Impact of Access Driveways on Accident Rates at Multilane Highways

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16. Abstract

The New Jersey Department of Transportation (NJDOT) is enforcing its access management standards within the limits of most of its highway improvement projects. In order to identify the impact of access points on accident rates, a study was conducted that concentrated on NJ State highways Rt. 27, 28, 33, and 35. The study concentrated primarily on the impact of major geometric and traffic flow characteristics on accident rates at the macroscopic level. The principal variables that were taken into consideration included the Annual Average Daily Traffic (AADT), number of lanes, shoulder existence, median existence, speed limit, and access points per mile (access density). The analysis included a comparative analysis between the occurrence of accidents at signalized intersections (intersection-accidents) and between intersections (section-accidents). In addition, a field study was conducted on one NJ state highway section where the main objective was to provide insights into the microscopic traffic flow characteristics such as the speed profile along the roadway, and the impact of turns from/to access points on the speed of the vehicles traveling on the mainline. The principal conclusions are: approximately 30% of the total accidents on the study routes were reported to occur between signalized intersections, approximately 7% of the accidents were attributed to vehicle maneuvers from/to access points, accident rates are better represented by a log-normal distribution, access density is a contributing factor to the occurrence of accidents between signalized intersections although not a necessary one, the highest percentage of accidents occurred during the evening peak from 3:00 to 6:00 PM, driver inattention is the primary factor in accident occurrence for both the section (37%) and signalized intersection accidents (33%), regression models were developed for 4-lane highway with shoulder, 2-lane highway without shoulder, and 4-lane highway with median that included a combination of the AADT and access density and/or the speed limit as independent variables. A more comprehensive statistical analysis of all NJ state highways and the US is recommended that could identify similarities and differences among various types of highways. This analysis should include sub-hourly traffic flow rates, the distribution of the speed and more detailed geometric characteristics. The development of a detailed GIS based database that would include accidents, traffic flow, geometric and weather characteristics would provide a universal basis for conducting similar analyses. A microscopic simulation model is needed, which can capture the traffic flow characteristics of multilane highways/arterials, especially capturing the impact of access points.

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TABLE OF CONTENTS

IMPACT OF ACCESS DRIVEWAYS ON ACCIDENT RATES ON NEW JERSEY MULTILANE HIGHWAYS/ARTERIALS

EXECUTIVE SUMMARY

Introduction

In urban and suburban areas, the rapid growth of the local economy has steadily increased the demand for access points along multilane highways. The availability of access is necessary to commercial or residential developments, usually at the expense of traffic operations and the safety of local highway systems. To achieve a good coordination of these two aspects, compromises are often required to be made between accessibility and mobility or capacity and safety. The study of how to provide access points without greatly deteriorating the safety and operations of local transportation systems is a continuing Access Management challenge at every state department of transportation and local transportation authorities. The highway system of New Jersey is one of the densest highway systems in the U. S. Multilane highways and arterials are the major components of this system. The New Jersey Department of Transportation (NJDOT) is enforcing its access management standards within the limits of most of its highway improvement projects. In order to identify the impact of access points on accident rates, a study was conducted that concentrated on NJ State highways Rt. 27, 28, 33, and 35. The study concentrated primarily on the impact of major geometric and traffic flow characteristics on accident rates at the macroscopic level. The principal variables that were taken into consideration included the Annual Average Daily Traffic (AADT), number of lanes, shoulder existence, median existence, speed limit, and access points per mile (access density). The analysis included a comparative analysis between the occurrence of accidents at signalized intersections (intersection-accidents) and between intersections (section-accidents). In addition, a field study was conducted on one NJ state highway section where the main objective was to provide insights into the microscopic traffic flow characteristics such as the speed profile along the roadway, and the impact of turns from/to access points on the speed of the vehicles traveling on the mainline.

Objectives

The primary objective of this study was to conduct a statistical analysis of the impact of mid-block access points on accident rates at multilane highways in the state of New Jersey, and to determine the primary explanatory variables that contribute to accident rates.

Findings

Key Findings

Approximately 30% of the total accidents on multilane highways for the NJ study routes are expected to occur between signalized intersections,
Approximately 7% of the accidents were due to access points, involving turning vehicles to/from access points,

Access density is a contributing factor to the occurrence of accidents between signalized intersections, although not necessarily the only one.

Accident rates are better represented by a log-normal distribution than a normal distribution.

The time of day plays a significant role in the occurrence of accidents, where the highest percentage occurs during the evening peak from 3:00 to 6:00 pm.

Driver inattention is the primary factor in accident occurrence for both the section (37%) and signalized intersection accidents (33%).

The three best regression models observed included as independent variables access density, AADT, and in some cases, speed limit.

4-lane highway with shoulder:

$$\ln(\text{Accident Rate}) = 18.782 - 2.4355 \times \text{Speed Limit} - 1.0204 \times \text{AADT} - 0.0008 \times \text{Access Density}$$

2-lane highway without shoulder:

$$\ln(\text{Accident Rate}) = 31.2916 - 0.216 \times \ln(\text{Speed Limit}) - 2.8146 \times \ln(\text{AADT}) - 0.4988 \times \ln(\text{Access Density})$$

4-lane highway with median

$$\ln(\text{Accident Rate}) = -0.9573 - 0.0000304 \times \text{AADT} + 0.0432 \times \text{Access Density}$$

Other Findings

AADT, access density, median, shoulder, speed limit, and intersection spacing have a significant impact on accident rates. The impact of the number of lanes is not as significant as the above factors.

Left turn collision and angle collision accidents were shown to be proportionally higher at signalized intersections in comparison to the corresponding proportion observed between signalized intersections. In contrast, collisions with objects, over turns, strike parking vehicles and same direction rear collisions reported between signalized intersections were proportionally higher than those reported at signalized intersections.

Mid-block section-accidents were mainly caused by vehicles entering and exiting mid-block access points. Seventy to eighty percent of the section-accidents were caused by a vehicle moving straight through on the mainline and a turning vehicle from/to an access point.

The percentage of accidents caused by improper turnings between intersections were higher than that occurred at intersections. Driving-inattention was the primary reason of these accidents.

Neither clear and rain weather conditions nor dry and wet roadway surface conditions showed significant different impacts on section-accidents and intersection-accidents. However, under snow weather conditions, or when the surface was covered with snow or ice, there was a distinct difference between the proportions observed on section-accidents and the corresponding intersection-accidents.

The proportion of weekday intersection-accidents is higher than that of weekend intersection-accidents, whereas the weekend section-accidents exhibits a higher proportion than the weekday section-accidents.

Through a limited field study, speed reduction, delay, and the percentage of affected vehicles due to turning movements to/from access points were identified as main variables in estimation of impact of access points on multilane highway accidents.

Approximately 25% of the entering/exiting vehicles from/to access points had impact on mainline traffic in the field study. Left turning movements had greater impact on mainline traffic than right turning movements. For left turning movements, the entering traffic had larger impact on mainline vehicles than the exiting traffic.

Recommendations

One of the most important questions of access management is what should be the spacing between access points that would optimize the traffic flow and improve traffic safety. The limitation of the data that were available for this study did not permit this study from reaching any definitive conclusion towards this question. Specifically, the following data may contribute towards a better understanding of the traffic operation and accident occurrence for these types of highway facilities: sub-hourly traffic volumes both at the mainline and access points, the speed profile along the roadway, the speed distribution for each section, detailed geometric characteristics, the trip generation characteristics of the various generators along the roadways, speed limit law enforcement, as well as the acceleration and deceleration along each section.

A limited field study was conducted to identify the impact of access points on the traffic operations of the highway. A more comprehensive study should be conducted with the main goal of developing a simulation model, which can capture the microscopic traffic flow characteristics of multilane highways between signalized intersections. The present version of CORSIM can not represent access points closely spaced together accurately. Such a simulation model will establish a tool for traffic impact analysis for access management. Furthermore, the simulation model should also be able to emulate the occurrence of accidents, which is a non-trivial task due to the unavailability of the pertinent data.

The analysis was conducted on a limited number of NJ State highways. A more comprehensive study should be undertaken to include all the NJ state highways, which can then be followed by a nationwide study that would identify the similarities and/or differences of different states.

Signal timing parameters and their effect on accidents either upstream or downstream of the intersection should be investigated.

Develop an Access Management Information System (AMIS) using a Geographic Information System (GIS) platform in conducting accidents analysis and traffic impact analysis on multilane highways. This could include links in conducting microscopic simulation analysis using a variation of CORSIM.

The present 1997 Highway Capacity Manual concentrates on capacity under normal conditions in establishing the level of service. Its treatment on the impact of access points on capacity is non-adequate. It should include explicitly, the impact of the number of left turns and right turns from the mainline to the access points and from the access points to the mainline, which was illustrated with the field study. In addition, other variables could be introduced, which would include the effect of accidents on the level of service of a roadway, such as:

Number of accidents per mile,
Number of fatal accidents per mile,
Total delay due to accidents per mile,
Benefit/Cost ratio per mile; should include the cost per accident, and the cost per time delay.

In essence the new manual will need to change to become the Highway Level of Service Manual or the Highway Benefit/Costs Analysis Manual. Capacity analysis will then become a part of this more comprehensive manual.

CHAPTER 1
INTRODUCTION

The degradation of operational efficiency and increase in accident rates along multilane highways prompted several states in developing access management techniques. One of the issues that is of critical importance is the impact of midblock access points on accident rates. This project was initiated by the New Jersey Department of Transportation (NJDOT) to analyze the impact of midblock access points on accident rates on NJ state highways. The analysis was conducted on a sample of NJ state highways based on accident records and pertinent geometric and traffic flow data provided by NJDOT.

1.1 Problem Identification

Two of the primary goals of transportation agencies are the improvement of the safety and the operational efficiency of the highway system. Multilane highways are primarily located in urban and suburban areas, connecting either two cities, an urban area and a suburban area, or two suburban areas. The rapid increase of development along multilane highways indicates a blossom of the local economy, while in the mean time, it deteriorates the operational performance of the transportation system. Several states, including the state of New Jersey, have developed an Access Code which restricts the number of access points along multilane highways and has developed standards for the geometric configuration of the access points. Whereas, numerous studies have been undertaken to examine the accidents at the vicinity of signalized intersections, only limited studies have addressed accidents between signalized intersections on multilane highways. These access points include unsignalized intersections, driveways, or direct access to various types of facilities, such as gas stations, restaurants, residences, etc. The state of New Jersey had requested that a study be undertaken which would identify the major causes of accidents between signalized intersections at six selected state routes.

Specifically, the following categories are identified as possible contributors to accidents on multilane highways:

- Accident location,
- Collision type,
- Vehicle action (turning movements),
- Light condition,
- Roadway surface,
- Weather condition,
- Day of week,
- Hour of day,
- Month,
- Vehicle contributing circumstances,
- Number of lanes
- Shoulder
- Median

- Speed limit
- Traffic volume

The analysis focused on the effects of the above mentioned elements on accidents reported on multilane highways for sections between signalized intersections.

1.2 Research Objectives of This Project

The primary research objectives of this study is to conduct a statistical analysis of the impact of midblock access points on accident rates at multilane highways and arterials in the state of New Jersey, and to determine (if feasible) the primary explanatory variables that contribute to accident rates.

1.3 Project Outline

This project is composed of seven chapters. Chapter 1 identifies the research problem and objectives. Chapter 2 provides a literature review on accident analysis and studies related to multilane highways. Chapter 3 presents the methodology used in this study. Chapter 4 outlines the data collection procedure. Chapter 5 presents the results of the statistical analysis. Chapter 6 summarizes the field study conducted on a section of NJ State Route 27. Chapter 7 presents the conclusions and recommendations. The appendix presents a sample of the road section database.

CHAPTER 2
LITERATURE REVIEW

This chapter presents the main literature related to accident rate analyses and the impact of access points on accident rates.

2.1 Accident Rate Analysis

The analysis of the relationship between safety, roadway design standards, and traffic volumes is the primary focus in safety studies. Several studies in traffic safety have been conducted in the past several decades.

Roadway geometric factors, pavement conditions, and operational factors have been reported to have a significant impact on traffic safety. According to McGee (1995), roadway geometric factors were divided into 5 subgroups: cross section, horizontal alignment, vertical alignment, median width and roadside design. TRB Special Report 214 (1987) stated: "In general, the relationship between safety and highway features is not well understood quantitatively, and the linkage between these relationships and highway design standards has been neither straight forward nor explicit," but great efforts have been devoted to this field.

The most well studied subject is the impact of cross section (shoulder and lane-width) on safety. Some basic statistical analysis, (see Belmont (1954) and Perkins (1956)), conducted in the 1950's, indicated that accident rates decrease in the facilities with wider shoulders. Opposite results were reported by Blensley and Head (1960). Dart(1970) found that wider shoulders have a relatively small impact on accident rates. Later, Dearinger (1970) reported a reduction in accident rates with the presence of wider lanes. Numerous other studies reported by Jorgensen Associates (1978) and Zegeer (1981) have also confirmed that accident rates decrease because of wider shoulders and lanes. Later, Goldstine (1991), verified the relationship among accident rates, AADT and road width. Most of the aforementioned studies were based on either before-and-after studies or comparison of the entity of specific interest with other similar entity groups. A before-and-after study follows a simple pattern: the count of accidents on entities of specific interest is compared with the record of accident occurrence after the treatment. On the basis of such a comparison, inferences are made about the effect of the measure of treatment, (see TRR 1068, Hauer and Lovell (1986)). In FHWA-RD-87-008 (Zegeer (1987)) an accident prediction model was developed and used to determine the expected effect of lane and shoulder widening improvements on accidents. This is the most complete and thorough quantitative study on the relationship of safety to lane width and shoulder width. Also in this study, accident classifications were considered to be necessary in fitting regression models. However, in Zegeer (1987), the models exhibited relatively low R square, therefore, the usefulness of the models is questionable. The models developed can only be applied to 2-lane rural highways. Despite these shortages, this study is still considered as one of the most critical research efforts on the safety impact of cross sections.

The safety impact of horizontal alignment design has also been investigated extensively. NCHRP Report 374 (1995) concluded: sufficient evidence appears to indicate that, in general, horizontal curves experience higher accident rates than tangent, and accident rates generally increase as a function of increasing degree of curvature. Two prediction models were developed in this area: Glennon's Horizontal Curve Model (1985), and Zegeer's Horizontal Curve Model (1991). Although both of these two models have limitations (Zegeer's model did not consider roadside, Glennon's model lost accuracy when curves are sharper than 15 degrees, etc.), they are still considered significant contributions to safety studies. According to NCHRP Report 374 (1995), Zegeer's model appears to represent the best available relationship to estimate the number of accidents on individual horizontal curves on 2-lane rural roads.

In comparison to horizontal alignment design, the effect of vertical alignment design on accident rates did not receive adequate attention. Neuman, and Glennon (1983), provided a model that relates accidents on crest curve to available sight distance, but this model has not been validated by using real accident data.

The median is another geometric factor that has been reported to have a significant impact on safety. Median width, median cross slope, and median type (raised, flush, depressed) are the 3 major variables which influence safety. According to NCHRP Report 374 (1995), in general, wider medians achieve a higher degree of safety. Median widths in the range of 60 to 80 feet or more with flat slopes are considered as adequate.

Roadside also has an impact on safety. Roadside refers to the area between the outside shoulder edge and the right-of-way limits. According to NCHRP Report 374 (1995), providing clear zones with traversal slopes greatly enhances traffic safety.

Pavement conditions also have impact on accident rates, where, according to NCHRP report 162 (1975) and the paper by Hakkert (1983), resurfacing can reduce accidents up to 33%. A recent research conducted by Craus (1991), who used data from Israel, concluded that if anti-skid treatment is provided, accident rates can be reduced.

In terms of operational factors, NCHRP report 330 (1990) provided guidelines for improving traffic operation on urban highways without changing the total curb-to-curb street width. TWLTL (two-way left-turn lanes) have been found to be a very effective method for improving traffic operation. TWLTLs were reported to reduce accidents on urban and suburban highways by 35 %. In a recent study, Harwood (1995) concluded: “Installing of passing lanes and short four-lane sections and reallocation of street width on urban highways, through use of narrower through lanes can lead to reduction of accident rates." The author also pointed out that further research is needed to establish the relationship between traffic congestion (v/c ratio) and safety.

One of the early studies of the relationship between traffic volume and safety, was reported by Veh (1937), where he found that as the average daily traffic volume increases to approximately 7000 vehicles per day, the number of accidents also increases. Beyond an Average Daily Traffic (ADT) of 7000 vehicles per day, there is a gradual decrease in the accident rate, despite an increase in traffic. Lundy (1965) developed a regression model where the independent variable is the ADT. One of the main critiques for this model is that the segment length was not incorporated. Numerous similar studies followed the aforementioned research by Lundy, however, inconsistent, and sometimes contradictory results were found. This discrepancy may be attributed to two reasons (Persaud and Mucsi (1995)): 1) The first reason lies in the use of the relationship between accidents and the Average Annual Daily Traffic (AADT), which has been used to provide estimates of accidents. However, if this relationship is nonlinear, the AADT based models would be unsuitable for the estimation of accidents during portions of a day, such as, specific hours, peak periods, and night. This makes it necessary to use hourly or sub-hourly volumes as one of the independent variables. 2) The second reason, for the aforementioned discrepancy, is that most of the early studies use the total number of accidents as a safety measure, but it was shown that accident classification is necessary in the estimation of accidents, where the pattern of single-vehicle accidents is different from that of multi-vehicle accidents. When hourly traffic volumes and accident classification are combined, the models become more robust. For example, for single-vehicle accidents, the accident potential is higher during the night, whereas for multi-vehicle accidents, the opposite is true.

In the 1960's, some early efforts were made to indicate the importance of differentiating between different types of accidents, and different portions of a day. Gwynn (1967) examined the hourly accident experience. He found that the highest accident rates happen during hours in the low-volume ranges (nighttime). An attempt to establish whether a relationship exists between hourly accident rates and the ratio of traffic volume to capacity was also made by Hall (1990). Orne (1980) described some preliminary efforts to examine the relationship between traffic accidents and actual traffic volumes at the time of the accident. This approach is hampered by the unavailability of reliable traffic volume data at accident sites. The differentiation of accident types was also considered by Kihlberg and Tharp (1968), who reported that single-vehicle accident rates decreased with an increase in ADT, whereas for multi-vehicle accident rates, the opposite was true. Similar findings were obtained by Bhagwant (1995). In general, by introducing accident types, and hourly traffic volume, the relationships between accidents and traffic volumes are much more robust.

The methodology used in safety studies can be divided into two groups:

1. Before-and-after study, and
2. Accident prediction models.

The first one is aimed at finding the "treatment effect" of improvement measures, which was the focus of earlier studies, and little emphasis was placed on accident prediction models.

Hauer (1986) summarized: "a typical before-and-after study follows a simple pattern, at some time a measure (treatment) that affects safety is implemented on a few entities. The count of accidents on these entities before treatment is compared with the record of accident occurrence after treatment. On the basis of such a comparison, inferences are made about the effect of the measure or treatment." Unfortunately, most of the results of before-and-after studies have a "Regression-To-Mean" (RTM) problem. RTM describes the situation where the count of accidents in the period after identification will generally revert toward its expected value even if a treatment is applied to the site, (see Abbess and Jarrett (1981)). Two possible reasons of RTM are the rarity of accidents and the annual variations in the accident count, and the sites chosen for treatment because of recent poor accident records.

A method developed by Lau (1989) to overcome the RTM problem was to use a combination of accident history. This method differs from the previous prediction models (regression models) in two aspects:

1. Use of an Empirical Bayesian (EB) procedure (Persaud and Mucsi (1995)).
2. Most of the regression theory is based on the assumption that the error structure is normal with mean equal to 0, and a constant variance; however, this hypothesis is not valid in traffic safety analysis.

Studies have shown that a negative binomial type of error is more appropriate to describe the variations in the number of accidents (see Belanger (1994)).

The data used in the EB procedure, (Hauer and Persaud (1988)), comes from two sources: casual factors, which tell something about the safety of similar entities, and accident records, which capture the history of the specific entity, the safety of which is examined. A major difficulty associated with the use of the EB method consists of defining a reference population, which have similar characteristics as the specific site, and is sufficiently homogeneous to be reliable, (see Belanger (1994)). In fact, the major task of the EB is to develop a method to estimate the expected accident rates. Two methods can be used to achieve this task, (see Hauer (1992)), the method of sample moments and the multivariate regression method. The first method depends on a large reference population, where the larger the population is, the more accurate the estimates are. Two practical difficulties arise here: first, it is rare that a sufficiently large data set can be found to allow for an adequate accurate estimation; second, even with very large data sets, one cannot find an adequate reference population when entities are described by several traits. The multivariate method extends the applicability of the EB procedure to circumstances in which a large reference population does not exit. The underlying basis of this method is that it can be described by some independent variables in a systematic way. These independent variables are called traits, such as daily traffic volumes, geometric design elements, etc. The importance of these methods is that they can be applied to a specific case, as well as to various types of entities.

2.2 Impact of Access Points on Accident Rates

The safety impact of access points is one of the major concerns of access management. This can be divided into two groups; the relationship between safety and geometric design factors pertaining to access points, and the relationship between safety and traffic volumes on access roads (driveways, unsignalized intersections, signalized intersections, etc.)

Among the geometric factors, access density, access classification, spacing and left-turn control are considered to be the most influential on safety. In a study conducted by Dart and Mann (1970), they found that accident rates increase as access density (number of access points along a particular highway section) increases. Similar conclusions can be found in NCHRP Report 93 (1970) and FHWA-IP-82-3 (1982). Left-turn control is considered to be very important to safety improvement, because, according to previous studies, 70% of driveway accidents involve left turning vehicles. By imposing proper left turn control techniques accidents can be reduced up to 50%. The access classification system defines where access can be allowed between proposed developments and public highways and where it should be denied or discouraged. Different approaches to access classification are provided in Chapter 6 of NCHRP report 348, Koepke and Levinson (1992). Spacing standards address the following questions: when should grade separations be considered? What is the desirable spacing of signals? What should the minimum driveway spacing be at unsignalized locations, etc. Guidelines for providing appropriate spacing are also provided. Quantitative safety impact analysis of both access classification and spacing has not been reported.

The safety impact of traffic volumes on access roads has not been well studied yet. Powers (1988) conducted a study where he addressed the operational impact of driveway volumes on speed. No direct safety impact studies have been reported.

CHAPTER 3
METHODOLOGY

In this research, six principal NJ state highways were selected as study objects that are composed of urban and suburban sections. These highways include NJ State Routes 21, 27, 28, 33, 35, 82. Due to data limitations, Route 82 was eliminated from the study. This study covers highway sections totaling about 175.8 miles, consisting of 4-lane and 2-lane sections. First, a graphical statistical analysis is conducted to identify the general trend of the impact of access points and other factors on accident rates. Then, a statistical analysis is conducted based on the distributions of accident rates and a set of regression and hypothesis tests are conducted.

3.1 Terminology of Principal Elements

This section presents the definition of the principal elements of the statistical analysis, such as: access density, accident rate, section accidents and intersection accidents.

- <u>Access density</u>: the number of access points per mile (abbreviated in #/mile) on a road section in each direction. It is obtained by dividing the number of access points with the corresponding section length (see equation 1 below). It is an important measurement of access spacing, which reflects the distance between access points.

  $$AD = N / L \qquad (1)$$

  Where,

  AD = access density, #/mile

  N = number of access points

  L = length of the corresponding roadway section, in miles

- <u>Accident rate</u>: the number of accidents occurred per million vehicle miles traveled (in #/MVM) on a road section in each direction. It is calculated by dividing the number of accidents occurred in each direction with the AADT and length of the road section (see equation 2).

  $$AR = M \times 10^6 / (365 \times AADT \times L) \qquad (2)$$

  Where,

  AR = accident rate, #/MVM

  M = number of accidents

  AADT= Annually Average Daily Traffic, in vehicles per day (vpd)

  L = length of the corresponding roadway section, in miles

One significant difference from previous studies is that both of the above rates were calculated per direction instead of combining them for both directions of traffic. The difference resulted from the finding that there is a significant variability of accidents and access points in the two opposite directions of traffic for the same roadway section. Next we define the section accidents and signalized intersection accidents.

- Section-accidents: accidents occurred between signalized intersections are defined as section-accidents. Section-accidents are considered to be more likely to be affected by access driveways.
- Intersection-accidents: accidents occurred at signalized intersections are defined as intersection-accidents.

3.2 Division of Study Sections

In order to conduct an unbiased regression analysis, a careful classification of roadway sections with uniform characteristics was necessary. Both geometric and traffic factors may also have significant impacts on accident rates. Therefore, the analysis was carried out by classifying the roadway sections based on common geometric characteristics, such as shoulder/no shoulder, median/no median, access classification, and traffic control factors such as the speed limit. Each study section has uniform characteristics in terms of number of lanes, median, shoulder, speed limit and AADT (Annually Average Daily Traffic). The analysis resulted in sections ranging from 0.3 to 2.0 miles of length. Several iterations were conducted in finalizing the appropriate sections.

To demonstrate how study sections were divided, a 3-mile highway section from milepost 12.6 to 15.6 on Rt. 33 westbound is presented as an example. The line diagram of this highway section is attached in Figure 3.1, and is used as the basis of the division of study sections. The first section starts at milepost 12.6 and ends at milepost 13.7. Prior to milepost 13.7, there is a 5-feet shoulder, and the speed limit is 45 mi/h. The next section starts at milepost 13.7 and ends at milepost 14.3, having a speed limit of 35 mi/h and no shoulder. After milepost 14.3, a shoulder appears again, and the speed limit increases from 25 mi/h to 35 mi/h. In this section, two different speed limits exist, 35 mi/h from milepost 13.7 to 14.0 and 25 mi/h from milepost 14.0 to 14.3. We used an average value of 30 mi/h as the speed limit for this section. Multi-criteria considered in the division of study sections sometimes causes inconsistency among different criteria. In such cases, compromises were made, and average values were often used. The third section is from milepost 14.3 to 15.0. At milepost 15.0, the number of lanes changes from 2 to 4, and the speed limit increases from 35 to 50. The last section in this 3-mile highway section is from milepost 15.0 to 15.6. Since the corresponding AADTs on the straight line diagram are not yearly based, they were not used in the dividing process for this study section. Instead, the AADTs posted on the NJDOT Bulletin Board were used. The four study routes have been divided into 200 study sections. The access density and accident rate were calculated for each study section, and stored in a Microsoft Access database (see Appendix 1) together with major geometric information which were used to identify the study sections. Table 3-1 presents a sample of the resulting database section, of the 3-mile highway section on Rt. 33.

