 sec
- Benton Northbound Single Phase Protected, Yellow clearance 3.0 sec, All-Red 1.0 sec
- Benton Southbound Single Phase Protected, Yellow clearance 3.0 sec, All-red 1.0 sec
- No flashing operation
- 10 Rear End accidents (32.3% of total):
    - 2 icy conditions
    - 2 snowy conditions
    - 1 faulty breaks
- Left Turn accidents (35.5% of total):
    - 6 Eastbound vehicles turned in front of Westbound vehicles
    - 3 Westbound vehicles turned in front of Eastbound vehicles
    - 1 Northbound vehicle stopped for red light then proceeded into intersection attempting left turn and collided with Westbound vehicle in intersection
    - 1 Northbound vehicle attempting to turn left was hit by Eastbound vehicle's trailer which became unhitched.
- 15 of 31 (48.4%) of accidents occurred when the weather was clear
- 19 of 31 (61.3%) of accidents occurred when the roads were dry

Montana Avenue and Prospect Avenue

- No protected/permissive left turns, Yellow clearance 3.0 sec, All-Red 1.0 sec
- No flashing operation
- Prospect Avenue is a one-way Westbound, east of Montana Avenue
- 12 Rear End accidents (48.0% of total):
    - 4 Southbound violators
    - 8 Westbound violators
- Right Angle accidents (28.0% of total):
    - 3 Northbound violators
    - 1 Southbound violator
    - 3 Westbound violators
- Left Turn accidents (26.0% of total):
    - 2 vehicles turned left from Prospect Avenue striking pedestrians crossing Montana Avenue
    - 1 Westbound vehicle ran red turning left and hit Northbound vehicle
    - 1 Westbound vehicle turned left and collided with a Southbound vehicle
    - 1 Southbound vehicle ran red and hit Westbound vehicle turning left
    - 1 Northbound vehicle failed to stop for red and hit Westbound vehicle turning left
- 14 of 25 (56.0%) of accidents occurred when the weather was clear
- 18 of 25 (72.0%) of accidents occurred when the roads were dry

Prospect Avenue and Lamborn Street

- Prospect Avenue no protected/permissive left turns, Yellow clearance 4.0 sec, All-Red 1.0 sec
- Lamborn street no protected/permissive left turns, Yellow clearance 3.0 sec, All-Red 1.0 sec
- Flashing operation begins at 6:30 p.m. on weekdays, 9:30 p.m. on weekends and ends at 06:30 a.m.
    - Prospect Avenue flashes yellow
    - Lamborn Street flashes red
    - No accidents during flashing operation
- Prospect Avenue is a one-way Westbound
- Right Angle accidents (77.8% of total):
    - 7 Westbound violators (2 snowy)
- 5 of 9 (55.6%) of accidents occurred when the weather was clear
- 5 of 9 (55.6%) of accidents occurred when the roads were dry

Prospect Avenue and Fee Street

- Prospect Avenue no protected/permissive left turns, Yellow clearance 4.0 sec, All-Red 1.0 sec
- Fee Street no protected/permissive left turns, Yellow clearance 4.0 sec, All-Red 1.0 sec
- Flashing operation begins at 6:30 p.m. on weekdays, 9:30 p.m. on weekends and ends at 06:30 a.m.
    - Prospect Avenue flashes yellow
    - Fee Street flashes red
    - 6 accidents during flashing operation
- Prospect Avenue is a one-way Westbound
- Right Angle accidents (40.0% of total):
    - 3 Northbound violators (1 during flashing operation)
    - 2 Southbound violators (2 during flashing operation)
    - 3 Westbound violators
- 3 accidents related to private approach just east of intersection
- 11 of 20 (55.0%) of accidents occurred when the weather was clear
- 12 of 20 (60.0%) of accidents occurred when the roads were dry

11th Avenue and Fee Street

- 11th Avenue no protected/permissive left turns, Yellow clearance 4.0 sec, All-Red 1.0 sec
- Fee Street Northbound permissive left turns, Yellow clearance 4.0 sec, All-Red 1.0 sec
- Fee Street Southbound Protected left turns, Yellow clearance 3.0 sec, All-red 1.0 sec
- No flashing operation
    - 11th Avenue is a one-way Eastbound
- 8 Right Angle accidents (47.1% of total):
    - 2 Northbound violators (1 snowy condition)
    - 6 Eastbound violators (1 accident involved a bicycle)
- 12 of 17 (70.6%) of accidents occurred when the weather was clear
- 14 of 17 (82.4%) of accidents occurred when the roads were dry

Bozeman

Main Street and 19th Avenue

- Main Street Left protected left turns, Yellow clearance 3.0 sec, All-Red 1.0 sec
- Main Street permissive left turns, Yellow clearance 3.0 sec, All-Red 1.0 sec
- 19th Avenue no protected/permissive left turns, Yellow clearance 3.0 sec, All-Red 1.0 sec
- Flashing operation begins at 02:30 a.m. and ends at 06:30 a.m.
    - Main Street flashes yellow
    - 19th Avenue flashes red
    - No accidents during flashing operation
- 18 Rear End accidents (50.0% of total):
    - 8 icy conditions
    - 1 snowy condition
    - 1 slushy condition
- Left Turn accidents (25.0% of total):
    - 4 Westbound vehicles turned left in front of Eastbound vehicles
    - 2 Eastbound vehicles turned left in front of Westbound vehicles
    - 1 Southbound vehicle turned left in front of Northbound vehicle
    - 1 Northbound vehicle turned left in front of Southbound vehicle
    - 1 Westbound vehicle tried to beat the red light as Eastbound vehicle was clearing intersection turning left
- 20 of 36 (55.6%) of accidents occurred when the weather was clear
- 17 of 36 (47.2%) of accidents occurred when the roads were dry
- 11 of 36 (30.6%) of accidents occurred when the road were icy

Main Street and Bozeman Avenue

- No protected/permissive left turns, Yellow clearance 3.0 sec, All-Red 0.0 sec
- Flashing operation begins at 02:30 a.m. and ends at 06:45 a.m.
    - Main Street flashes yellow
    - Bozeman Avenue flashes red
    - No accidents during flashing operation
- 4 Rear End accidents (44.4% of total)
- 4 of 9 (44.4%) of accidents occurred when the weather was clear
- 2 of 9 (22.2%) of accidents occurred when the roads were dry
- 5 of 9 (55.6%) of accidents occurred when the roads were wet

Rouse Avenue and Tamarack Street

- No protected/permissive left turns, Yellow clearance 3.0 sec, All-Red 0.0 sec
- Flashing operation begins at 02:30 a.m. and ends at 06:45 a.m.
    - Rouse Avenue flashes yellow
    - Tamarack Street flashes red
    - No accidents during flashing operation
- 5 Rear End accidents (62.5% of total)
- 7 of 8 (87.5%) of accidents occurred when the weather was clear
- 5 of 8 (62.5%) of accidents occurred when the roads were dry