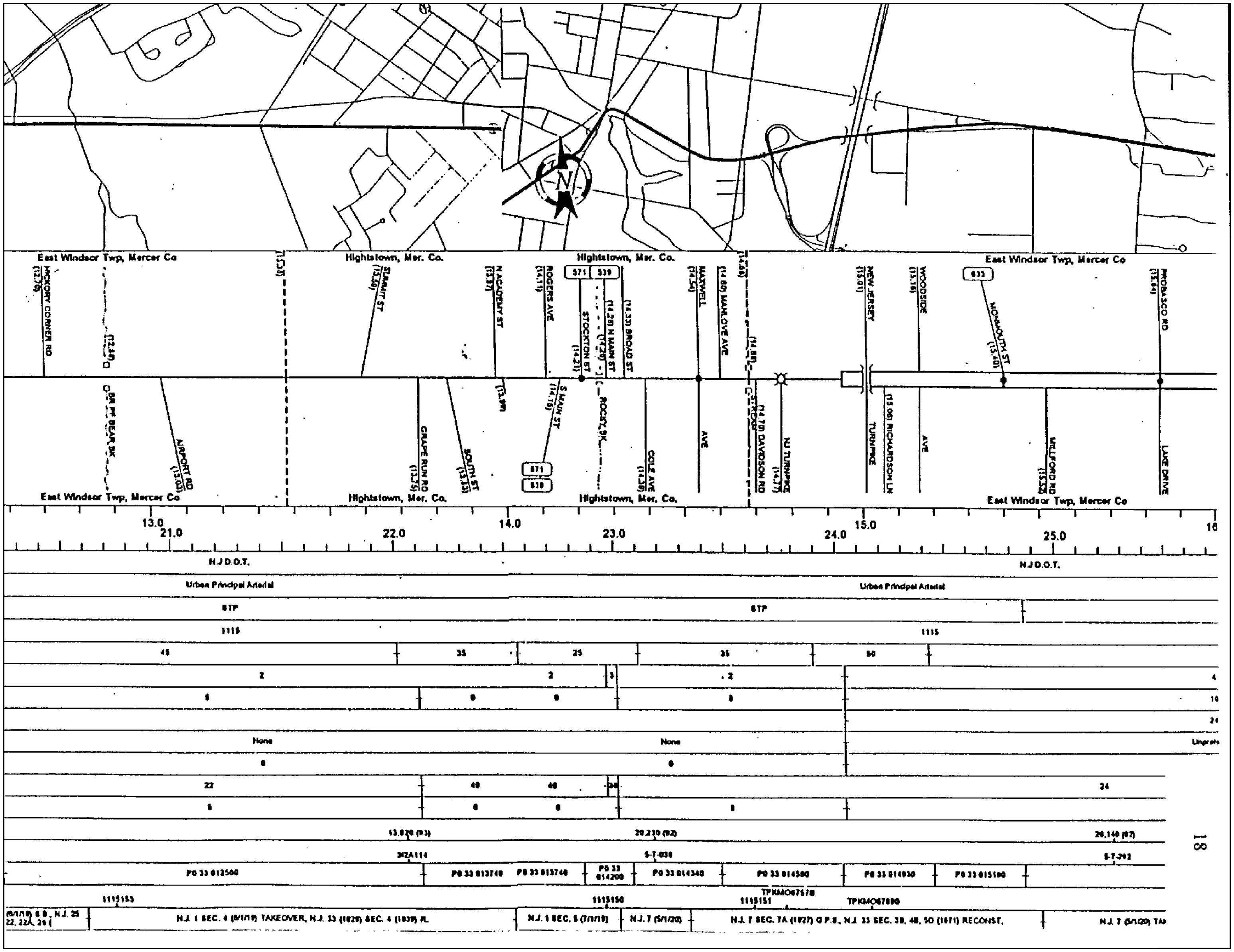

Figure 3.1 Sample Straight Line Diagram

Table 3-1. Sample Section Database of Route 33

Start	End	Length (mile)	AADT	Lane	Speed Limit (mi/hr)	Shoulder	Median	Access Density (#/mile)	Accident Rate MVM (1:10)
12.6	13.7	1.1	13500	2	45	N	Y	13.63636	1.844933
13.7	14.3	0.6	21000	2	30	N	N	31.66667	4.348771
14.3	15.0	0.7	21000	2	35	N	Y	22.85714	1.863759
15.0	15.6	0.6	25000	4	50	Y	Y	10	7.305936

3.3 Descriptive Statistical Analysis

A descriptive statistical analysis of accidents reported on New Jersey State multilane highways was conducted for NJ state routes 21, 27, 28, 33, and 35. The analysis was based on both route and direction. The principal independent variables used in this analysis were: access density, accident location, collision type, vehicle contributing factors, road conditions, weather conditions, accident occurrence time, highway geometric characteristics, and traffic flow conditions.

3.3.1 Relationship Between Access Density and Accident Rate

Access density is considered as one of the main factors affecting accident rates. Access densities and accident rates were computed by section, and were plotted on an access density-accident rate diagram along the milepost. The graphical representation of this relationship is used to identify the correlation between the access density and accident rate at the routes selected for this study. In addition, a standard correlation analysis has been conducted to quantify the correlation of these two variables analytically.

3.3.2 Comparison Studies of Section Accidents and Intersection Accidents

This analysis was conducted to identify the potential impact of different factors (accident location, collision type, light condition, road surface condition, weather condition, accident occurrence time and vehicle contributing factors) on both section accidents and intersection accidents. Comparisons were made between section accident analysis results and intersection accident analysis results. The principal descriptive statistics for this comparative analysis are described below.

3.3.2.1. Accident Locations

All accident records were categorized into two types of locations: at signalized intersections and between intersections. A comparative analysis was conducted to identify similarities and differences between these two types of locations.

3.3.2.2. Collision Types

The following collision types were identified: same direction rear collision, same direction side collision, turn collision, object obstacles, overturn, head-on, strike parked vehicle or pedestrian. While some of these accidents may be attributed to pure driver inattention, some of them may be attributed to the impact of access points, such as a turning collision or same direction rear or side-collision resulting from a sudden appearance of turning in/out vehicles. Comparisons among different collision types could provide insights to the potential contribution of access points to accidents.

Usually two vehicles are involved and reported in an accident. The actions and directions of vehicle-1 and vehicle-2 reflect the current conditions of the accident. In the accident records, the vehicle actions are categorized in several combinations such as: vehicle-1 going straight while vehile-2 is turning left from an access point, or vehicle-1 being parked while vehicle-2 is turning right into an access point. The left-turning and right-turning accidents occurred between intersections are directly related to vehicles turning into/out of access points. By studying the combination of the vehicle actions involved in accidents in each direction, the contribution of access points to accidents and the vehicle actions most frequently involved in accidents could be identified.

3.3.2.3 Other Factors

Other elements, such as light, road surface, weather, day of week, time, month, vehicle contributing circumstances, were also taken into consideration in order to further identify the potential differences among the reported accidents under the impact of access points.

3.3.3 General Accident Analysis

Other major factors considered in this study include: highway geometric characteristics (number of lanes, shoulder/no shoulder, median/no median), traffic flow conditions, and speed limits. These factors were chosen because they are generally considered to have a significant impact on accident rates.

3.4 Statistical Analysis

The first step in this section presents the distribution patterns of accident rates, including parameter estimations. In the second step, a set of mean equality tests are conducted to identify the impact of single factors on accident rates. These single factors include access density, median/no median, shoulder/no shoulder, speed limit, and intersection spacing. In the last step, a set of regression models is developed to identify the quantitative impacts of independent variables on accident rates. These independent variables include the AADT, access density, speed limit, and segment length.

3.4.1 Distribution Patterns of Accident Rates

Normality tests were conducted using normality plots for all accident data, and for accident data by subgroup. These subgroups were categorized by: AADT, access density, median/no median, number of lanes, shoulder/no shoulder, speed limit and intersection spacing. If the points on normality plots demonstrate linear trends, then the accident rates are normally distributed.

Lognormal distribution tests were also conducted because the shape of accident rates data on dot plots indicated lognormal patterns. A nonnegative random variable X is said to have a lognormal distribution if the random variable $Y = \ln(X)$ has a normal distribution.

The resulting probability density function of a lognormal random variable when ln(X) is normally distributed with parameters μ and δ is

$$f(x;\mu,\delta)=\begin{cases}\frac{1}{\sqrt{2\pi}\delta x}e^{-[\ln(x)-\mu]^2/(2\delta^2)} & x\geq 0\\ 0 & x<0\end{cases} \quad (3)$$

where

μ is the mean of ln(X)

δ is the standard deviation of ln(X).

To test lognormality, the logarithmic values of accident rates are calculated, and normality plots are drawn based on these logarithmic values.

Finally, parameters of probability density functions of accident rates are calculated using collected data samples.

3.4.2 Tests of Single Factor Impacts on Accident Rates (Mean Equality Tests)

Single-factor mean equality tests are used to identify the impact of a single factor on a random variable. Suppose the mean of population i is μ_i $i=1,2,\ldots,n$. If $H_0{:}\mu_1=\mu_2=\ldots=\mu_n$ is true, the tested single factor does not have significant impact on the random variable, otherwise if $H_0{:}\mu_1=\mu_2=\ldots=\mu_n$ is not true, the tested single factor has significant impact on the random variable.

The most commonly used single-factor mean equality test is the Analysis of Variance (ANOVA) model, however, this model can only be used when the random variable of all populations are normally distributed with the same variance. The normality test results on the data used in this analysis don't support the normal distribution assumption, thus the single-factor ANOVA model could not be used.

The Kruskal-Wallis test is a distribution-free analysis of variance method for testing equality of the μ_i's depends only on the random variable having the same continuous distribution. As demonstrated in previous sections, accident rates are all lognormally distributed, so the validity of the Kruskal-Wallis test is satisfied in our case. A brief summary of the Kruskal-Wallis Test is presented next.

Let N= $\Sigma J_{i,}$ to denote the total number of observations in the data set, and suppose we rank all N observations from 1 (the smallest X_{ij}) to N (the largest X_{ij}). When H_0: $\mu_1=\mu_2=\ldots=\mu_i$ is true, the N observations all come from the same distribution, in which case all possible assignments of the ranks 1, 2, …, N to the I samples are equally likely and we expect ranks to be intermingled in these samples. If, however, H_0 is false, then some samples will consist mostly of observations having small ranks in the combined sample while others will consist mostly of observations having large ranks. More specifically, if R_{ij} denotes the rank of X_{ij} among the N observations and R_i and $\bar{R}_i$ denote the total and average of the ranks in the i^{th} sample, respectively, then when H_0 is true

$E(R_{ij}) = (N+1)/2$, and $E(\bar{R}_i) = \frac{1}{Ji} \Sigma E(R_{ij}) = (N+1)/2$

The K-W test statistic is a measure of the extent to which the $\bar{R}_i$ deviate from their common expected value (N+1)/2, and H_0 is rejected if the computed value of the statistic indicates too great a discrepancy between observed and expected rank averages.

$$K = \frac{12}{N(N+1)} \sum_{j=1}^{I} Ji(\bar{R}_i - (N+1)/2)^2$$

$$= \frac{12}{N(N+1)} \sum_{j=1}^{I} \frac{Ri^2}{Ji} - 3(N+1)$$

When H_0 is true and either

$I = 3$, $Ji \geq 6$ $i=1, 2, 3$, or

$I > 3$, $J_i \geq 5$ $I=1, \ldots, I$

then K has approximately a chi-squared distribution with I-1 d.f.

This implies that a test with approximate significance level α rejects H_0 if $k \geq X^2_{\alpha, I-1.}$

3.4.3 Regression Models

Regression models were developed to identify the quantitative impacts of independent variables on accident rates. There are two types of independent variables: quantitative and descriptive. Quantitative variables include the AADT, access density, speed limit and segment length. The square and logarithmic forms of these variables were also included, all together. Descriptive factors include the number of lanes, median/no median, and shoulder/no shoulder. Accident rates were grouped into 7 subgroups using descriptive factors: 4-lane with shoulder, 4-lane without shoulder, 2-lane with shoulder, 2-lane without shoulder, 4-lane with median, 4-lane without median and 2-lane without median highways. Highway sections of 2-lane with median were not considered in this study, because, virtually all the 2-lane highway sections in this study were without median.

Regression models were developed separately for each of the seven groups. Prior to the development of regression models, the correlation among the 12 quantitative independent variables was tested. A high correlation value between an independent variable and a dependent variable indicates that the independent variable has significant impact on the dependent variable, thus it becomes a favorite candidate that might be included in the regression model. A high correlation between two independent variables indicates that the appearance of both of them in the regression model is not appropriate due to the effect of multi-collinearity. First the correlation matrix was estimated and then the best independent variables were chosen to be included in the regression models.

Based on data availability, year 1994 is chosen as the study year. Out of the six potential study locations, routes 21, 27, 28, 33, and 35 are chosen. Route 82 was dropped, because its data sample size was too small. In the descriptive statistical analysis step, the Microsoft Access and Excel software were used. In the statistical analysis step, the StataQuest 4.0 software was used.

3.5 Field Study

The field study was conducted on the Union County Linden Section of NJ State Route 27, which was one of the study objects. The study section is about 0.6 miles long with two lanes in each direction and without medians. The study included taking traffic counts and speed measurements. Traffic volumes both at access points and on the main road were counted simultaneously by using traffic counters. A video camera was used to record the speed measurements in a test vehicle. This survey covered both the AM and PM peak periods and the off-periods for the five weekdays from Monday to Friday.

CHAPTER 4
DATA COLLECTION

The accident analysis was conducted taking into consideration both the geometric and traffic factors that may have significant impacts on accident rates. The analysis was carried out by classifying the roadway sections based on geometric characteristics, such as shoulder/no shoulder, median/no median, access classification, and traffic control factors such as the speed limit. Each study section had uniform characteristics in terms of number of lanes, median, shoulder, speed limit and Annual Average Daily Traffic (AADT). The four study routes were divided into 200 study sections ranging from 0.3 to 2.0 miles of length. The access density and the accident rate were calculated for each study section. Table 3-1 shows a sample fraction of the database developed for a 3-mile highway section on Route 33. The year 1994 was used as the base year for this analysis. A description of the data collected for this analysis is presented next.

Accident Data: The accident data for Rt. 27, 28, 33 and 35 in New Jersey from 1989 to 1994 were provided by the NJDOT. In order to be consistent with geometric, volume and access data, only 1994 accident data was used in this study. Although the four studied routes were all multilane highways, some sections had only two lanes. These data were stored in a file called MACLSTRT-2 that included the following: the number of accidents, accident type, accident severity, accident location, accident occurrence time, collision type, vehicle contribution circumstance, vehicle action, surface condition, weather condition, etc. The accident location information in the accident record file MACLSTRT-2, which was provided by NJDOT, enabled the authors to separate section accidents from intersection accidents. Accident rates were calculated based on the number of accidents, traffic volume and section length for each of the study sections. The accident rates of the study sections were found to range between 0.00 MVM and 5.71 MVM for the year 1994.

Traffic Volume Data: Two types of traffic volume data were obtained: the AADT on the main-road sections, and traffic volume at access points. The AADT data from 1992 to 1996 were obtained by accessing the NJDOT database through their bulletin board. Only the 1994 AADT was used in the analysis. The AADT of the study sections range from 8000 vehicles per day to 37000 vehicles per day.

Roadway Geometric Characteristic Data: The 1996 straight line diagram for all multilane highways in New Jersey was used to obtain the roadway geometric characteristics such as: number of lanes, shoulder/no-shoulder, median/no-median, and speed limit. Although the year chosen for the analysis was 1994, it was assumed that the no significant changes in geometric characteristics on most of the studied occurred that would have significantly impact the analysis. Due to limited available information, more detailed geometric information, such as the type of intersection (such as intersections with jughandle etc.), the existence of turn lanes, and horizontal and vertical alignments, could not be obtained.

Access Information: Several video tapes shot from 1991 to 1995 were provided by NJDOT and were used to obtain access point information, such as types of access points (e.g. unsignalised intersetions, gas stations, restaurants, etc.) and milepost. Only some of the sections of the studied routes were videotaped in 1994, which was used as the base year of analysis. For other road sections, videotapes that were shot in the nearest year to the base year were used. The changes of access points from 1994 to the corresponding nearest year were judged to be negligible. Access density was calculated by route and direction for each of the study sections based on the number of access points and section length. The access density of the study sections was found to range between 0 access points per mile and 68 access points per mile.

CHAPTER 5
RESULTS

5.1 Descriptive Statistical Analysis Results

This chapter presents a descriptive statistical analysis of accident rates at signalized intersections and between signalized intersections, and the relationship between accident rates versus access density. Section 5.1.1 presents a graphical representation of the correlation between access density and accident rate for each of the study routes. Section 5.1.2 presents a comparative analysis of the factors that may contribute to accidents for both section and intersection accidents. Section 5.1.3 presents a general accident analysis by factor, such as highway geometric characteristics, traffic flow conditions and speed limit, which are considered to have significant impact on accident rates.

5.1.1 Relationship Between Access Density and Accident Rate

One of the most common figures found in the literature is a plot of access density and accident rate versus the milepost. The corresponding graphs for each of the study routes per direction are presented in Figures 5.1 to 5.8.

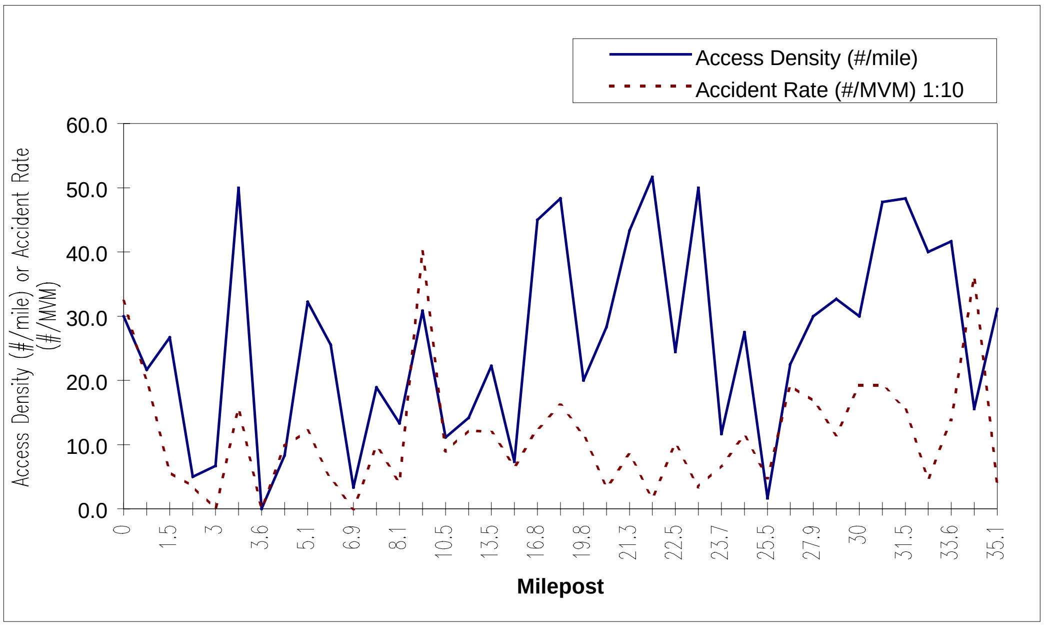

Figure 5. 1 Accident Rate and Access Density vs. Milepost
(Rt. 27 Northbound, 1994)

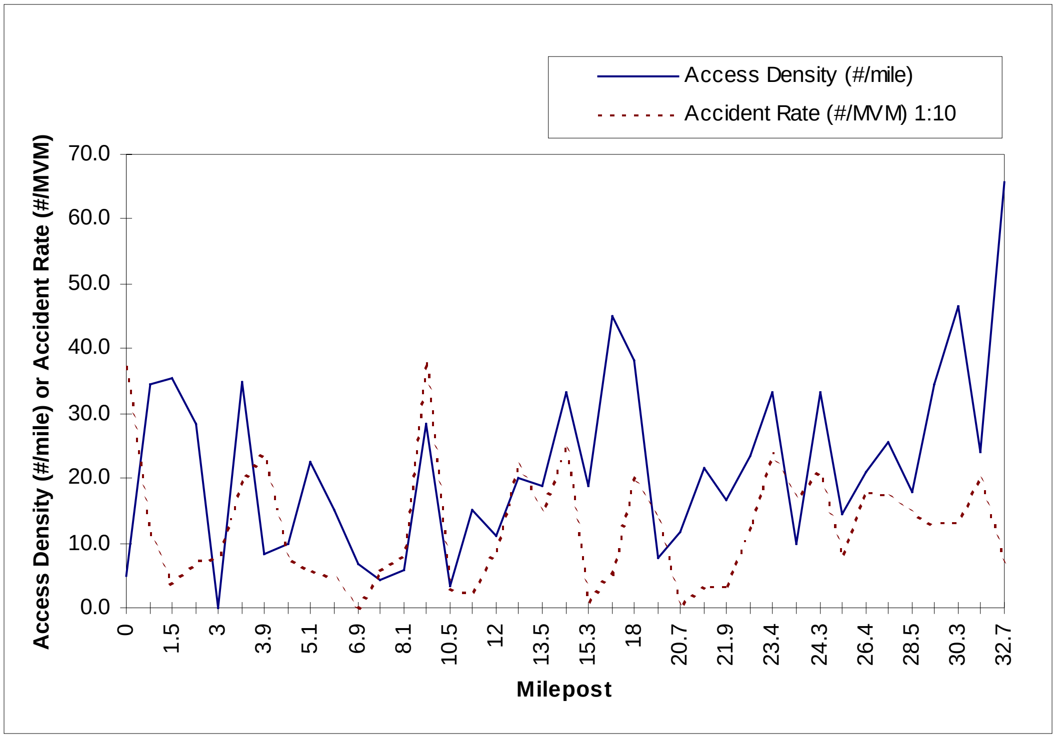

Figure 5. 2 Accident Rate and Access Density vs. Milepost
(Rt. 27 Southbound, 1994)

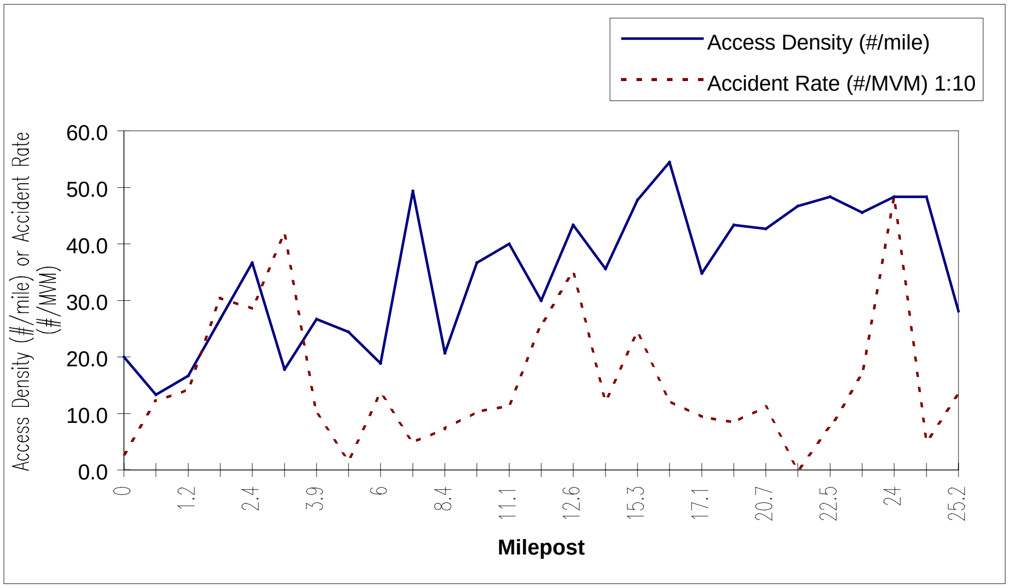

Figure 5. 3 Accident Rate and Access Density vs. Milepost
(Rt. 28, Eastbound, 1994)

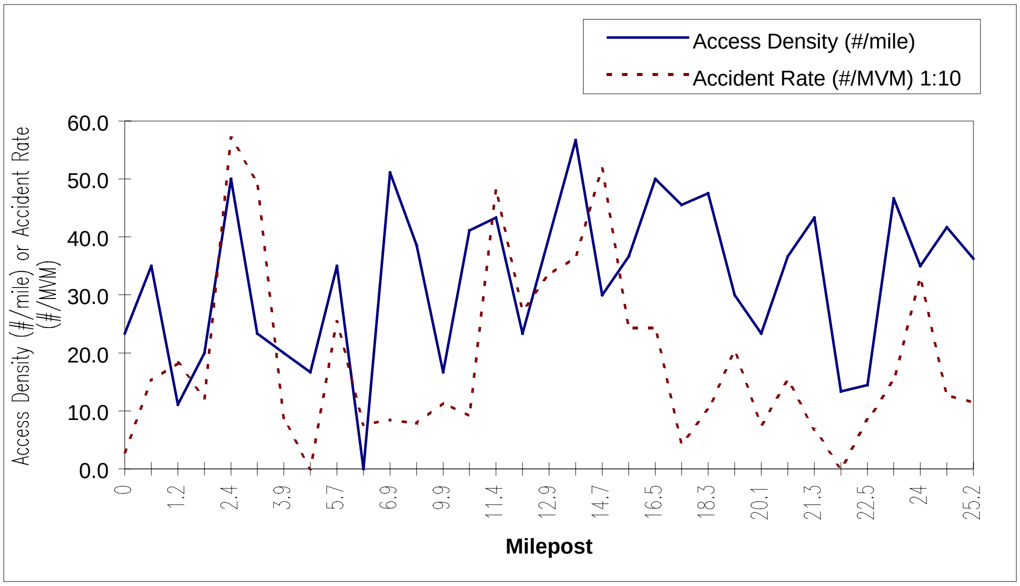

Figure 5. 4 Accident Rate and Access Density vs. Milepost
(Rt. 28, Westbound, 1994)

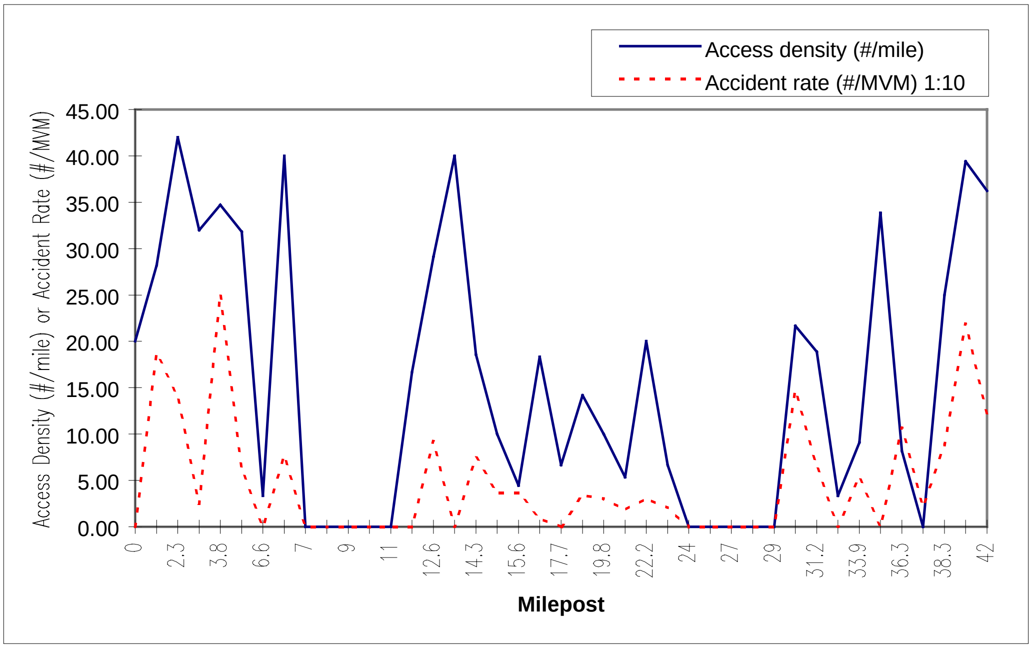

Figure 5. 5 Accident Rate and Access Density vs. Milepost
(Rt. 33, Eastbound, 1994)

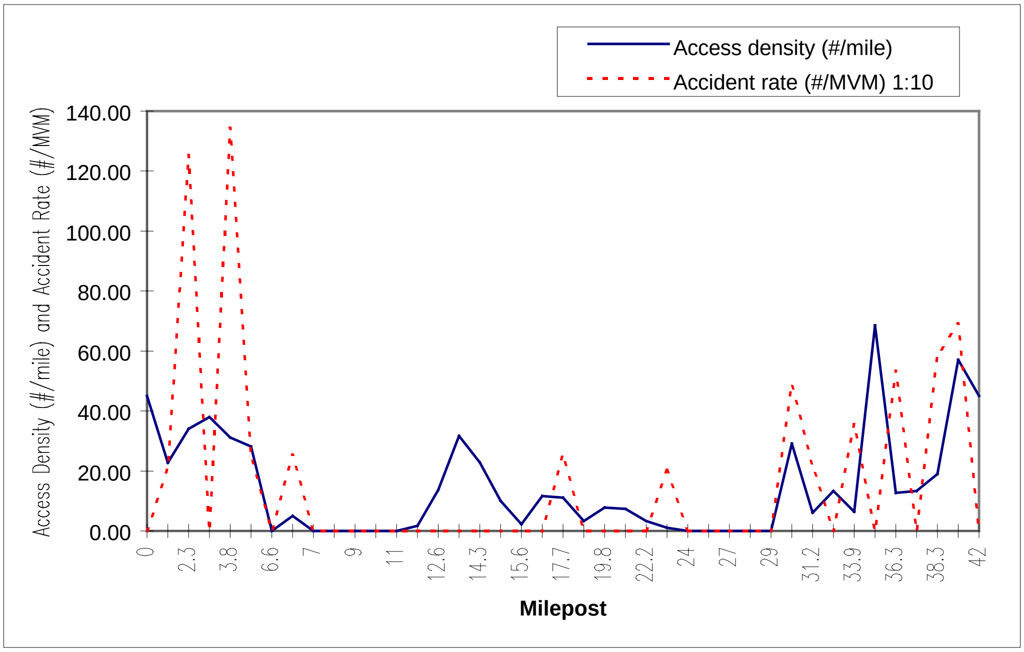

Figure 5. 6 Accident Rate and Access Density vs. Milepost
(Rt. 33, Westbound, 1994)

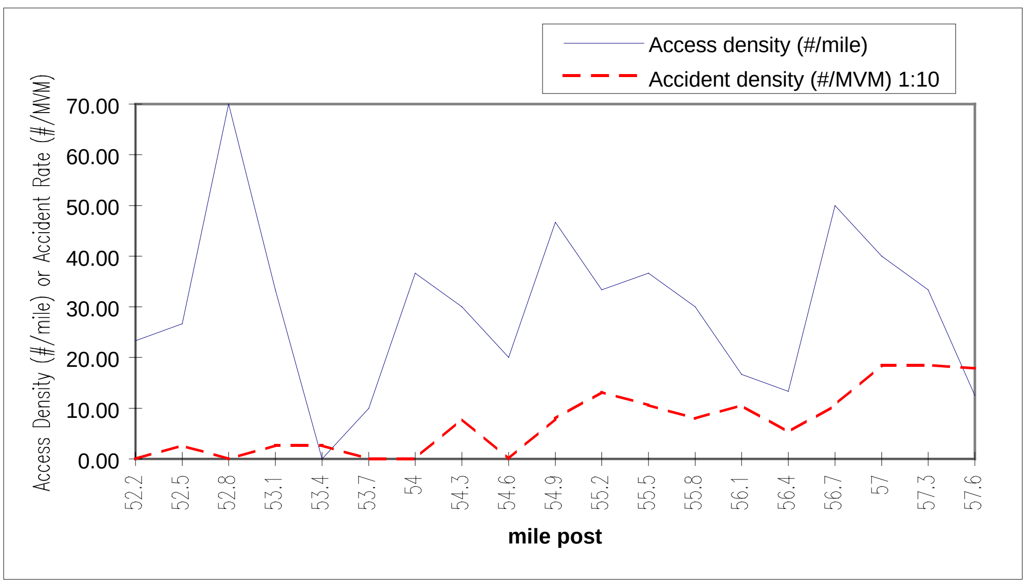

Figure 5. 7 Accident Rate and Access Density vs. Milepost
(Rt. 35, Northbound, 1994)

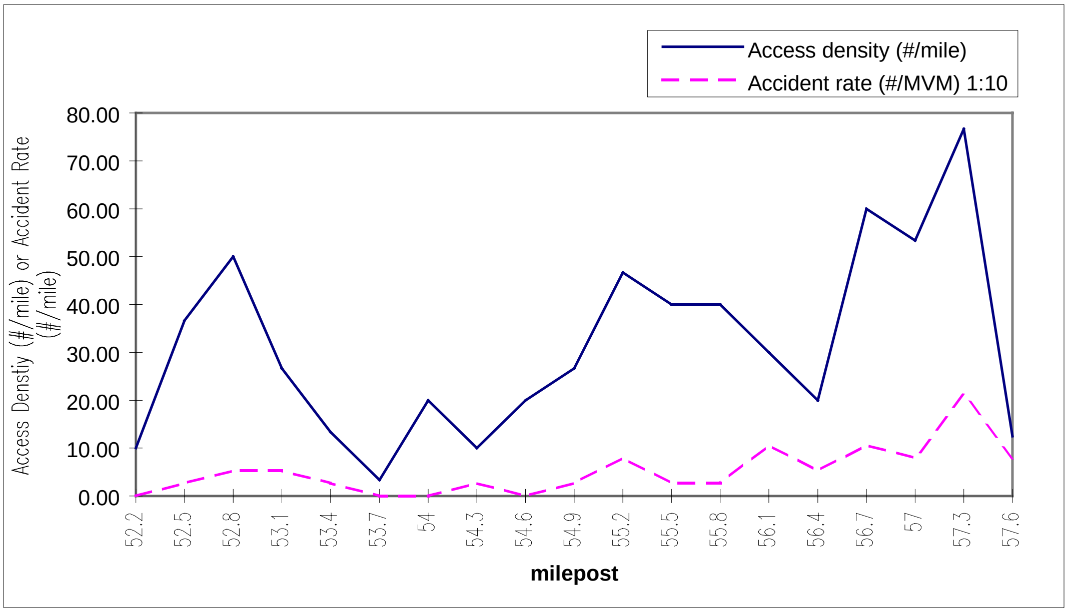

Figure 5. 8 Accident Rate and Access Density vs. Milepost
(Rt. 35, Southbound, 1994)

The principal conclusion of the above figures is that for the majority of the sections, the access density has a positive relationship with the accident rate. However, the reverse is true for some of the sections such as, from milepost 0 to 3.0 on Route 27 southbound, and from milepost 17.1 to 24.0 on Route 28 eastbound. This signifies that there are other factors that may contribute to accidents, other than the conflicting volumes at the vicinity of access points.

In order to examine the overall relationship between accident rates and access densities of all study routes, the access densities were divided into to six groups: 0-10, 10-20, 20-30, 30-40, 40-50, and >50 (#/mile), and the corresponding accident rates were calculated for each of these groups. The corresponding graph of the average accident rate versus access density is shown in Figure 5.9 below.

Accident rate increases with access density when access density is relatively low. However, when access density reaches 20 access points/mile, the increasing trend slows down. At the level of 40-50 access points/mile, the accident rate reaches its peak and then it declines significantly. When the access density is between 20 and 50 access points/mile, accidents are more likely to occur. However, this conclusion should not be taken as a necessary condition, taking into consideration the previous conclusion that access density may not be a necessary factor for the occurrence of accidents.

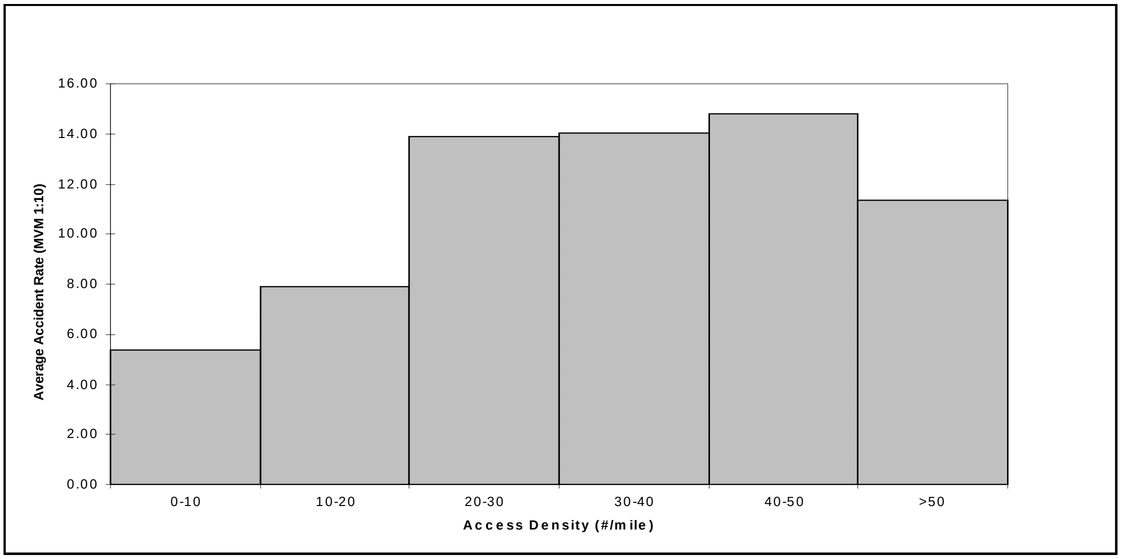

Figure 5. 9 Average Accident Rate (MVM 1:10) vs. Access Density (#/mile)

5.1.2 Comparision Study Results of Section and Intersection Accidents

5.1.2.1 Accident Analysis by Location

The percentage of section-accidents as part of the total number of accidents on all routes (Route 21,27, 28, 33, and 35) and the percentage of section-accidents per route are presented in Figures 5.10 and 5.11, respectively.

The above figures values indicate that the majority, about 70%, of the reported accidents occurred at signalized intersections, and only about 30% of the accidents occurred between intersections. The section accidents could be caused either by vehicles entering or exiting mid-block access points or by vehicles passing through the road segment. The number of accidents occurred in the vicinity of access points can only be identified with the help of access location information, which is addressed later in section 5.1.2.3.

5.1.2.2 Accident Analysis by Collision Type

A comparison of section-accidents and intersection-accidents was conducted based on collision type, which include same direction rear collision (SAME DIR-REAR), same direction side collision (SAME DIR-SIDE), left turn collision (LEFT TURN), collision with objects (OBJ), overturn (OVERTURN), strike parking vehicles (STR PK VEH), collision with pedestrians (PEDEST), angle collision (ANGLE), head-on collision (HEAD-ON), and other collisions (OTHER). The corresponding percentages of these types of collisions are summarized in Table 5-1 and in Figures 5.12 to 5.20.

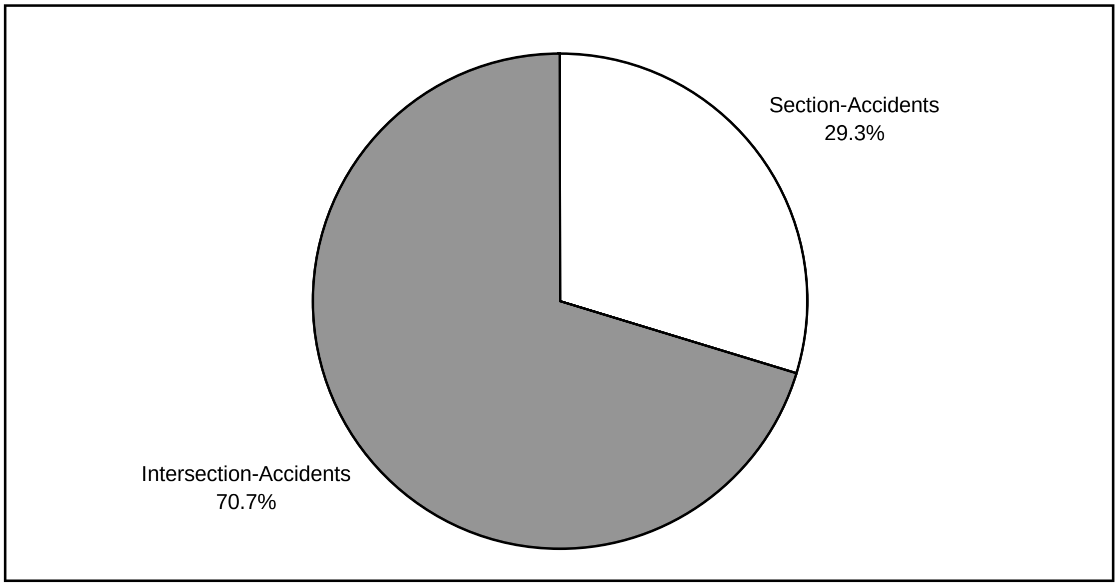

Figure 5. 10 Percentage of Section-Accidents as Part of the Total Accidents of all Routes (Routes 21, 27, 28, 33 and 35); 1991-1994

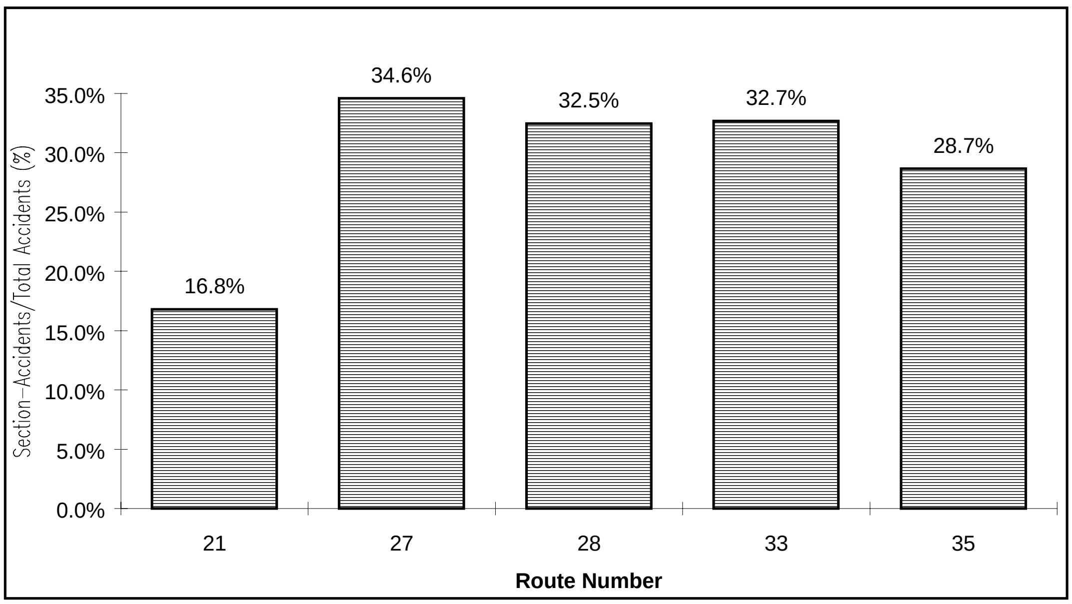

Figure 5. 11 Percentage of Section-Accidents (Section-Accidents/ Total accidents) vs. Route Number

Table 5-1. Accident Distribution by Collision Type

Route #	Collision Type	Section-accidents	Intersection-accidents	Total
21	SAME DIR-REAR	32.02%	32.35%	32.29%
	SAME DIR-SIDE	27.53%	16.46%	18.32%
	LEFT TURN	0.56%	6.81%	5.76%
	OBJ	22.47%	13.39%	14.92%
	OVERTURN	3.37%	0.34%	0.85%
	STR PK VEH	4.49%	2.04%	2.46%
	PEDEST	1.69%	2.84%	2.64%
	ANGLE	0.56%	14.64%	12.28%
	HEAD-ON	1.69%	2.95%	2.74%
	OTHER	5.62%	8.17%	7.74%
27	SAME DIR-REAR	36.52%	28.14%	31.04%
	SAME DIR-SIDE	14.93%	12.35%	13.24%
	LEFT TURN	10.58%	20.25%	16.90%
	OBJ	5.80%	4.75%	5.12%
	OVERTURN	0.29%	0.23%	0.25%
	STR PK VEH	7.83%	3.22%	4.81%
	PEDEST	2.46%	2.38%	2.41%
	ANGLE	15.22%	22.24%	19.81%
	HEAD-ON	2.61%	2.99%	2.86%
	OTHER	3.77%	3.45%	3.56%
28	SAME DIR-REAR	32.86%	28.70%	30.05%
	SAME DIR-SIDE	15.13%	15.49%	15.37%
	LEFT TURN	4.73%	11.39%	9.22%
	OBJ	5.91%	4.33%	4.84%
	OVERTURN	0.24%	0.00%	0.08%
	STR PK VEH	18.44%	3.30%	8.22%
	PEDEST	4.49%	2.96%	3.46%
	ANGLE	12.06%	26.54%	21.83%
	HEAD-ON	3.55%	2.85%	3.07%
	OTHER	2.60%	4.44%	3.84%
33	SAME DIR-REAR	38.35%	33.04%	34.78%
	SAME DIR-SIDE	10.39%	14.61%	13.23%
	LEFT TURN	5.02%	15.13%	11.83%
	OBJ	9.68%	6.43%	7.49%
	OVERTURN	0.72%	0.17%	0.35%
	STR PK VEH	2.87%	1.91%	2.22%
	PEDEST	1.43%	0.35%	0.70%
	ANGLE	15.41%	23.13%	20.61%
	HEAD-ON	3.58%	2.43%	2.81%
	OTHER	12.54%	2.78%	5.97%
35	SAME DIR-REAR	39.74%	39.40%	39.50%
	SAME DIR-SIDE	18.48%	17.67%	17.90%
	LEFT TURN	3.52%	9.84%	8.03%
	OBJ	13.64%	6.60%	8.61%
	OVERTURN	0.29%	0.12%	0.17%
	STR PK VEH	3.52%	0.88%	1.64%
	PEDEST	2.20%	1.35%	1.60%
	ANGLE	11.44%	19.91%	17.48%
	HEAD-ON	3.37%	1.65%	2.14%
	OTHER	3.81%	2.59%	2.94%

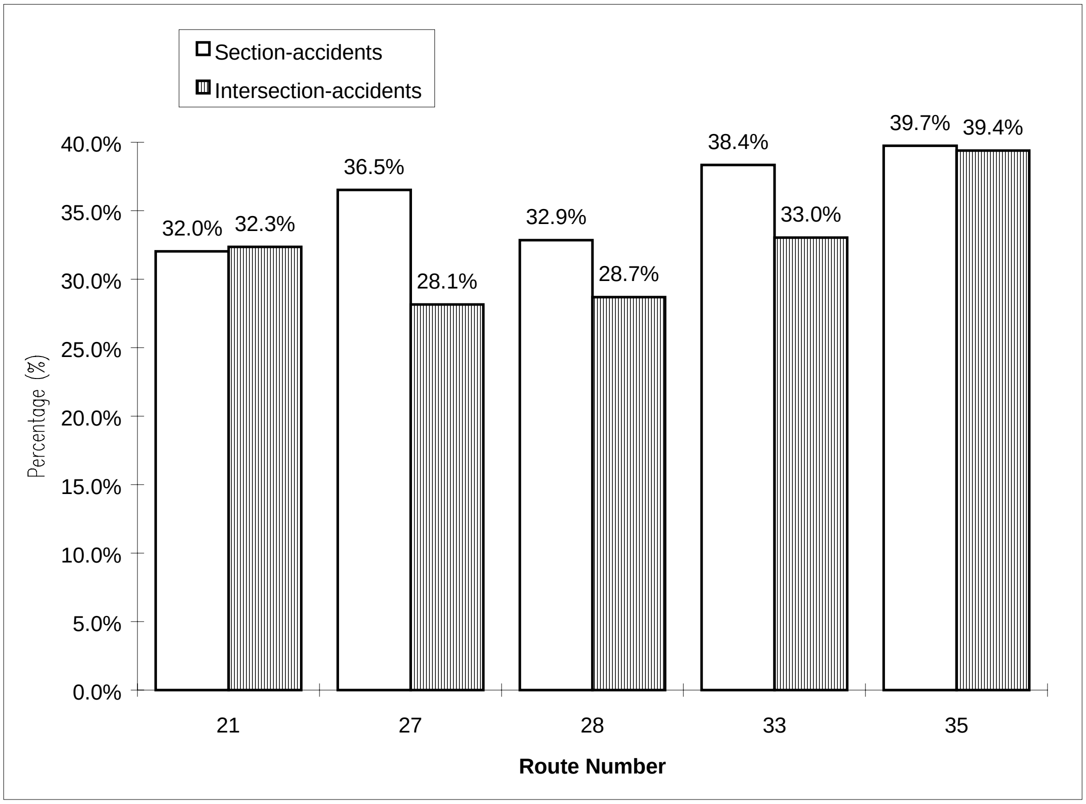

Figure 5. 12 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Same Direction Rear)

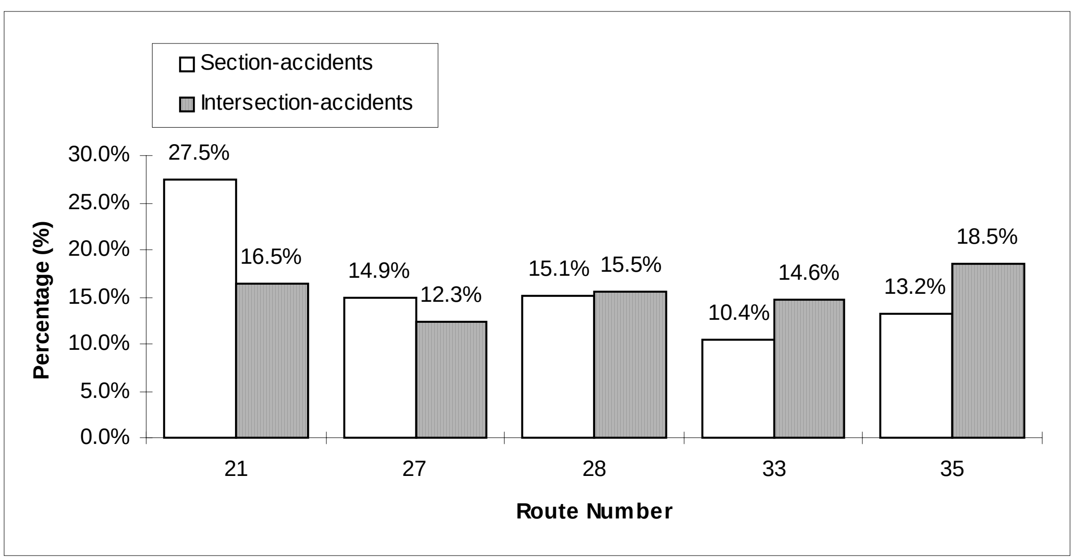

Figure 5. 13 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Same Direction Side Collision)

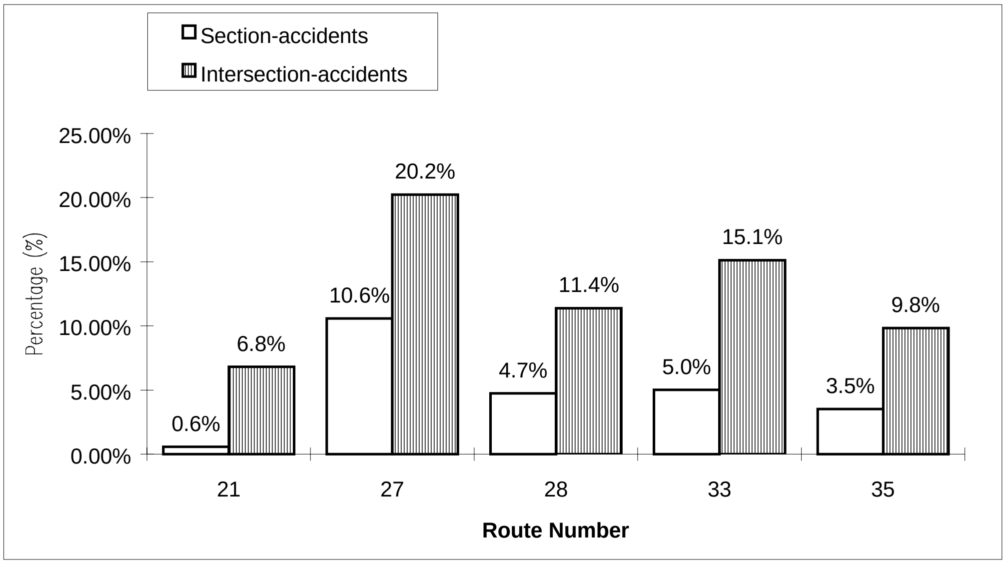

Figure 5. 14 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Left-turn Collision)

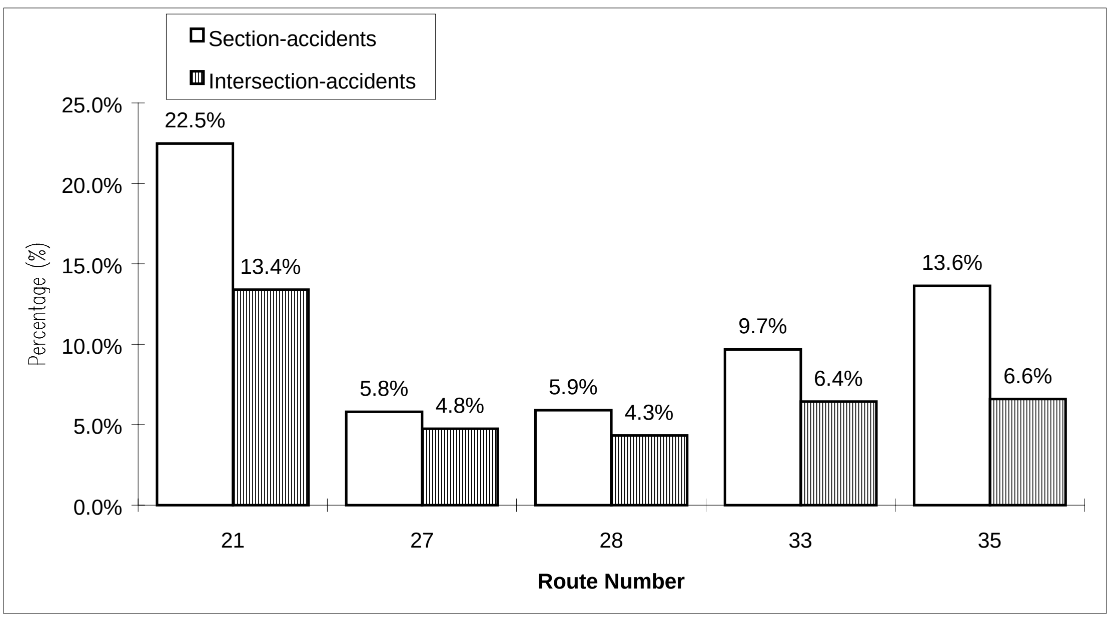

Figure 5. 15 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Collisions with Objects)

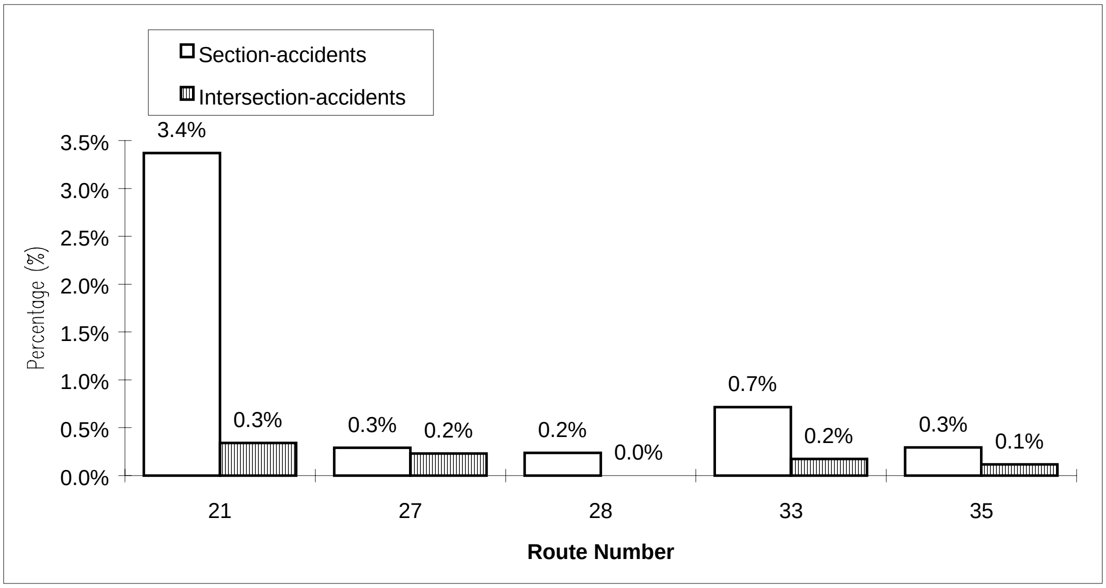

Figure 5. 16 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Overturn Collision)

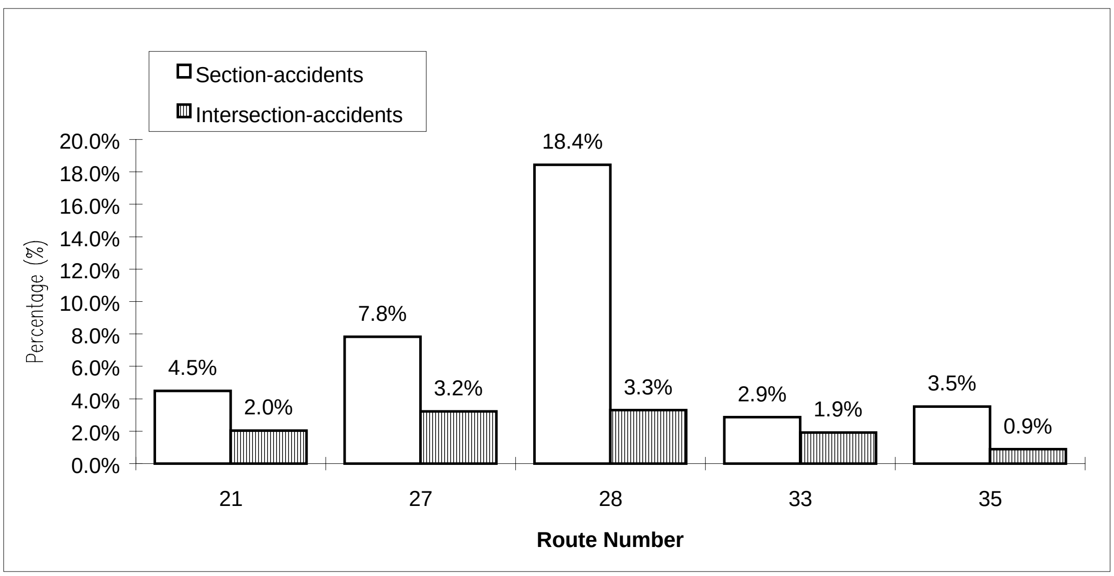

Figure 5. 17 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Strike Parking Vehicle Collision)

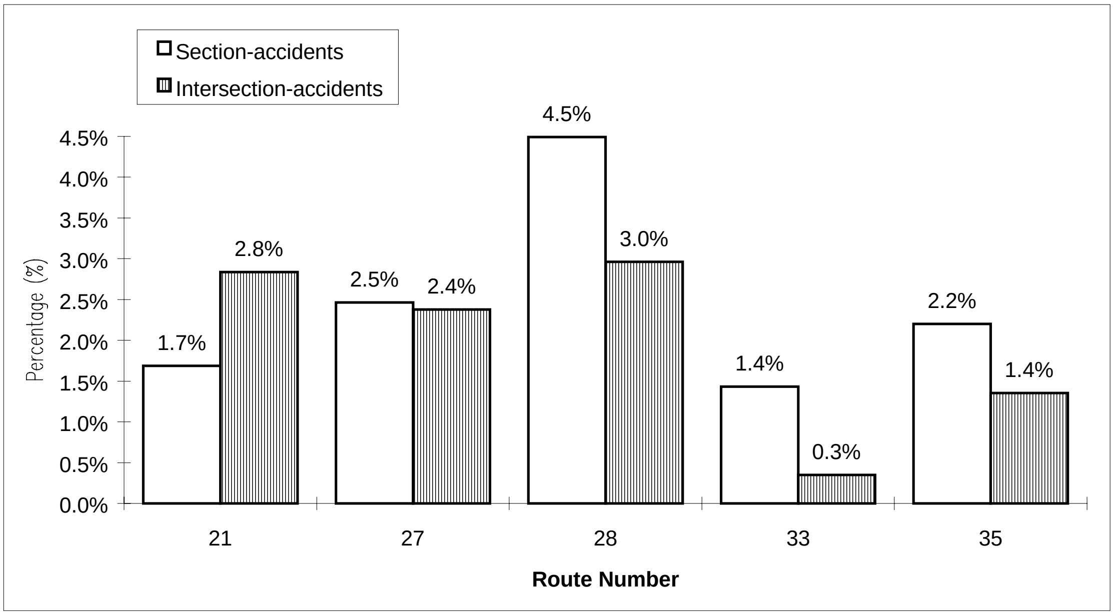

Figure 5. 18 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Pedestrian Collision)

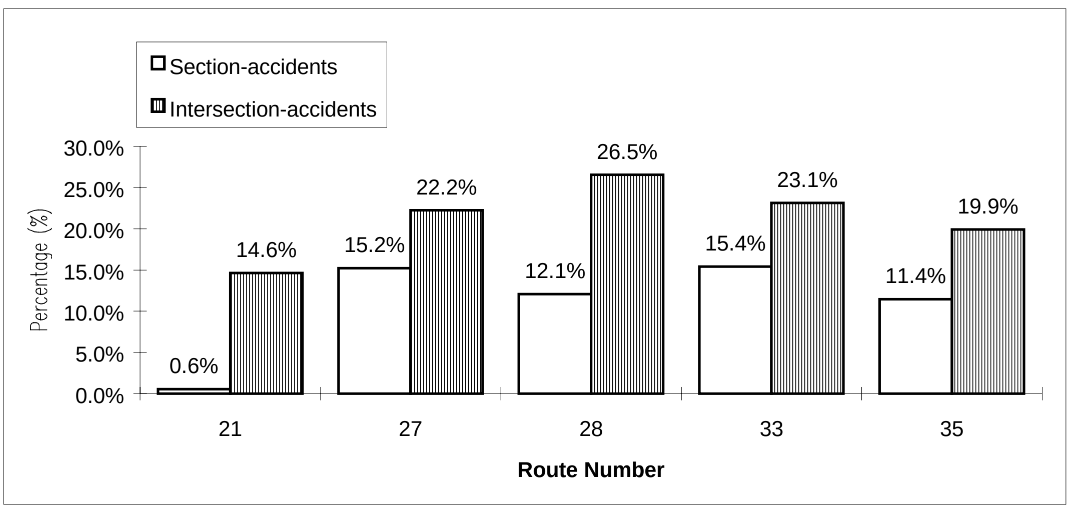

Figure 5. 19 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Angle Collision)

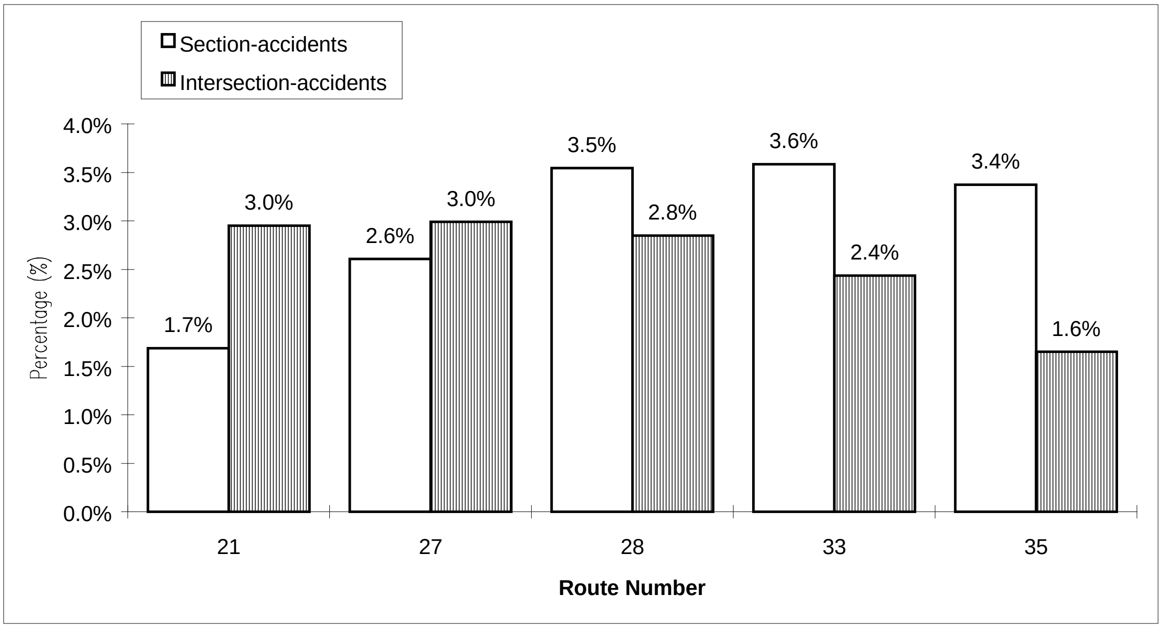

Figure 5. 20 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Head-on Collision)

The percentages of left turn collisions and angle collisions of intersection-accidents are higher that the corresponding percentages reported for section-accidents (See Figures 5.14 and 5.19, respectively). This may be attributed to the relatively larger left turning traffic volumes observed at signalized intersections in comparison to those observed between intersections.

The percentages of collisions with objects, over turns and strike parking vehicles in intersection-accidents are lower than those in section-accidents (see Figures 5.15 to 5.17). This may be attributed to the following reasons:

- Collision with object accidents: The concentration of drivers rises as they approach a signalized intersection that may explain the lower percentage observed. The concentration of the drivers as they drive between intersections may be reduced due to the presence of various distractions such as pedestrians, restaurants, gas stations, etc.
- Strike parking vehicle accidents: Driver inattention on vehicles engaged in parking maneuvers, in combination with insufficient spacing between the leading and the following vehicles, are the primary causes of these types of accidents. The expected alert increase of drivers at the vicinity of signalized intersections may explain the relative lower accident percentages observed (see Figure 5.17).

For head-on collision accidents, the results are mixed for different routes. The occurrence of these accidents may be attributed to driver carelessness, entering into the lanes of the opposing traffic.

For collisions with pedestrians, signalized intersection accidents exhibit lower accident percentages, except for Route 21. The occurrence of this type of accidents at signalized intersections may be attributed to either drivers or pedestrians or both. However, for accidents occurring between intersections, they may primarily be attributed to pedestrians trying to cross the highway or arterial.

5.1.2.3 Accident Analysis by Vehicle Action

Comparisons of section-accidents and intersection-accidents by vehicle actions are presented in this section. In MACLSTRT-2, vehicle actions are classified into right-turn, left-turn, going straight, changing lanes, merging, backing, and others. In this study, only left-turn and right-turn actions were taken into consideration. As long as any one of the two vehicles was in left-turn or right-turn actions, the accident was considered as a left-turn accident or a right-turn accident, respectively. The results are presented in Figures 5.21 to 5.23.

The percentages of section-accidents attributed to left-turning vehicles range from 14% to 25%, while for intersection-accidents the percentages range from 24% to 38%. The percentages of section-accidents attributed to right-turning vehicles range from 5% to 8%, while the percentages of intersection-accidents range from 8% to 11 %. Route 21 was not taken into consideration due to the small sample size. The percentages of accidents attributed to both left-turning and right-turning vehicles in intersection-accidents are relatively higher than those in section-accidents.

Because section-accidents attributed to turning vehicles were directly related to the maneuvering to and from access points, it was important to investigate how many accidents were caused by turning vehicles, either left turning or right turning (see Figure 5-23).

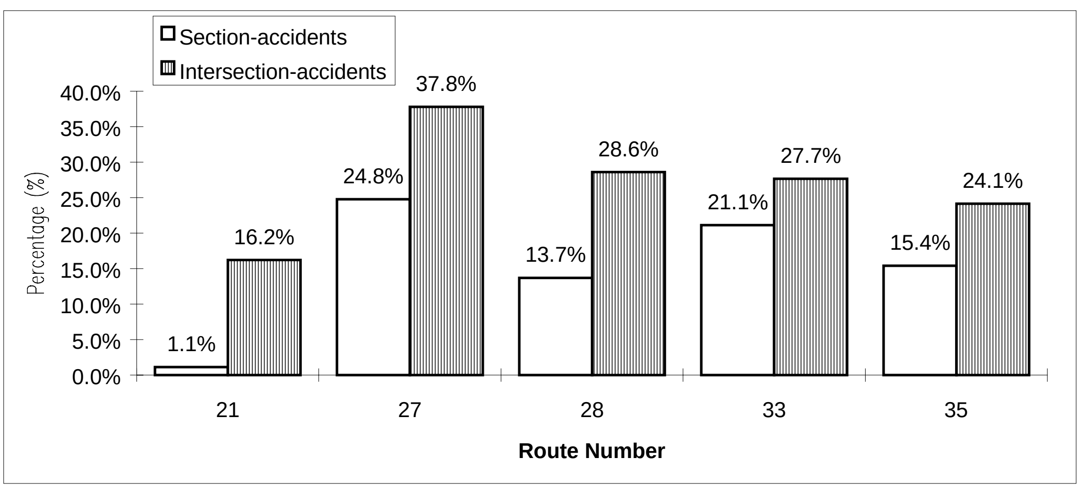

Figure 5. 21 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Left-turn Accidents)

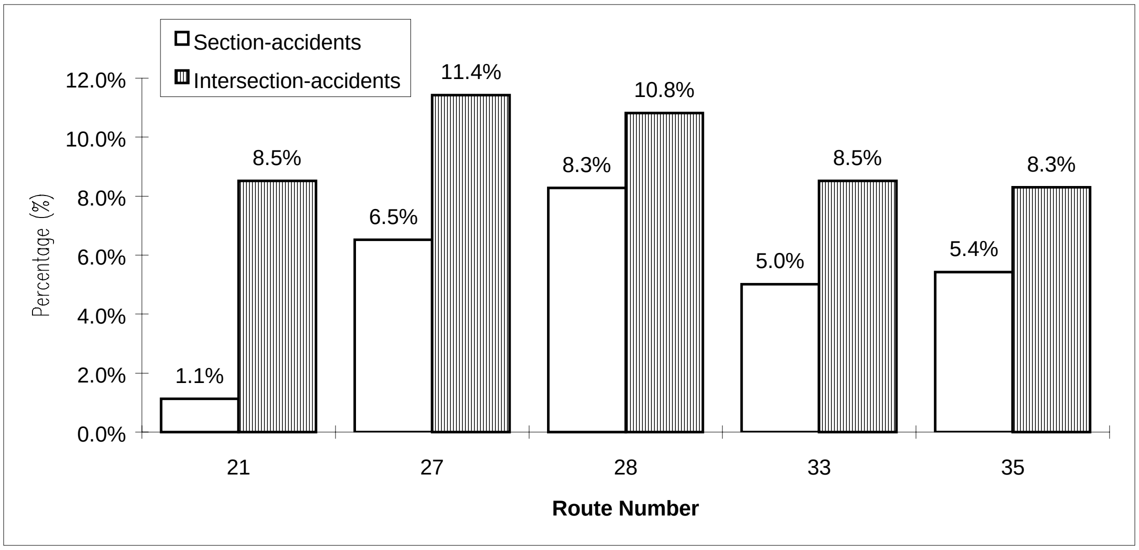

Figure 5. 22 Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number (Right-turn Accidents)

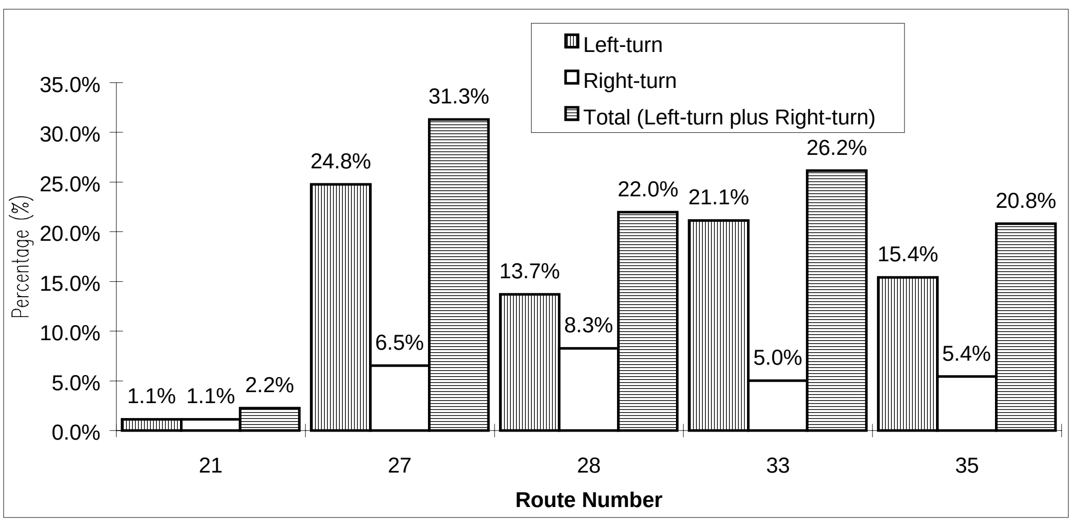

Figure 5. 23 Percentage of Section-Accidents Caused by Turning Vehicles vs. Route Number

The percentage of section-accidents attributed to turning vehicles entering or exiting access points ranges between 21% and 31%, with the exclusion of Route 21. Given that for the specific study routes, about 30% of all reported accidents were section-accidents, it can be concluded that approximately 7% of the accidents were due to access points, involving vehicles turning to/from access points.

5.1.2.4 Section-Accident Analysis by Turning Action

In this section, section-accidents attributed to turning vehicles are analyzed according to the movement of the vehicles involved as follows: Left turn related accidents are divided into subgroups of going through plus left-turn, parked plus left-turn, stopped plus left-turn, right-turn plus left-turn, and others. Right turn related accidents are divided in a similar manner. The results are summarized in Figures 5.24 and 5.25 for the left-turn and right-turn accidents, respectively.

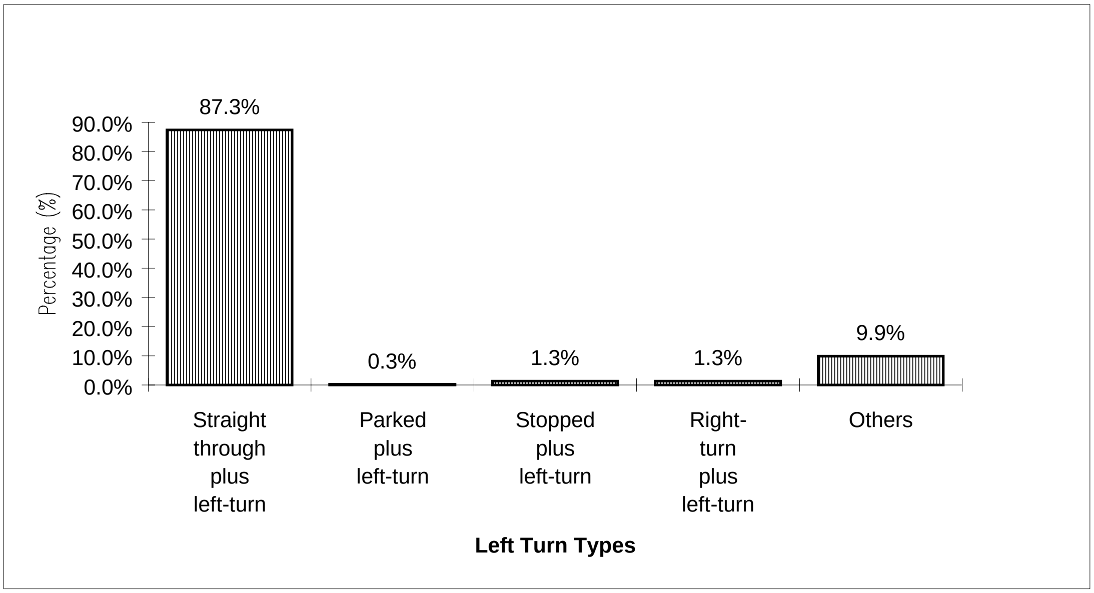

Figure 5. 24 Left-turn Section-Accidents Percentage by Collision Type

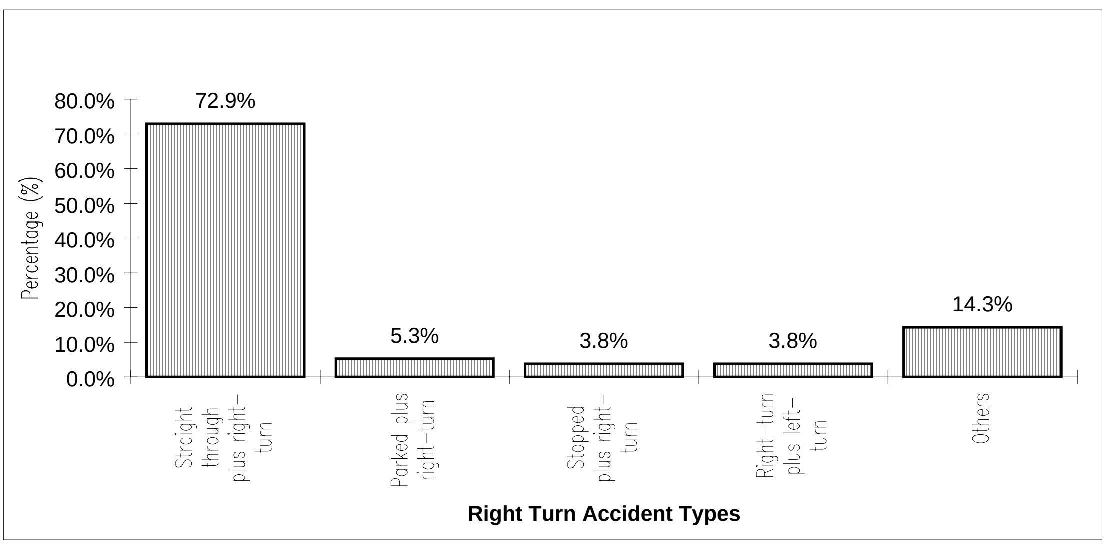

Figure 5. 25 Right-turn Section-Accident Percentage by Collision Type

Figures 5.24 and 5.25 indicate that the majority of section-accidents involved with turning vehicles are attributed to a straight through vehicle (on the main road) and a turning vehicle which could be either entering or exiting an access point. The accident percentages are 88% and 73% for left-turn and right-turn related accidents, respectively.

5.1.2.5 Accident Analysis by Vehicle Contribution Circumstance

In MACLSTRT-2, vehicle contribution circumstances were divided into improper turning, driving inattention, following too close, unsafe speed, improper parking, improper lane changing, improper passing, and the type of others. The corresponding accident distribution of vehicle contribution circumstances is presented in Figure 5.26.

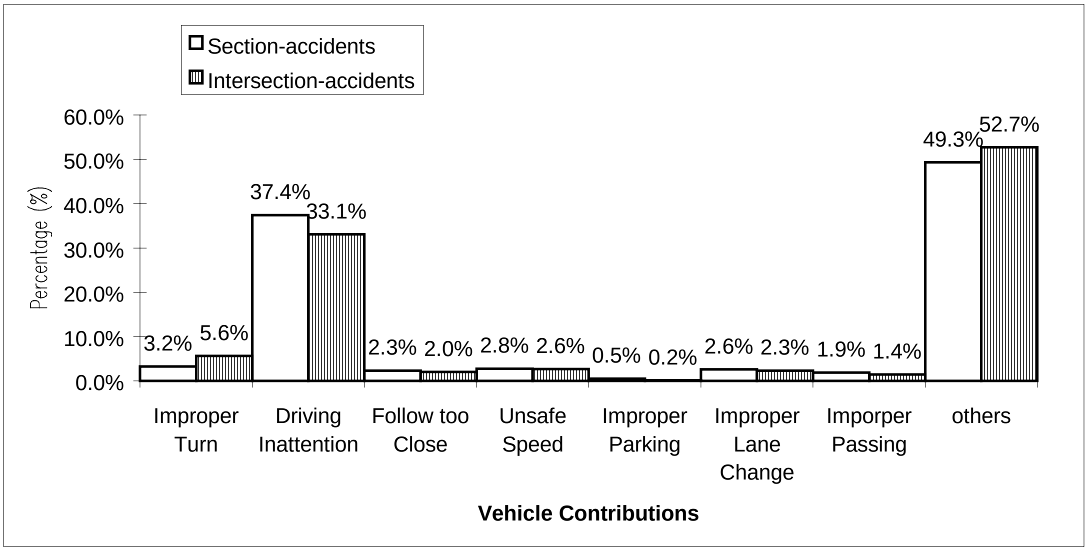

Figure 5. 26 Percentage of Section-Accidents (%) and Intersection-Accidents (%) by Vehicle Contribution Circumstances

5.1.2.6 Accident Analysis by Weather Condition

The weather conditions were classified into three groups: clear, rain, and snow. In this section a comparison of the impact of weather conditions on section-accidents and intersection-accidents was conducted by calculating the percentage of accidents under different weather conditions for each route. The results are summarized in Figures 5.27 to 5.29.

As seen from Figures 5.27 and 5.28, clear and rain weather conditions did not demonstrate significantly different impact on section-accidents and intersection-accidents. However, as shown in Figure 5.29, under snow weather the percentages of section accidents are consistently higher for all routes than the corresponding percentages of intersection accidents.

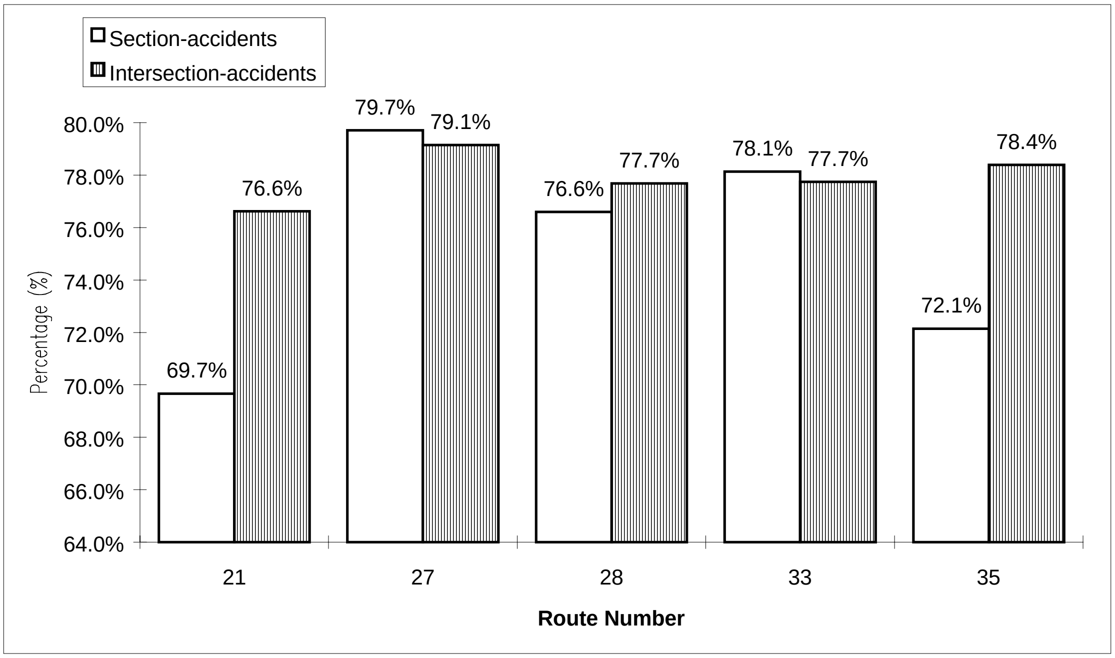

Figure 5. 27 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Clear Weather Conditions

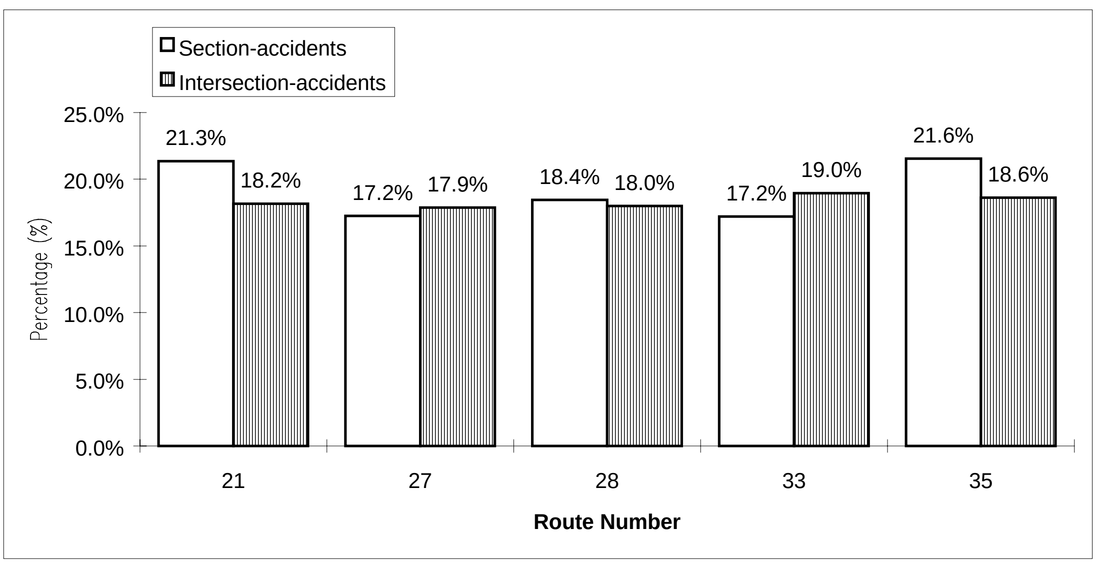

Figure 5. 28 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Rain Weather Conditions

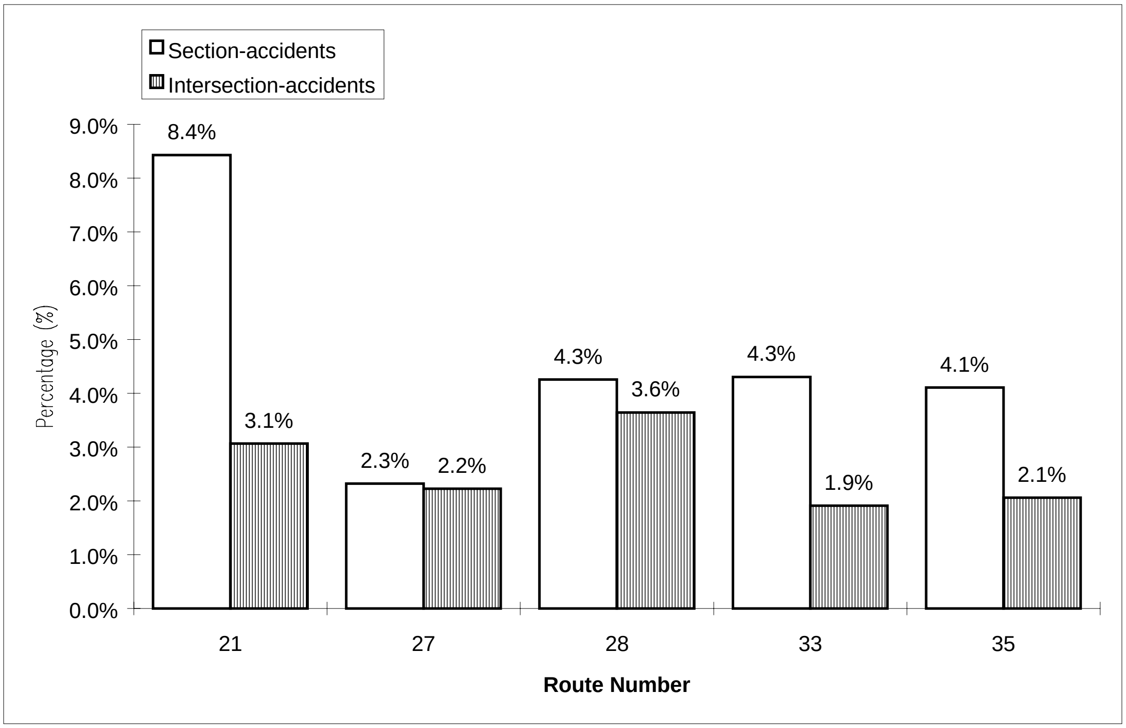

Figure 5. 29 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Snow Weather Conditions

5.1.2.7 Accident Analysis by Surface Condition

Another very important contributing factor to highway accidents is the condition of the surface of the pavement. Surface conditions are closely related to weather conditions, although they are not identical, as they may last for several days beyond the duration of the specific weather conditions. Based on the information in MACLSTRT-2, surface conditions were grouped into dry, wet, snow and ice. This classification parallels the classification of weather conditions, namely, clear, rain, and snow, respectively, where snow and ice are grouped into one category. The accident percetages for both section-accidents and intersection-accidents are presented in Figures 5.30, 5.31 and 5.32, for dry, wet, snow and ice pavement surface conditions, respectively.

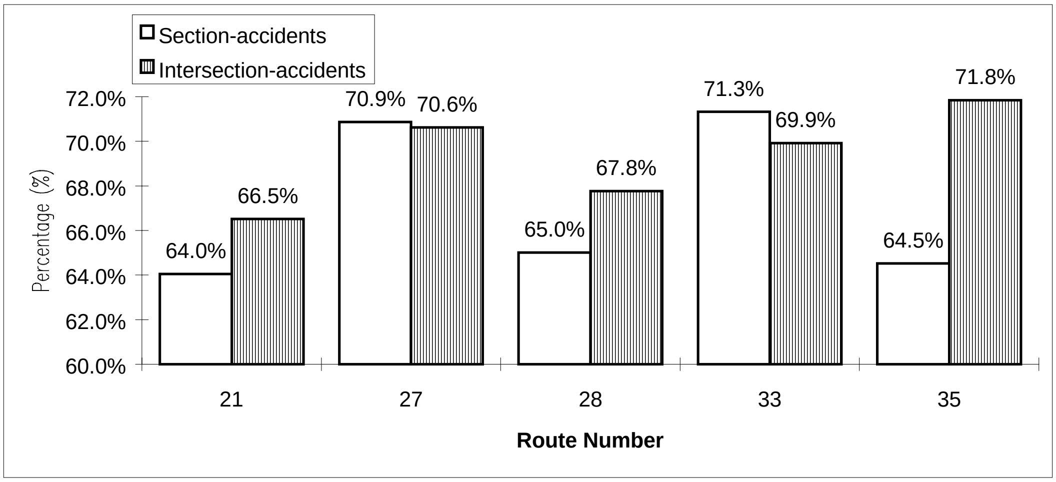

Figure 5. 30 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Dry Pavement Surface Conditions

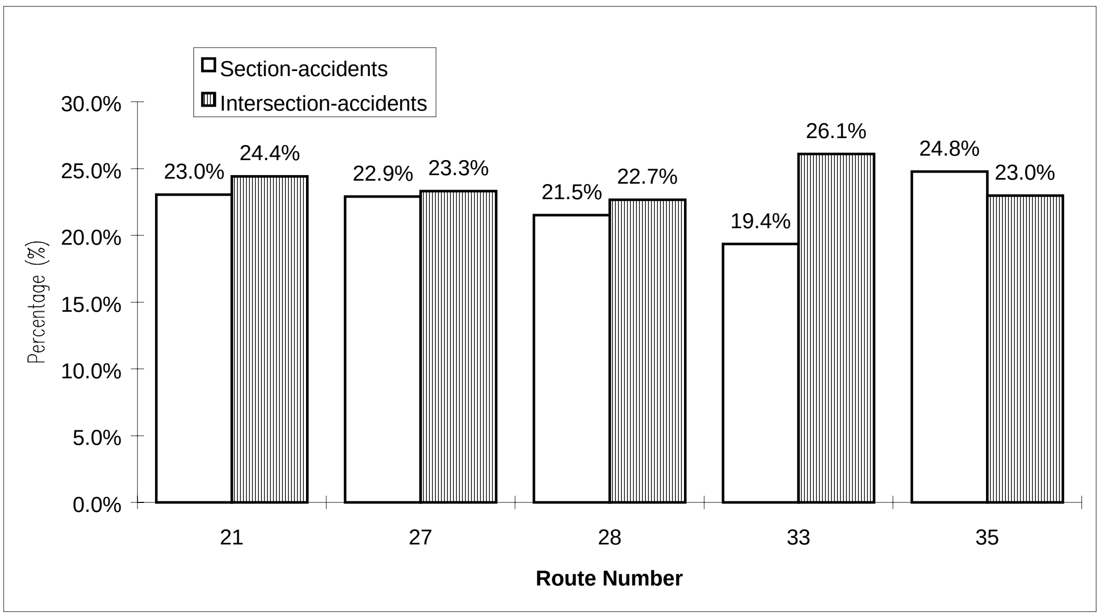

Figure 5. 31 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Wet Pavement Surface Conditions

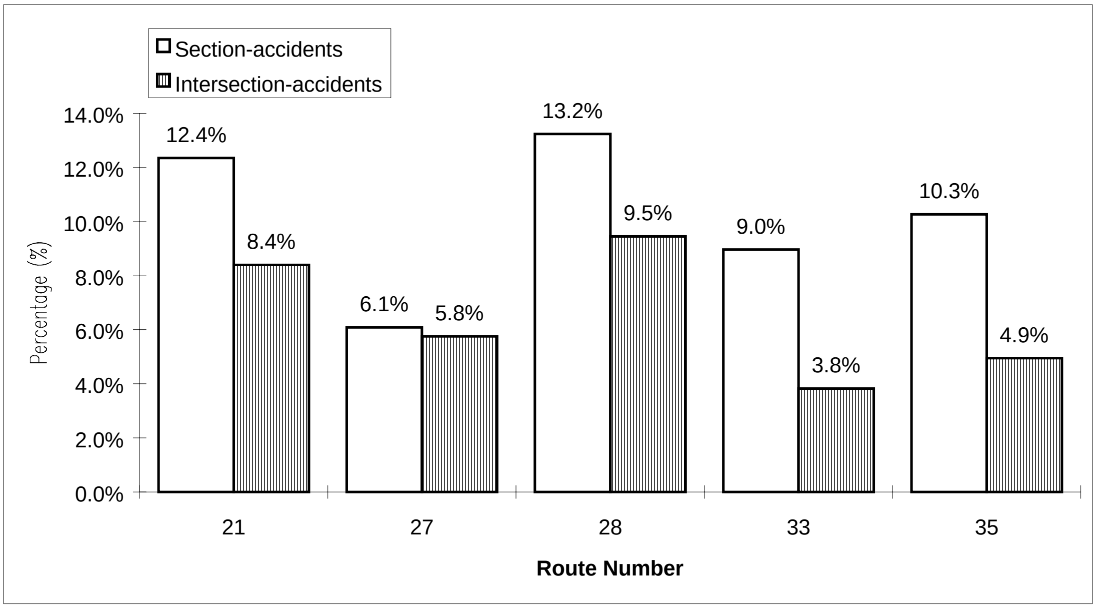

Figure 5. 32 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Snow and Ice Pavement Surface Conditions

The results for the accidents reported under dry surface conditions (Figure 5.30) show no significant difference between section-accidents and intersection-accidents. Under wet surface conditions (Figure 5.31), the percentages of intersection-accidents are slightly higher than the percentages of section-accidents, except for route 35. However, under snow and ice surface conditions (Figure 5.32), the accident percentages of section-accidents are consistently higher than the percentages of intersection-accidents on all routes. The results of the surface condition analysis are consistent with those of weather condition analysis.

5.1.2.8 Accident Analysis by Light Condition

Light conditions were divided into DAY, DARK, and DNDK (Dawn plus Daybreak). The percentages of section-accidents and intersection-accidents occurred under different light conditions are presented in Figures 5.33, 5.34, and 5.35, respectively.
As seen from Figures 5.33, 5.34, and 5.35, over 70%, of the accidents occurred under day light conditions, with the exception of Route 21 that is not typical because of its small sample size. The percentages of accidents occurred under dark light conditions range between 20% and 30%. Day light and dark light conditions did not show any significant different impact between section-accidents and intersection-accidents.

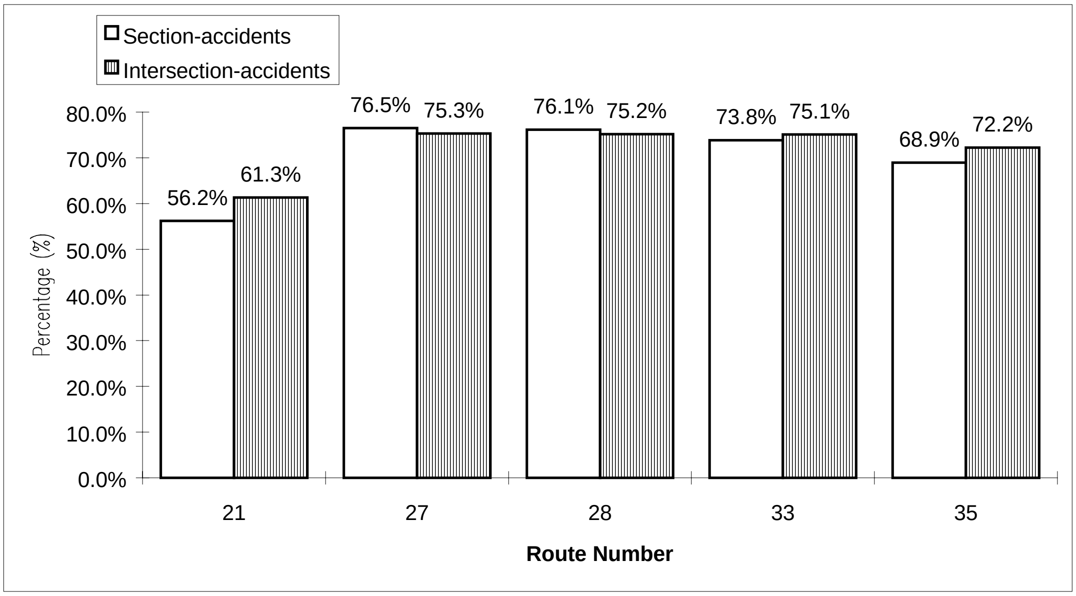

Figure 5. 33 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Daytime Conditions

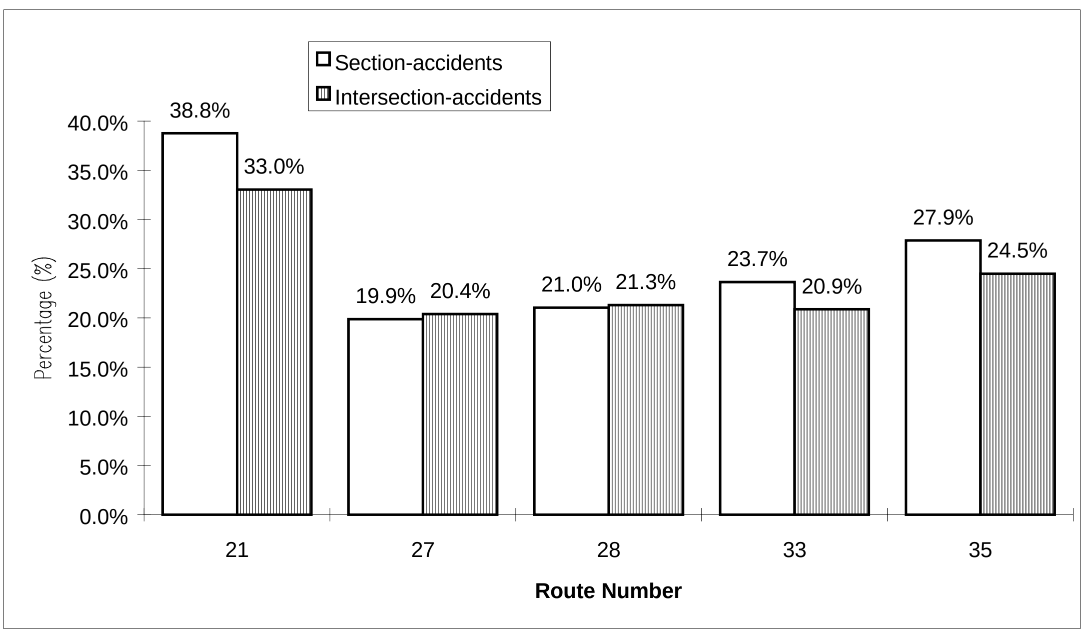

Figure 5. 34 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Dark Conditions

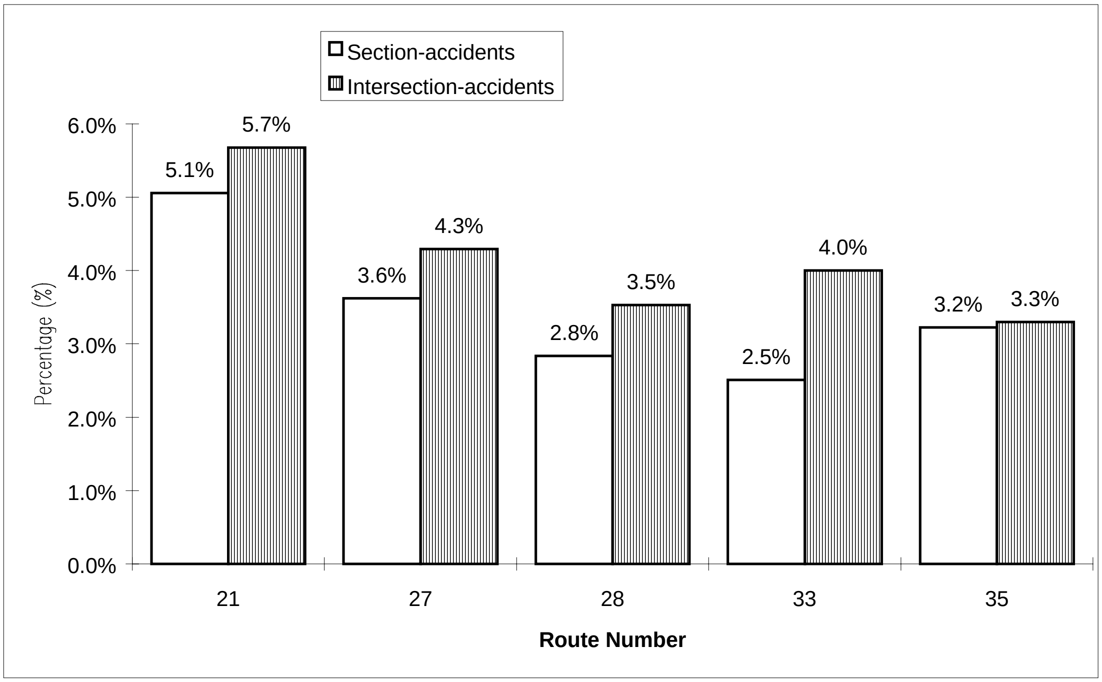

Figure 5. 35 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Dawn and Daybreak (DNDK) Conditions

5.1.2.9 Accident Variations by Month, Day of Week, and Hour

In this section, accidents were analyzed by month, day of week, and hour. The corresponding results are presented in Figures 5.36 to 5.39.

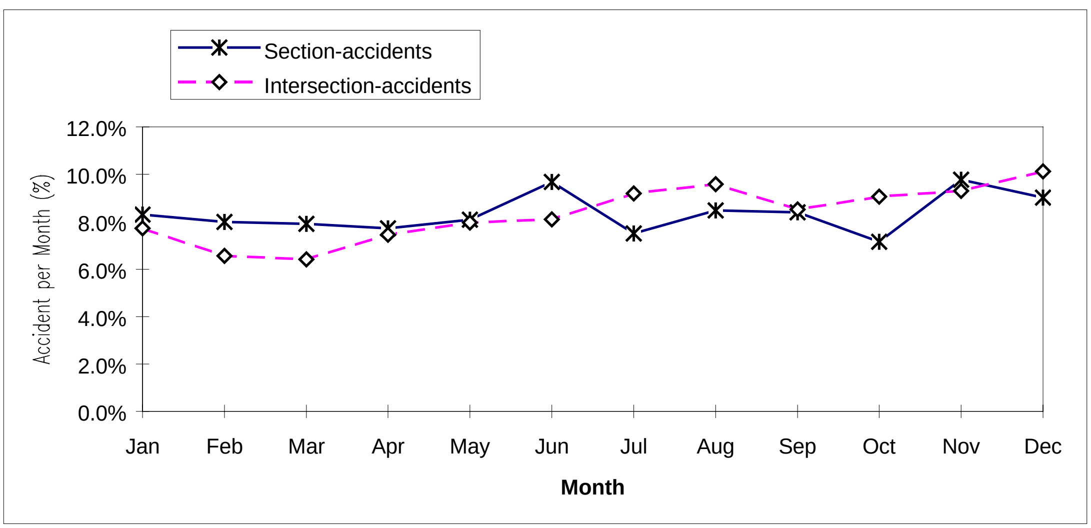

Figure 5. 36 Accident Percentage for all Routes vs. Month

The intersection-accidents exhibit a monthly accident percentage range between 6.4% to 10.1%, while the corresponding one for section-accidents ranges from 7.1% to 9.7%. It is noted that, for the first half of a year, the monthly percentages of intersection-accidents were lower than those of section-accidents, while for the second half of the year, the trend was the opposite.

The accident analysis by day of the week was divided into two categories, weekdays and weekends. The results for both section-accidents and intersection-accidents occurred on weekdays and weekends are presented in Figures 5.37 and 5.38, respectively.

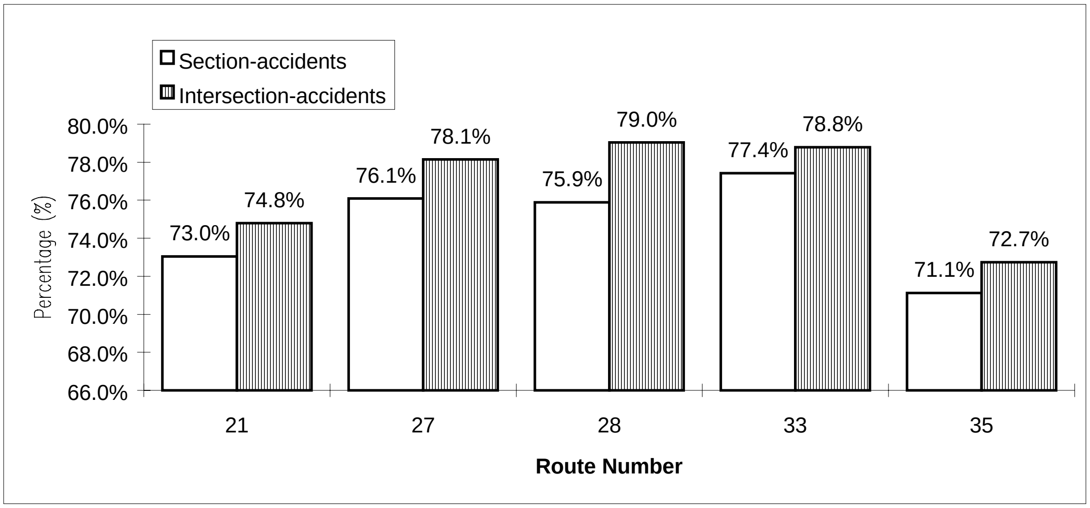

Figure 5. 37 Percentage of Section-Accidents (%) and Intersection-Accidents (%) on Weekdays vs. Route Number

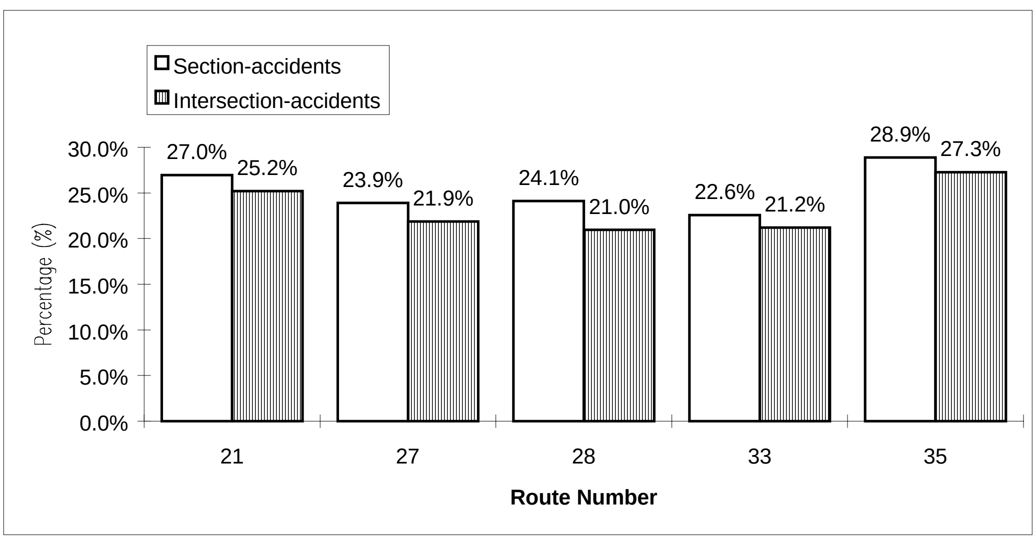

Figure 5. 38 Percentage of Section-Accidents (%) and Intersection-Accidents (%) on Weekends vs. Route Number

As observed in Figure 5.37, the percentages of the weekday section-accidents range from 71% to 77%, while for intersection-accidents the range is slightly higher, 73% to 79%. The distribution of accidents on weekends shows an opposite pattern, the percentages of weekend section-accidents are higher than the corresponding intersection-accidents.

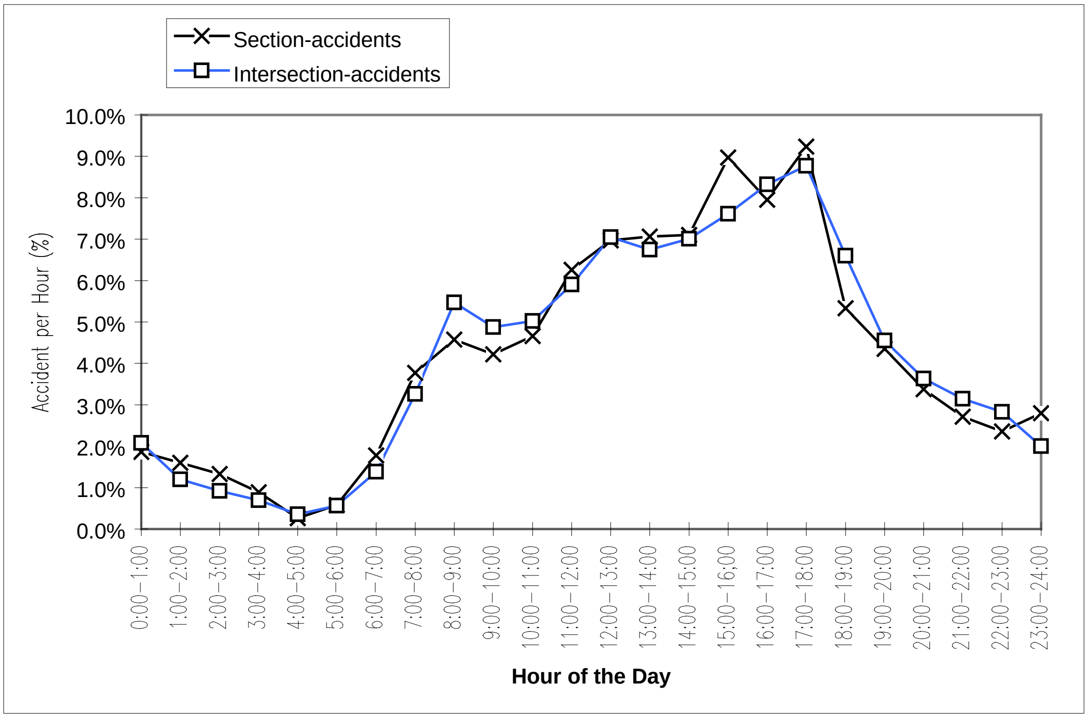

Figure 5. 39 Accident Percentage (%) versus Hour of the Day

The hourly distribution patterns of section-accidents and intersection-accidents are very similar. The lowest accident rate occurred between 4:00am to 5:00am, and then it started to climb continuously. Between 5:00pm to 6:00pm, the accident rate reached its peak, and then started to decline until the period of 4:00am to 5:00am. The high accident rates observed during the period of 3:00pm to 6:00pm were consistent with the afternoon peak traffic. The morning peak hour (for most routes, it is in the period of 7:00am to 11:00am), exhibited lower accident rates than the evening peak. The period of the least occurrence of accidents was the early morning from 4:00am to 6:00am.

5.1.3 General Accident Analysis

In this section, we present the analysis conducted to identify the impact of geometric and traffic flow factors, such as number of lanes, shoulder, median, speed limit and AADT, on traffic accidents.

5.1.3.1 Number of Lanes

The study sections either had two lanes or four lanes. The corresponding average accident rates and the variances for two-lane and four-lane highways are shown in Table 5-2.

Table 5-2. Comparison between Two-lane and Four-lane Highway Accident Rates

Highway type	Road sections	Average accident rate	
		(MVM 1:10)	Variance
Two-lane	115	13.13	153.82
Four-lane	85	9.13	72.20

Although, the average accident rate on 2-lane highways tend to be higher than that on 4-lane highways, no conclusion could be made before formal statistical tests, because the variances were very large relative to the corresponding means. This result indicates that other factors also contribute to accidents than the number of lanes.

5.1.3.2 Shoulder

Shoulders provide good sight distance for both mainline traffic and entering/exiting traffic at access points. Additionally, they are used as deceleration/acceleration lanes for vehicles entering or exiting to/from access points. The average accident rates and variances by shoulder type are summarized in Table 5-3. The average accident rates for two-lane highway sections without shoulders exhibit higher percentage than the sections with shoulders. For 4-lane highways, the reverse is true. Again, because of the large variances exhibited in all four categories, other factors should be included in the analysis, which would further reduce the variance.

Table 5-3. Comparison between Highways with Shoulders and Highways without Shoulders on Accident Rates

Highway type	Road sections	Average accident rate	
		(MVM 1:10)	Variance
2-lane with shoulder	71	11.22	123.92
2-lane without shoulder	44	16.22	190.32
4-lane with shoulder	48	9.60	90.78
4-lane without shoulder	37	8.58	50.68

5.1.3.3 Median

The median separates the opposing traffic streams and reduces access from the mainline to the access points, and from access points to the mainline. In this study, there are 27 road sections with median and 58 sections without median. Virtually all 2-lane highway sections in this study were without median. Consequently, only 4-lane highway sections were considered for this analysis. The average accident rates and variances are summarized in Table 5-4. Similarly, the variances of both categories are very large to produce any meaningful comparison.

Table 5-4. Access Density and Accident Rate on Four-lane Highways with/without Median

Highway type	Road sections	Average accident rate	
		(MVM 1:10)	Variance
Four-lane with median	27	19.48	198.35
Four-lane without median	58	11.06	61.58

5.1.3.4 Speed Limit

The speed limit of the NJ State highways studied ranges from 25 mile per hour to 55 mile per hour. Table 5-5 shows the number of road sections, average accident rates and variances computed for each speed limit. Average accident rate starts at a very low level at speed limit 25 mi/h, it reaches its peak at 35 mi/h, and then begins to decline again, at 55 mi/h, it hits another low level. The most "dangerous" speed limit is within the range of 30-40 mi/h, however no formal conclusions can be made based solely on these results. It is noted that a more important variable than the speed limit would have been the distribution of the speeds on each of these sections. However, it was not possible to obtain these data for this analysis. In the future, it would be advisable that several sections of the highways be monitored on a 24-hour basis throughout the year, to obtain the impact of the speed distribution on accidents.

Table 5-5. Average Accident Rate by Speed Limit

Speed Limit (mile/hour)	Road sections	Average accident rate (MVM 1:10)	Variance
25	6	1.25	7.10
30	18	13.01	178.43
35	49	15.33	145.75
40	34	13.77	73.05
45	29	7.04	44.72
50	36	8.29	67.96
55	18	2.83	3.25

5.1.3.5 Traffic Volume

All road sections were grouped into 9 categories based on AADT in intervals of 2000 vehicles per day. The average accident rates and variances are presented in Table 5-6. No clear trends between AADT and average accident rate could be found from Table 5-6.

Table 5-6. Comparison of Access Density and Accident Rate by AADT

AADT (vpd)	Road Sections	Average Accident Rate (MVM 1:10)	Variance
0-10000	14	32.75	174.26
10000-12000	15	10.67	171.28
12000-14000	25	8.88	54.93
14000-16000	34	13.42	117.23
16000-18000	23	12.55	112.00
18000-20000	24	9.19	40.92
20000-22000	27	11.11	106.60
22000-24000	6	3.30	4.98
24000-26000	12	7.80	49.05
>26000	20	7.21	35.29

5.2 Statistical Analysis Results

5.2.1 Distribution Patterns of Accident Rates

The first step of the statistical analysis was to identify whether the accident data were normally distributed. Distribution tests were conducted using normality plot for all data, and data grouped by AADT, access density, median, number of lanes, shoulder, speed limit and intersection spacing.

5.2.1.1 Normality Tests

Two normality plots are presented here as examples. Figure 5.40 is the normality plot of all data. Figures 5.41(a) and 5.41(b) show the normality plots for 2-lane and 4-lane accident data respectively.

As it can be observed from the above figures, the shape of the plots are not linear, so the accident rates are not normally distributed in these two cases. Normality tests were also conducted for accident data grouped by AADT, access density, median, shoulder, speed limit and intersection spacing. Test results can be found in Appendix 2. None of these plots show a linear pattern. The above facts lead to the conclusion that the accident rates are not normally distributed.

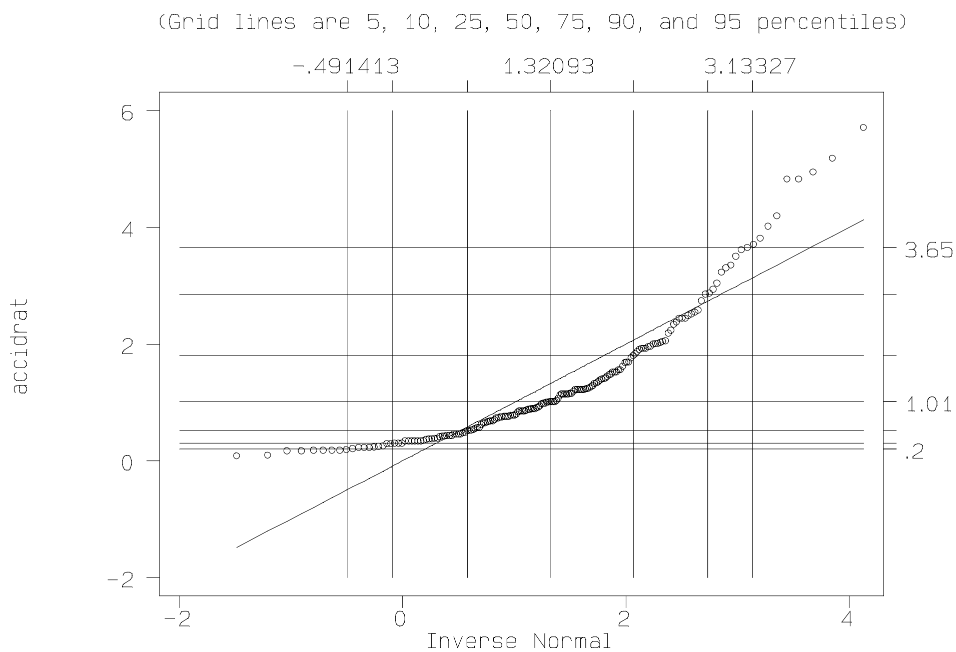

Figure 5.40. Normal plot of all accident rate data

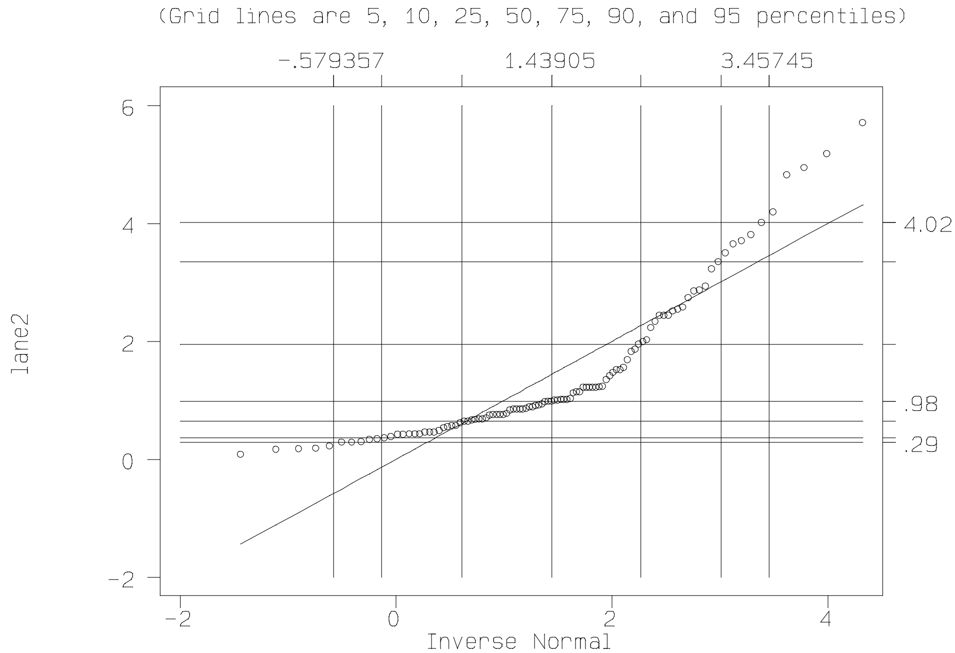

Figure 5.41(a). Normal plot of accident rate data on 2-lane highway

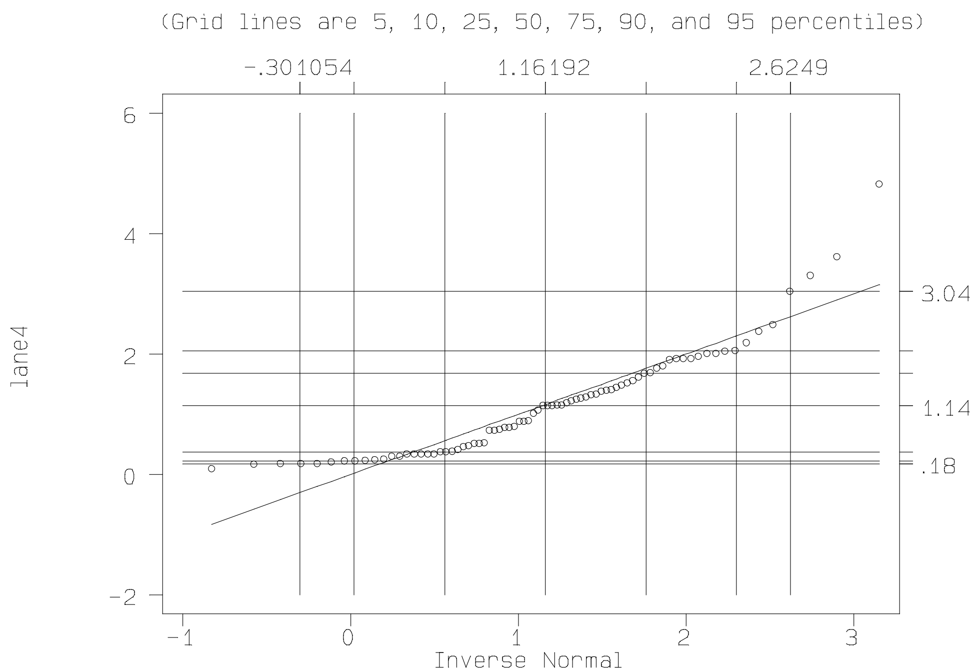

Figure 5.41(b). Normal plot of accident rate data on 4-lane highway

5.2.1.2. Lognormal Tests

In order to identify the shape of the accident rate distributions, dot plots of all data and data by subgroups were plotted. The dot plots of all accident rate data, and accident rate data of 2-lane and 4-lane highway sections are shown in Figures 5.42, 5.43(a) and 5.43(b), respectively, as examples.

```
:
         :
         :..
         ::::.
         ::::::
         ::::::
         ::::::
        .:::::::
        :::::::: :. .
        ::::::::::: :
        ::::::::::.: . . .     .
        :::::::::::::.:.:.:.:   :.  .
       -+---------+---------+---------+-  (183 obs.)
        0         2         4         6
```

Figure 5.42 Dot plot of all accident rate data

```
          .::
          :::
          :::.
         ::::::
         ::::::.    :
        :::::::: .  : .
        ::::::::.::::.: :.:.:   :.  .
       -+---------+---------+---------+-  (105 obs.)
        0         2         4         6
```

Figure 5.43(a) Dot plot of accident rate data of 2-lane highway

```
         :
         :
         :
         :
         :   ::
        .::. ::....
        :::::::::::
        :::::::::::..  .. .     .
       -+---------+---------+---------+-  (78 obs.)
        0         2         4         6
```

Figure 5.43(b) Dot plot of accident rate data of 4-lane highway

The shapes of these three plots are close to that of lognormal distributions. Dot plots of accident rates of the remaining subgroups demonstrated similar patterns. Dot plot results for all accident data can be found in Appendix 3.

To test lognormality, the logarithmic values of accident rates were calculated, and normality plots were plotted based on these logarithmic values. Figures 5.44, 5.45(a) and 5.45(b) are normality plots of logarithmic accident rates for all accident rate data and accident rate data of 2-lane and 4-lane highway segments, respectively.

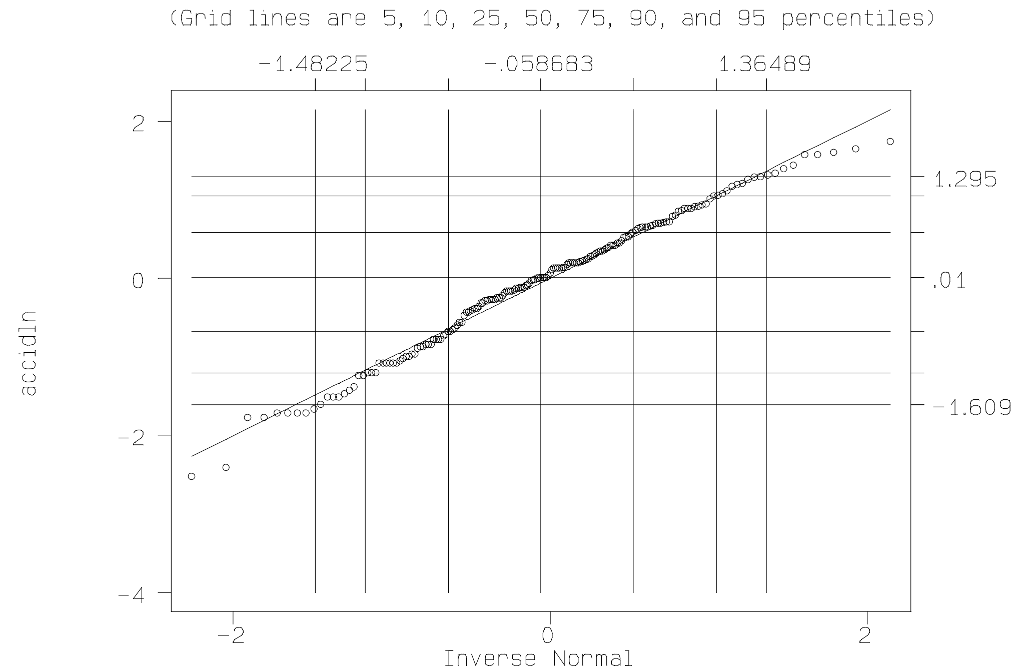

Figure 5.44 Normality plot of ln values of all accident rates

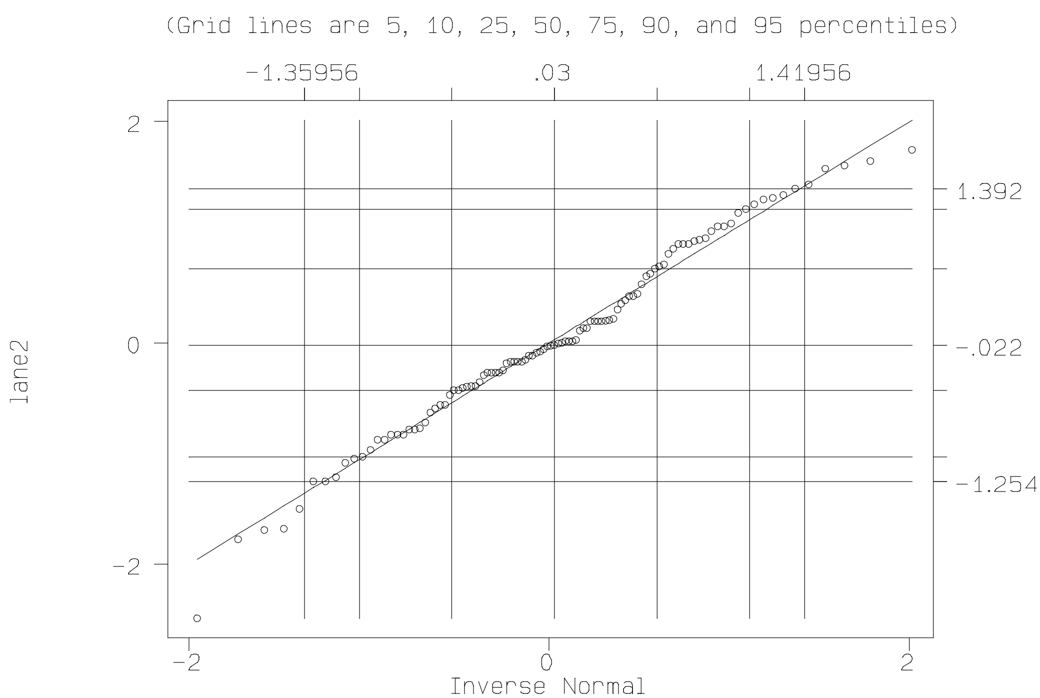

Figure 5.45(a) Normality plot of ln values of accident rate data of 2-lane highways

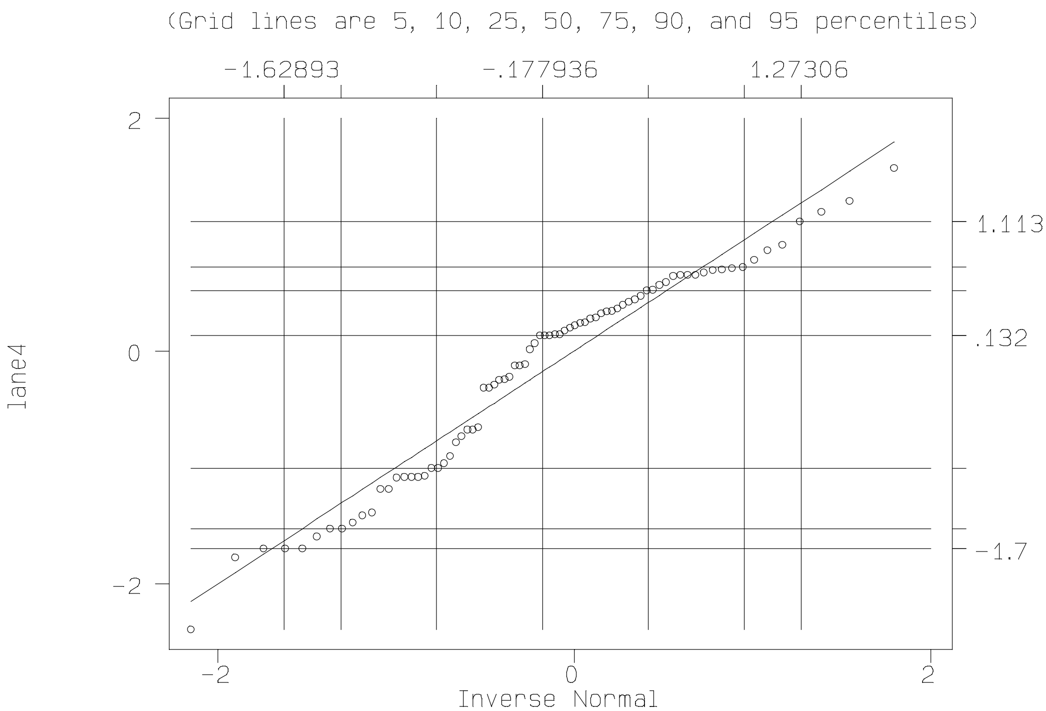

Figure 5.45(b) Normality plot of ln values of accident rate data of 4-lane highways

The shapes of these three normality plots show clear linear patterns. Normality plots of logarithmic accident rates for accident data grouped by AADT, access density, median, shoulder, speed limit and intersection spacing can be found in appendix 4, all of them showed similar linear patterns. This implies that accident rates are likely to be lognormally distributed.

5.2.1.3 Parameter Estimation

The probability density function of lognormally distributed accident rate data is formula (3) in chapter 3. Parameters, μ and δ are calculated using the corresponding logarithmic values of accident rates, and are summarized in Table 5-7.

5.2.2 Mean Equality Tests

The purpose of the mean equality tests is to identify the impact of single factors on accident rates. These factors include: AADT, access density, median, number of lanes, shoulder, speed limit, intersection spacing (2-lane highway) and intersection spacing (4-lane highway). Distribution-free mean equality test method Kruskal-Wallis test is chosen in this section. All the factors are further subgrouped as shown in Table 5-8. Means of each subgroup u_i are calculated. Kruskal-Wallis test is run to test if $H_0: \mu_1 = \mu_2 = \ldots = \mu_n$ holds for each factor. The test results are summarized in Table 5-8.

Table 5-7. Distribution Parameters

Factor	Subgroups	Observations	Mean of $\ln X$ (μ)	Standard Deviation of $\ln X$ (δ)
AADT	8000-10000	14	1.092571	.4734847
	10000-12000	10	.2084	.7570227
	12000-14000	31	-.2422258	.7356159
	14000-16000	24	-.0339583	.8595241
	16000-18000	28	.1947143	.661749
	18000-20000	31	-.2177419	.7432485
	20000-22000	26	-.2336539	.9400068
	>22000	19	-.6532631	.8777611
Access Density (#/mile)	0-10	5	-.5867508	.6236993
	10-20	38	-.3902988	.9043741
	20-30	40	.165917	.8512674
	30-40	37	.2398732	.7242655
	40-50	30	.2442888	.7151583
	>50	6	-.029876	1.049533
Num. of Lanes	lane2	105	.03	.8447895
	lane4	78	-.1779359	.8821401
Median	with median	26	-.7493846	.9825399
	without median	157	.0557643	.7904924
Shoulder	with shoulder	126	-.2274762	.8915535
	without shoulder	57	.314614	.6706142
Speed limit (m/h)	25	2	-1.44893	1.470386
	30	29	.1467018	.8952285
	35	61	.2869238	.7113365
	40	18	.3067284	.7238336
	45	26	-.2031921	.6780154
	50	31	-.3130281	.7432605
	55	16	-1.257546	.5039747
Intersection Spacing (2 lane highway)	.05	35	2.0347428	.82129385
	.1	59	1.6964068	.75516137
	.15	43	1.374	.75221432
	.2	23	1.1029565	.86036395
	.25	14	.71142857	.71136464
	.3	13	1.0329231	.81089614
	>1	25	.06496	.93403427
Intersection Spacing (4 lane highway)	.05	63	1.8791746	.76541797
	.1	57	1.2326842	.71845739
	.15	39	1.045359	.77978454
	.2	18	1.0792222	.81676186
	.25	6	.81249999	.87406651
	.3	6	.27233333	.80923509
	>1	31	-.31793548	.74740042

Table 5-8. Kruskal-Wallis test results

Factor	Chi-square	Prob.	d.f.	Subgroup	Average Accident Rate	Obser.	_RankSum
AADT	29.028	0.0001	5	10000	2.981931	14	2263.00
				12000	1.231706	10	1061.50
				14000	0.784879	31	2461.00
				16000	0.966612	24	2225.50
				18000	1.214964	28	2998.00
				20000	0.804333	31	2574.00
				22000	0.791636	26	2146.00
				>22000	0.520345	19	1107.00
Access Density (#/mi)	29.028	0.0001	5	10	0.556131	32	1852.00
				20	0.676855	38	2780.00
				30	1.180475	40	4243.50
				40	1.271088	37	4126.50
				50	1.276713	30	3268.50
				>50	0.970566	6	565.50
Medi.	16.041	0.0001	1	N	1.030455	157	15446.00
				Y	0.836996	26	1390.00
Num of Lanes	1.159	0.2817	1	2	0.472657	105	10041.50
				4	1.057348	78	6794.50
Shoul.	14.359	0.0002	1	N	0.796541	57	6501.50
				Y	1.36973	126	10334.50
Speed Limit (mi/h)	49.782	0.0001	6	25	0.234821	2	57.00
				30	1.158009	29	3028.00
				35	1.332323	61	6884.50
				40	1.358972	18	2106.00
				45	0.816121	26	2097.00
				50	0.731229	31	2294.00
				55	2.0347428	16	369.50
Inters. Spac. (2 lane hyw)	69.103	0.0001	6	.05	1.6964068	35	5226.50
				.1	1.374	59	7676.5
				.15	1.1029565	43	4673.00
				.2	.71142857	23	2108.5
				.25	1.0329231	14	874.5
				.3	.06496	13	1127.5
				>1	1.3243679	25	891.5
Inters. Spac. (4 lane hyw)	93.435	0.0001	6	.05	9.3055873	63	10049.00
				.1	4.756965	57	6601.00
				.15	3.8301795	39	4103.5
				.2	3.9305556	18	1949.5
				.25	3.1591667	6	530.00
				.3	1.7016667	6	339.00
				>1	.9691875	32	959.00

The results show significant differences in the accident rates of subgroups defined by the following test factors: AADT, access density, median, shoulder, speed limit, and intersection spacing , 4-lane and 2-lane highway are tested separately for intersection spacing. The probability of equal means of subgroup defined by the number of lanes (4-lane and 2-lane) is 28.17%, which is much larger compared with other factors. The conclusion is that AADT, access density, median, shoulder, speed limit, and intersection spacing, have significant impact on accident rates. The impact of the number of lanes on accident rates is not as significant as other factors.

5.2.3 Regression Models

Regression models were estimated to identify the quantitative impacts of independent variables on accident rates. Seven regression models were developed for various cases, including, 4-lane with shoulder, 4-lane without shoulder, 2-lane with shoulder, 2-lane without shoulder, 4-lane with median, 4-lane without median and 2-lane without median. The main independent candidate variables considered were the following: AADT, access density, speed limit, and segment length. The square forms of these variables were also considered as candidate independent variables.

5.2.3.1. Correlation Matrix

Table 5-9 shows an example of the correlation matrix for the 4-lane with median case. The correlations between accident rate and speed limit have relatively high values, -0.7036 and 0.6840 respectively. However, the correlation value between speed limit and access density is also very large. Only one of the two variables can be integrated in the regression model to reduce the risk of multi-collinearity. Although the absolute correlation value between accident rate and speed limit (0.7036) is slightly higher than that of between accident rate and access density (0.6840), the access density was chosen as the independent variable because the focus of this study was to investigate the impact of access points on accident rates. In order to reflect the impact of traffic volume on the occurrence of accidents, AADT was chosen as another independent variable in the regression model. AADT exhibited a correlation value of –0.1764 with accident rate.

Table 5-9 Correlation Matrix (4-lane with median)

	Segment Length	Speed Limit	AADT	Access Density	Accident Rate
Segment Length	1.0000				
Speed Limit	0.1766	1.0000			
AADT	0.0410	0.3147	1.0000		
Access Density	-0.2747	-0.9147	-0.1830	1.0000	
Accident Rate	-0.3388	-0.7036	-0.1764	0.6840	1.0000

5.2.3.2. Regression Models

Based on the correlation matrix, the best independent variables were chosen to be included in the regression models for each of the seven cases, as shown in Table 5-10. As an example, the regression results of the 4-lane with median case is summarized and shown in Table 5-11. The regression model with the highest R-square for the 4-lane with median case is shown below:

$$\ln(\text{Accident Rate}) = -0.9573 - 0.0000304 \times \text{AADT} + 0.0432 \times \text{Access Density}$$

The regression results for all seven cases are summarized in Table 5-12. As seen in Tables 5 to12, some of the regression models do not show any significant causal effect, having small R square values, such as regression models developed for 4-lane without shoulder, 2-lane with shoulder, 2-lane without median, and 4-lane without median highway sections. For the following types of highway sections, the regression results can be used to predict accident rates with caution: 4-lane highway with shoulder, 2-lane highway without shoulder, and 4-lane highway with median. The regression results demonstrated that access density and AADT always participated in the best models, while for some models, namely 4-lane with shoulder and 2-lane without shoulder highway types, speed limit was also found to be a contributing factor to the occurrence of accidents. For 4-lane with shoulder and 4-lane with median highway sections the coefficients of access density are positive, indicating that an increase of access points along these types of routes may cause more accidents. However, some of the results are counter-intuitive. For 2-lane without shoulder highway sections, the coefficient of the affecting access density factor is negative. This indicates that there are other causes that contribute to accidents and that access density is not a necessary contributor to accidents. In all cases, the coefficients of AADT are negative, indicating that an increase in traffic volume may lead to a reduction to the accident rate which is contrary to the common perception. For 4-lane with shoulder and 2-lane without shoulder cases, speed limit coefficients are found to be negative, which implies that a higher speed limit actually leads to a reduction in accident rates. These results indicate that a more in depth analysis is required to further explain these rather contradictory results. Specifically, we need to explore the impact of hourly and sub-hourly traffic volumes, speed distributions, driver types, more detailed geometric data such as width of shoulders and lanes on accidents. In addition, we should further explore other types of accident distributions that are mentioned in the literature such as the Poisson and the negative binomial distributions.

Table 5-10 Independent Variables in Regression Models

Type of Highway	Independent Variables
4 lane with shoulder	speed limit, access density, AADT
4 lane without shoulder	speed limit, access density, AADT
2 lane with shoulder	speed limit, access density, AADT
2 lane without shoulder	speed limit, access density, AADT
4 lane with median	access density, AADT
4 lane without median	speed limit, access density, AADT
2 lane without median	speed limit, access density, AADT

Table 5-11 Regression Models for the 4-lane Highway with Median Highway Sections

Dependent Variable	Independent Variable	Coefficient	Std. Err.	t	P>|t|	[95% Conf. Interval]		R^2	Adj. R^2
Accident Rate	Constant	0.2134	1.0295	0.2073	0.8376	-1.9216	2.3485	0.4647	0.4160
	AADT	-1.2E-05	4.8E-05	-0.2507	0.8043	-0.0001	8.75E-05		
	Acs. Den.	0.0444	0.0107	4.1372	0.0004	0.0221	0.0667		
ln (Accident Rate)	Constant	-0.9573	0.8351	-1.1463	0.4428	-2.6893	0.7746	0.5712	0.5322
	AADT	-3.04E-5	3.89E-5	-0.7816	5.91E-5	-0.0001	5.03E-5		
	Acs. Den.	0.0432	0.0087	4.9526	0.2640	0.0251	0.0612		
Accident Rate	Constant	4.9335	9.9451	0.4960	0.6247	-15.6914	25.5584	0.3245	0.2631
	Ln (AADT)	-0.5600	0.9998	-0.5601	0.5810	-2.6335	1.5134		
	Ln (Acs. Den.)	0.5671	0.1839	3.0829	0.0054	0.1856	0.9486		
ln (Accident Rate)	Constant	6.8592	8.5185	0.8052	0.4293	-10.8071	24.5256	0.3966	0.3418
	Ln (AADT)	-0.9071	0.8563	-1.0592	0.300	-2.6831	0.8689		
	Ln (Acs. Den.)	0.5441	0.1575	3.4537	0.0022	0.2174	0.8709		

Table 5-12 Regression Models for the 7 Highway Sections

Highway Type	Dependent Variable	Independent Variable	Coefficient	Std. Err.	t	P>|t|	[95% Conf. Interval]		R^2	Adj. R^2
4-lane with shoulder	ln (Accident Rate)	Constant	18.7820	4.9469	3.7966	0.0004	8.8638	28.7001	0.4493	0.4198
		Spd. Lmt.	-2.4355	0.5809	-4.1927	0.0001	-3.6002	-1.2709		
		AADT	-1.0204	0.4160	-2.4530	0.0174	-1.8545	-0.1864		
		Acs. Den.	0.0008	0.1391	0.0056	0.9955	-0.2781	0.2797		
4-lane without shoulder	Accident Rate	Constant	-0.8809	8.7337	-0.1008	0.9210	-19.6131	17.8512	0.1294	-0.0571
		Ln(Spd. Lmt)	0.4610	1.1758	0.3920	0.7009	-2.0609	2.9830		
		Ln(AADT)	-0.1607	0.6693	-0.2401	0.8137	-1.5964	1.2749		
		Ln(Acs.Den.)	0.6334	0.4469	1.4172	0.1782	-0.3251	1.5920		
2-lane with shoulder	Accident Rate	Constant	12.1277	6.0035	2.0200	0.0478	0.1228	24.1327	0.1078	0.0640
		Ln(Spd. Lmt)	-0.4205	0.7551	-0.5569	0.5795	-1.9305	1.0893		
		Ln(AADT)	-1.0420	0.5560	-1.8739	0.0657	-2.1539	0.0698		
		Ln(Acs.Den.)	0.2689	0.2025	1.3279	0.1891	-0.1360	0.6738		
2-lane without shoulder	ln (Accident Rate)	Constant	31.2916	7.0951	4.4102	9.38E-05	16.8877	45.6955	0.5270	0.4865
		Ln(Spd. Lmt)	-0.2160	1.5603	-0.1384	0.8906	-3.3838	2.9516		
		Ln(AADT)	-2.8146	0.4775	-5.8941	1.06E-06	-3.7840	-1.8451		
		Ln(Acs.Den.)	-0.4988	0.4045	-1.2332	0.2257	-1.3200	0.3223		
2-lane without median	Accident Rate	Constant	21.7597	4.1120	5.2917	7.17E-07	13.6016	29.9178	0.2805	0.2590
		Ln(Spd. Lmt)	-0.6119	0.6065	-1.0088	0.3154	-1.8152	0.5914		
		Ln(AADT)	-1.9233	0.3693	-5.2076	1.03E-06	-2.6561	-1.1906		
		Ln(Acs.Den.)	0.16738	0.1785	0.9374	0.3507	-0.1868	0.5216		
4-lane with median	ln (Accident Rate)	Constant	-0.9573	0.8351	-1.1463	0.4428	-2.6893	0.7746	0.5712	0.5322
		AADT	-3.04E-5	3.89E-5	-0.7816	5.91E-5	-0.0001	5.03E-5		
		Acs. Den.	0.0432	0.0087	4.9526	0.2640	0.0251	0.0612		
4-lane without median	ln (Accident Rate)	Constant	5.8995	5.3286	1.1071	0.2738	-4.8201	16.6191	0.0483	-0.0124
		Speed Limit	0.0028	0.6853	0.0040	0.9967	-1.3759	1.3815		
		AADT	-0.6145	0.3988	-1.5406	0.1301	-1.4168	0.1878		
		Acs. Den.	0.0777	0.1456	0.5336	0.5961	-0.2153	0.3707		

The three best regression models observed included as independent variables access density, AADT, and in some cases, speed limit.

4-lane highway with shoulder:

$$\ln(\text{Accident Rate}) = 18.782 - 2.4355 \times \text{Speed Limit} - 1.0204 \times \text{AADT} \\ - 0.0008 \times \text{Access Density}$$

2-lane highway without shoulder:

$$\ln(\text{Accident Rate}) = 31.2916 - 0.216 \times \ln(\text{Speed Limit}) - 2.8146 \times \ln(\text{AADT}) \\ - 0.4988 \times \ln(\text{Access Density})$$

4-lane highway with median

$$\ln(\text{Accident Rate}) = -0.9573 - 0.0000304 \times \text{AADT} + 0.0432 \times \text{Access Density}$$

CHAPTER 6
FIELD STUDY AND DATA ANALYSIS

The field study was conducted in late August and early September 1997 on the section of NJ State Route 27, between Chestnut Street and Summit Street, Linden, New Jersey. The study section was about 0.6 miles long with two lanes in each direction and without any median. The objective of the field study was to record the operational characteristics of a multilane highway/arterial section, mainly the speed and the traffic volumes egressing and accessing from/to the access points as well as the mainline.

6.1 Data Collection

The study involved taking traffic counts and speed measurements. Traffic volumes both at access points and on the main road were collected by observers located near access points throughout the study section using traffic counters. Speed data were collected through the use of a study vehicle moving along the study section, covering both directions of traffic. A video camera was used to tape the speed indication from the odometer of the test vehicle. This survey covered the AM and PM peak periods and the off-peak periods for five weekdays from Monday to Friday. The diagram of the study section is shown in Figure 6.1.

6.1.1 Speed Data Collection

Speed data collection was conducted for 3 days on September 4, 8 and 11, 1997. All the access points were labeled before the study, as shown in Figure 6.1; The study section consisted of 31 points southbound and 18 points northbound. A test vehicle was used to traverse the road segment between Summit Street and Roselle Street. The driver was instructed to make round trips traveling either in lane-1 or lane-2, which was recorded by the observer. A total number of 43 test runs on lane-1 and lane-2 were conducted, respectively. A video camera was used to video tape the odometer of the vehicle. Speed information was read and recorded from the tapes into a Microsoft Excel worksheet for analysis after the field study. The information obtained includes: speed at each access point, speed reduction and delay of test vehicle caused by vehicles entering/exiting access points, and the types of vehicle operations that affected the test vehicle.

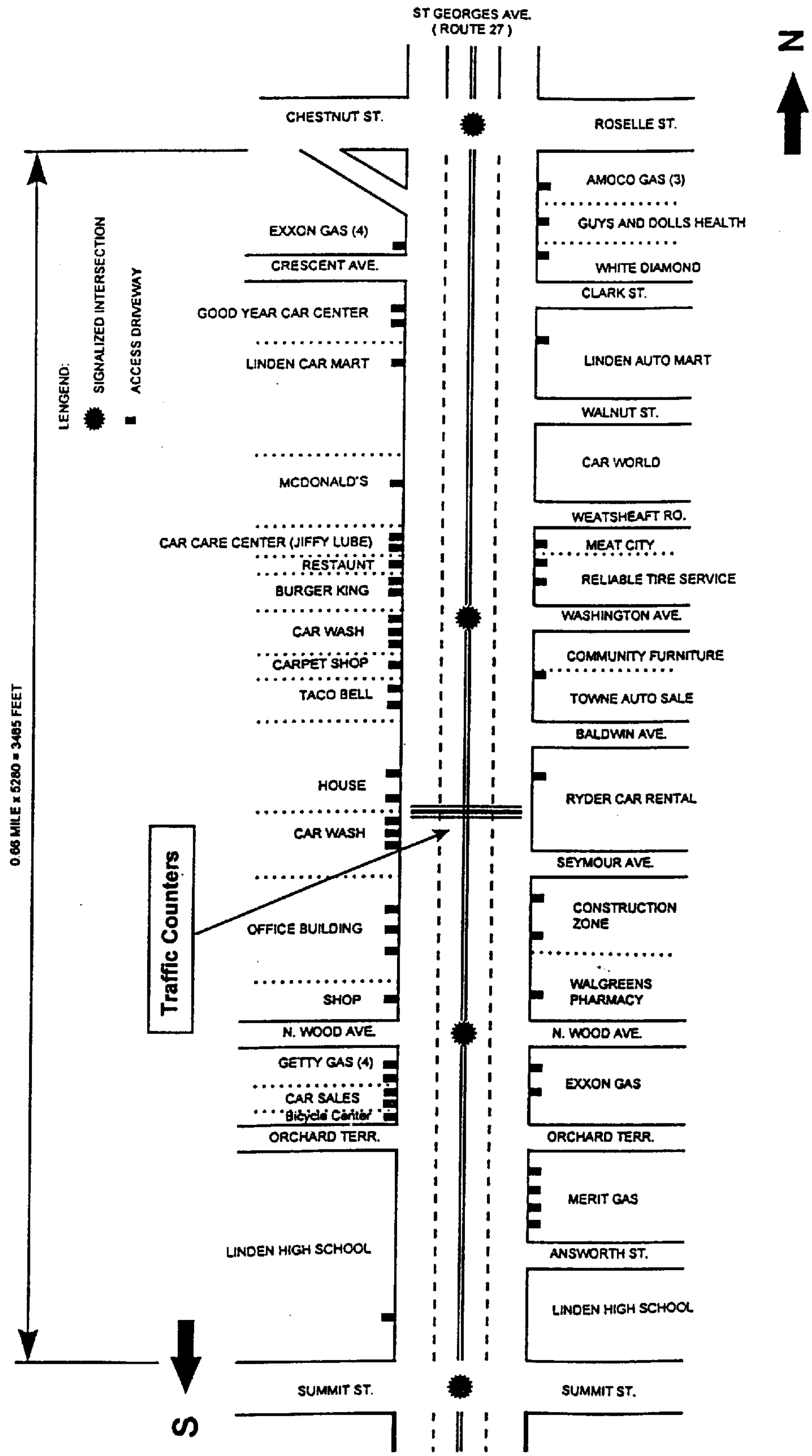

Figure 6. 1 Field Study Site Diagram

6.1.2 Traffic Data Collection

The traffic volume study was conducted for 6 days as follows: 8/26, 8/27, 8/28, 9/4, 9/5 and 9/8, 1997. The study covered all weekdays, Monday through Friday. Six persons participated in this study, where each of them was responsible for 5 to 6 adjacent access points. Data was collected on three morning periods, from 07:00 to 12:00, and three afternoon periods, from 14:00 to 19:00. The collected traffic volume data included the traffic volume on the main roadway for both directions and the traffic volume at the access points. Traffic at access points was divided into entering and exiting volumes, which were further grouped according to turning movements and their impact on other vehicles. For entering volumes, the data categories on the tally sheet (see Table 6-1) included: left turning vehicles which had impact on other vehicles, left turning vehicles which had no impact on other vehicles, right turning vehicles which had impact on other vehicles, and right turning vehicles which had no impact on other vehicles. For exiting vehicles, the data categories on the tally sheet were grouped in a similar manner. Hand-held traffic counters were used to collect the traffic of the main roadway, and the tally sheets were used for traffic counts at access points.

Table 6-1. Sample Tally Sheet for Traffic Counts at Access Points

Access point No.________	Entering Vehicles				Exiting Vehicles			
	Impact		No impact		Impact		No impact	
Time period	L-turn	R-turn	L-turn	R-turn	L-turn	R-turn	L-turn	R-turn
7:00-7:15	5	3	4	3	5	4	2	5
7:15-7:30	3	4	6	4	1	7	5	3
7:30-7:45	9	2	1	3	2	3	8	3
7:45-8:00	1	8	4	2	7	2	2	3

6.2 Speed Data Analysis

6.2.1 Average Speed Not Affected by Vehicle Turning at Access Points

In this section, the average speeds for the trips that were not affected by the vehicles entering or exiting access points are reported. The average speeds were calculated for both lane-1and lane-2 for the southbound and northbound streets, respectively. The speed of northbound lane-1 ranged from 24 to 31 miles per hour, averaging to 29 miles per hour. The values for northbound lane-1 ranged from 19 to 34 miles per hour, averaging to 30 miles per hour. The speed of southbound lane-1 ranged from 20 to 31 miles per hour, averaging to 27 miles per hour. The speed for southbound lane-2 ranged from 18 to 36 miles per hour, and averaging to 30 miles per hour. The average speeds affected by turning vehicles are presented in Figures 6.2 and 6.3.

The average speeds of lane-2 were slightly higher than those of lane-1, which is expected since lane-1 tends to be affected by the vehicles entering and/or exiting access points.

Another observation is that at access points 6 and 11 northbound (see Figure 6.2), and access points 11 and 25 southbound (Figure 6.3), there are significant speed reductions, which are justified due to the closeness of these locations to traffic signals. Although speed is affected by vehicle maneuvers at access points traffic signals have a higher impact on speed than access points.

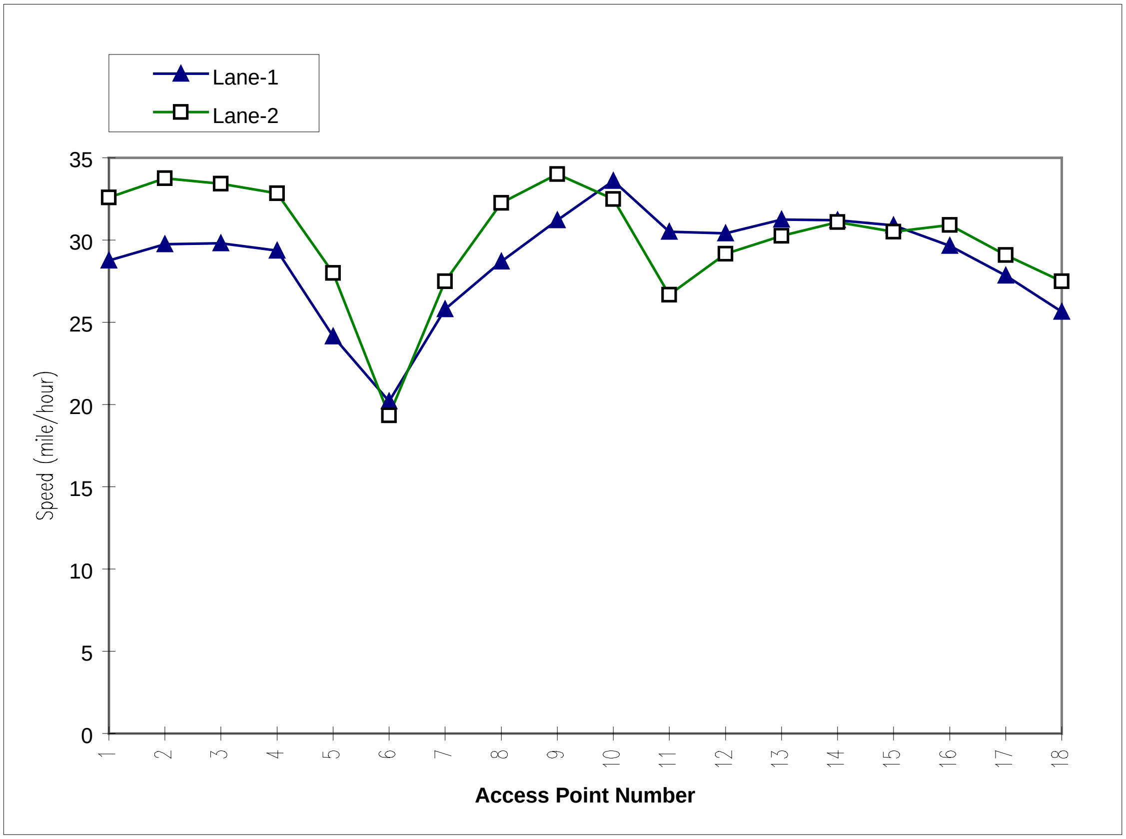

Figure 6. 2 Vehicle Speed Not Affected vs. Access Point Number (Northbound)

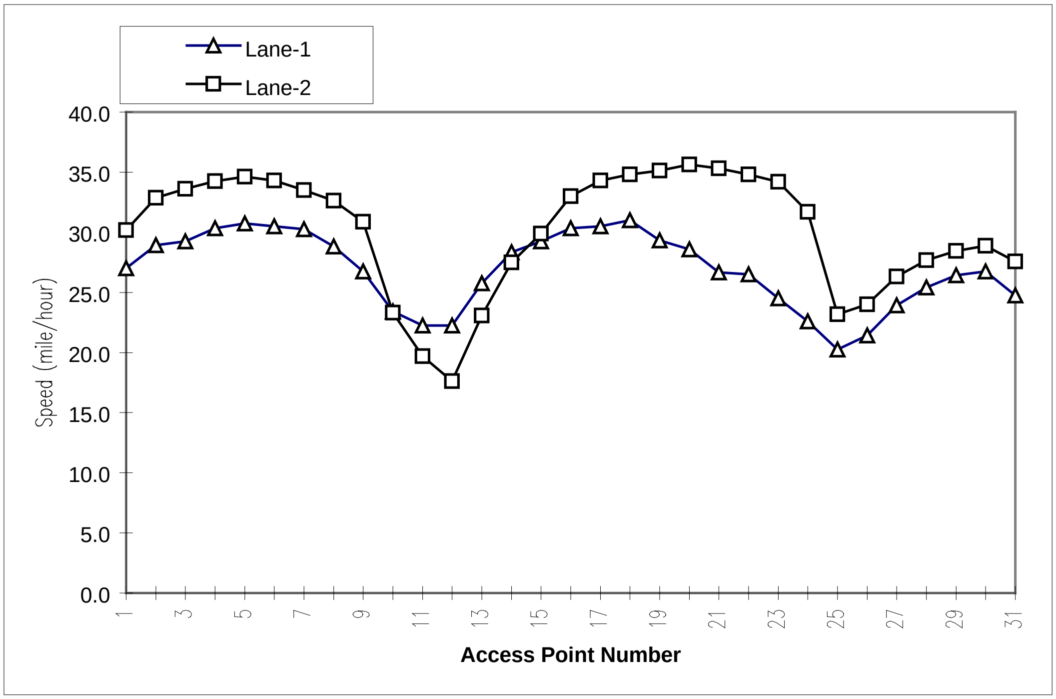

Figure 6. 3 Vehicle Speed Not Affected vs. Access Point Number (Southbound)

6.2.2 Mainline Speed Affected by Vehicle Turns into Access Points

In this section, the impact on the speed of vehicles traveling on the mainline, which are affected by vehicles turning from the mainline into access points is presented.

1). Speed affected by movements entering into access points

The cases considered in this section include the following conditions: affected by opposite direction left-turn from lane-2, opposite direction left-turn from lane-1, same direction left-turn from lane-2, same direction right-turn from lane-1, and same direction left-turn from lane-1.

The speed profile of lane-2 in the case where speed is affected by opposite direction left-turn movements is depicted in Figure 6.4.

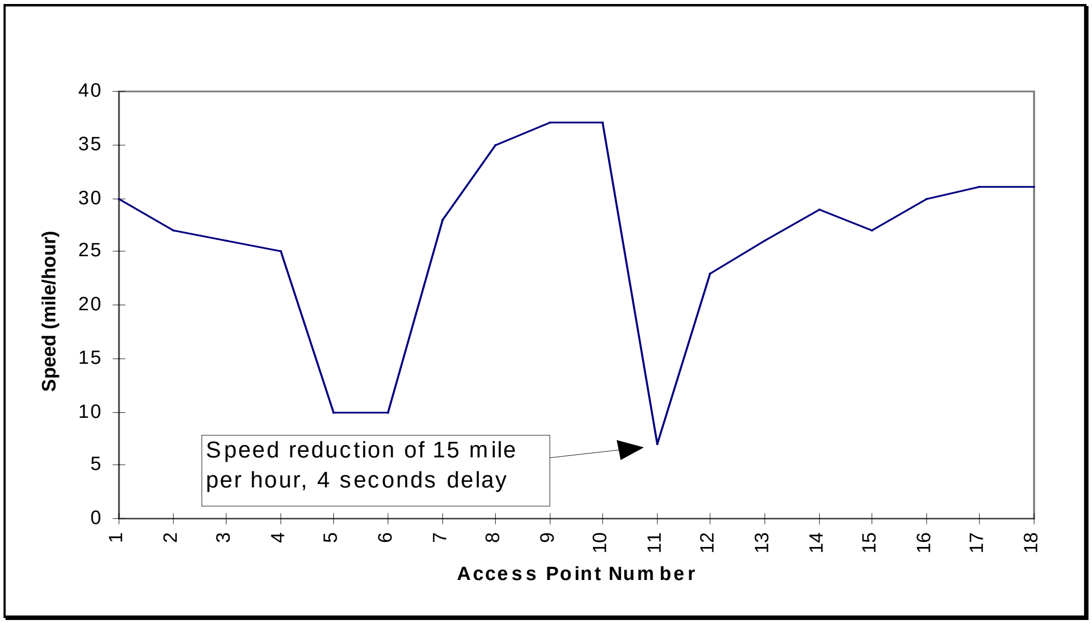

Figure 6. 4 Speed of Lane-2 Affected by Opposite Direction Left-turn Movements vs. Access Point Number

The speed profile of lane-2 in the case where speed is affected by same direction left-turn movements is depicted in Figure 6.5.

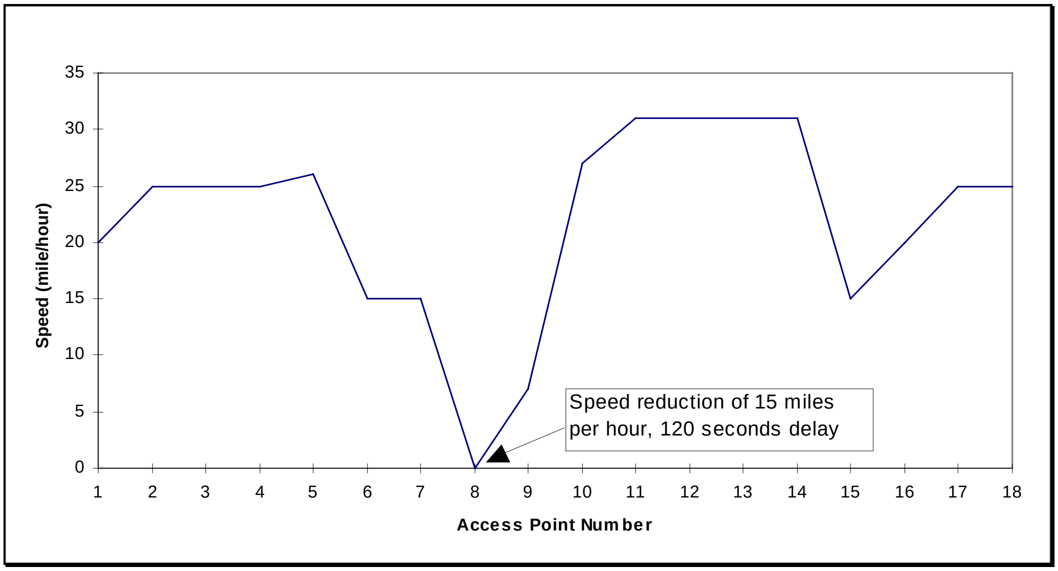

Figure 6. 5 Speed of Lane-2 Affected by Same Direction Left-turn Movements vs. Access Point Number

The speed profile of lane-1 in the case where speed is affected by same direction right-turn movements is depicted in Figure 6.6.

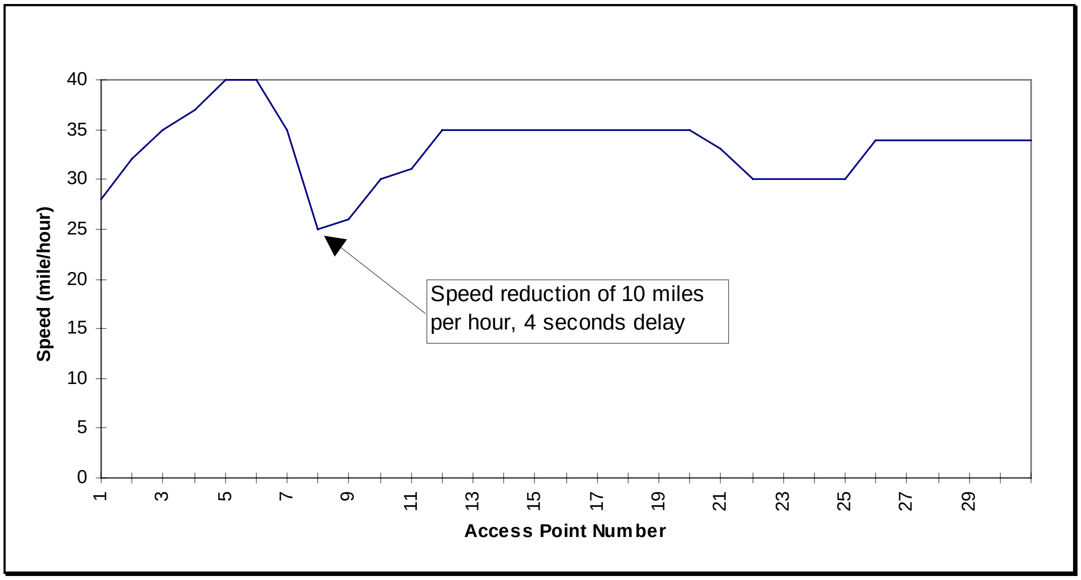

Figure 6. 6 Speed of Lane-1 Affected by Same Direction Right-turn Movements vs. Access Point Number

The speed profile of lane-1 in the case where speed is affected by same direction left-turn movements is depicted in Figure 6.7.

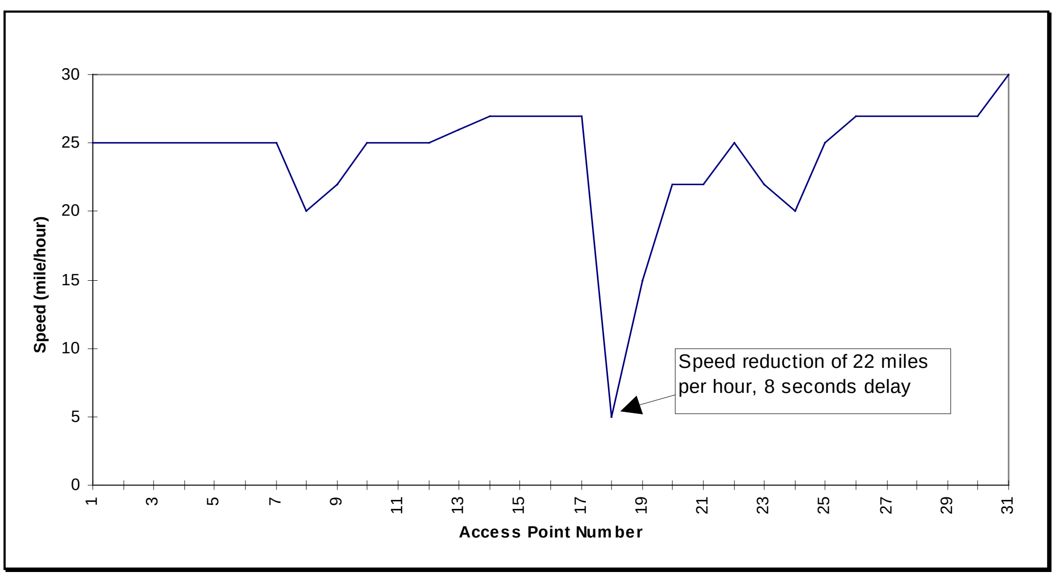

Figure 6. 7 Speed of Lane-1 Affected by Same Direction Left-turn Movements vs. Access Point Number

The speed profile of lane-1 in the case where speed is affected by opposite direction left-turn movements is depicted in Figure 6.8.

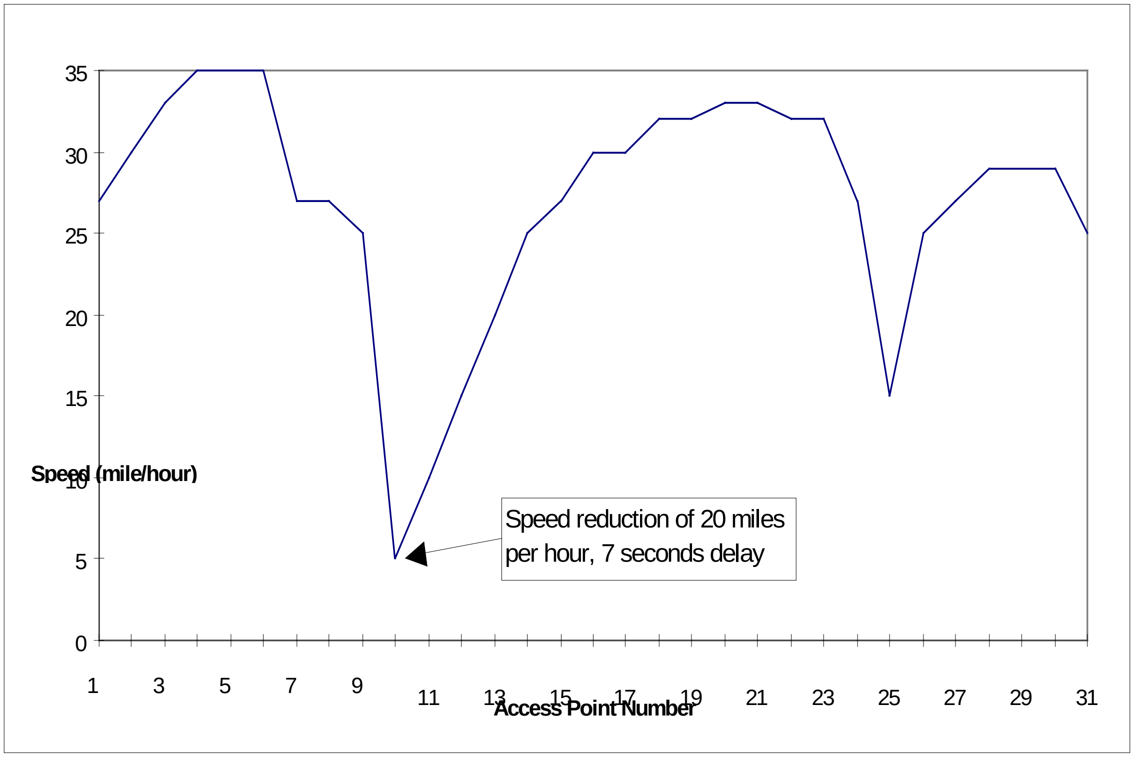

Figure 6. 8 Speed of Lane-1 Affected by Opposite Direction Left-turn Movements vs. Access Point Number

2). Speed affected by exiting movements from the access points
For exiting movements, the cases considered in this section include test runs affected by left-turn and right-turn vehicles from access points into the mainline.

The speed reduction due to left-turns from access points is shown in Figure 6.9.

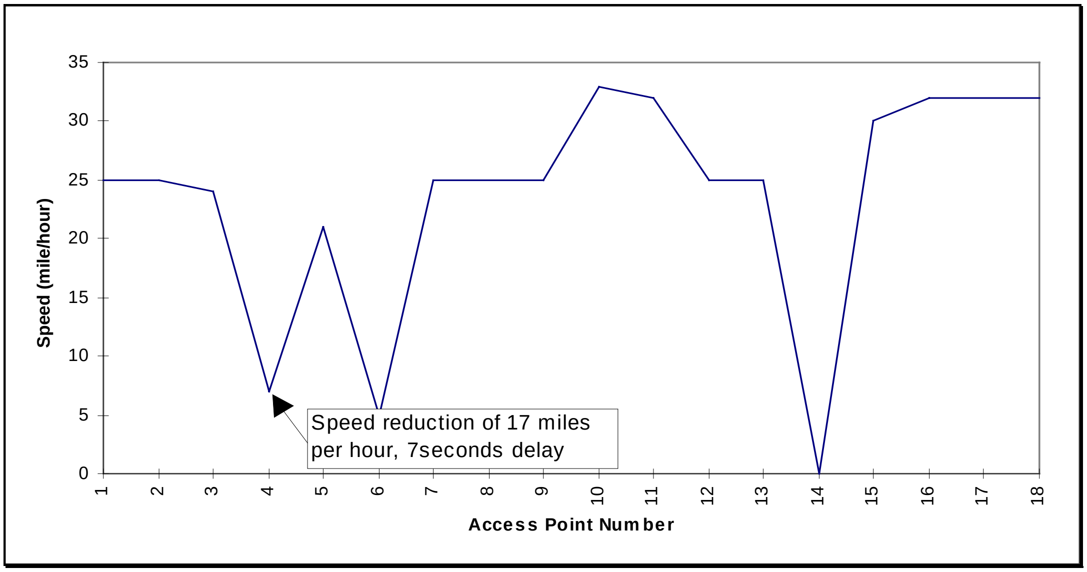

Figure 6. 9 Speed Affected by Left-turn Exiting Movements vs. Access Point Number

The speed reduction due to right turns from access points is shown in Figure 6.10.

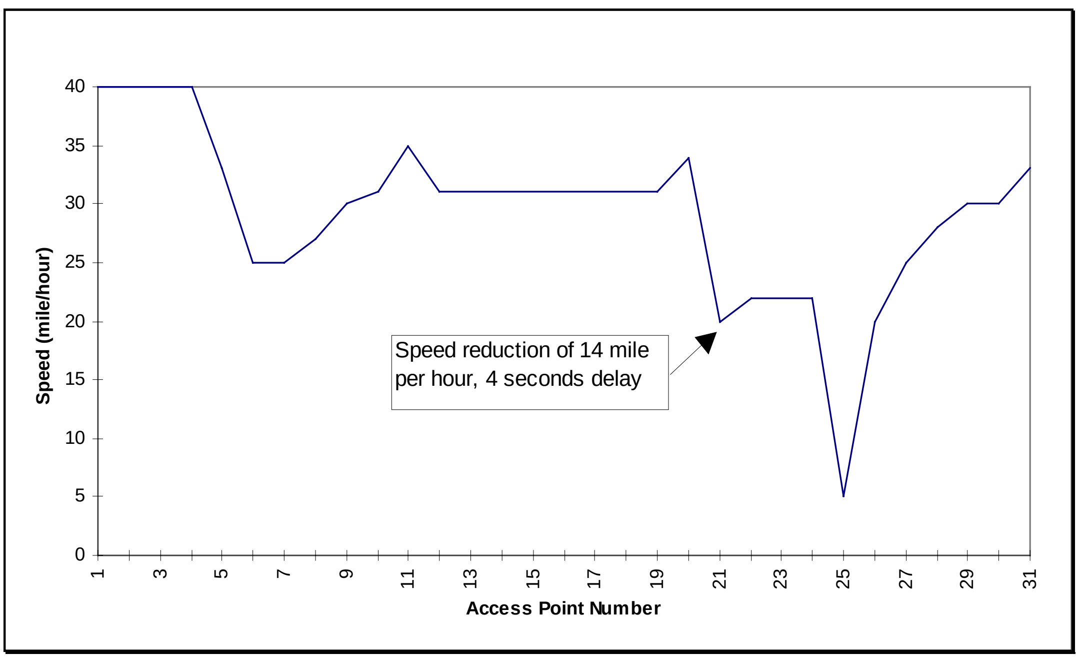

Figure 6. 10 Speed Affected by Right-turn Exiting Movements vs. Access Point Number

6.2.3 Percentage of Test Runs Affected by Turning Vehicles at Access Points

The total number of test runs conducted was 86; 43 runs were conducted on lane-2, and the other 43 runs were conducted on lane-1. Thirty (30) percent of the test runs were affected by turning movements at access points. Analyzing lane-2 and lane-1 separately, Lane-2 exhibits a higher percentage of test runs affected by turning movements, as shown in Table 6-2.

Table 6-2 Percentage of Test Runs Affected by Turning Movements

Test runs	Affected	Not affected
On lane-1	26%	74%
On lane-2	35%	65%
On both lanes	30%	70%

6.2.4 Delay and Speed Reduction Due to Turning Movements at Access Points

In this section, the analysis of the impact of maneuvering vehicles from/to access points on the test vehicle going straight through is presented. Maneuvering vehicles include both vehicles entering into and exiting from access points. The drivers of exiting vehicles are very cautious when they try to exit from an access point, whereas those entering into access points are more aggressive. The drivers exiting access points would make an exiting maneuver, only when they find an acceptable gap occurring on the main road. The impact of these exiting vehicles on through vehicles was observed to be not significant. In this section, only the analysis of entering maneuvers is presented. These entering maneuvers include: opposite direction left-turning on lane-2, same direction left-turning on lane-2, same direction right-turning on lane-1, and opposite direction left-turning on lane-1. The average delay and speed reduction was calculated for each type of these maneuvers, and the results are shown in Table 6-3.

Table 6-3 Delay and Speed Reduction due to Turning Movements

Case	Average Delay (seconds)	Average Speed Reduction (mph)
Same direction right-turning on lane-1	5.0	10.6
Opposite direction left-turning on lane-1	6.0	11.7
Same direction right-turning on lane-2	8.6	16.4
Opposite direction left-turning on lane-2	3.8	10.3

The delays and speed reductions of different turning maneuvers were ranked in descending order as follows: same direction left-turning movement on lane-2, opposite direction left-turning movement on lane-1, same-direction right turning movements on lane-1 and opposite direction left turning movements on lane-2.

The delay and speed reduction due to the opposite direction left turning movements on lane-2 is the lowest of all. This may be attributed to the rather quick execution of the left-turning maneuver of the drivers. Under more congested conditions, this may not hold true, as left-turning vehicles will have less acceptable gaps to complete their maneuvers.

6.3 Traffic Volume Data Analysis

6.3.1 Main Roadway Traffic

The hourly traffic volumes on the main roadway are summarized in Table 6-4. The hourly traffic volume ranges from 664 to 1529 in the morning period, and 788 to 2204 in the afternoon period. The afternoon peak hour is observed to occur between 16:00 to 18:00. However, the morning peak hour occurs between 10:00 to 12:00 AM instead of the more widely used 07:00 to 09:00 AM. Another observation is that approximately forty percent of the traffic travels on lane-2 and sixty percent travels on lane-1. Figure 6.11 presents the distribution of the average traffic volume on weekdays.

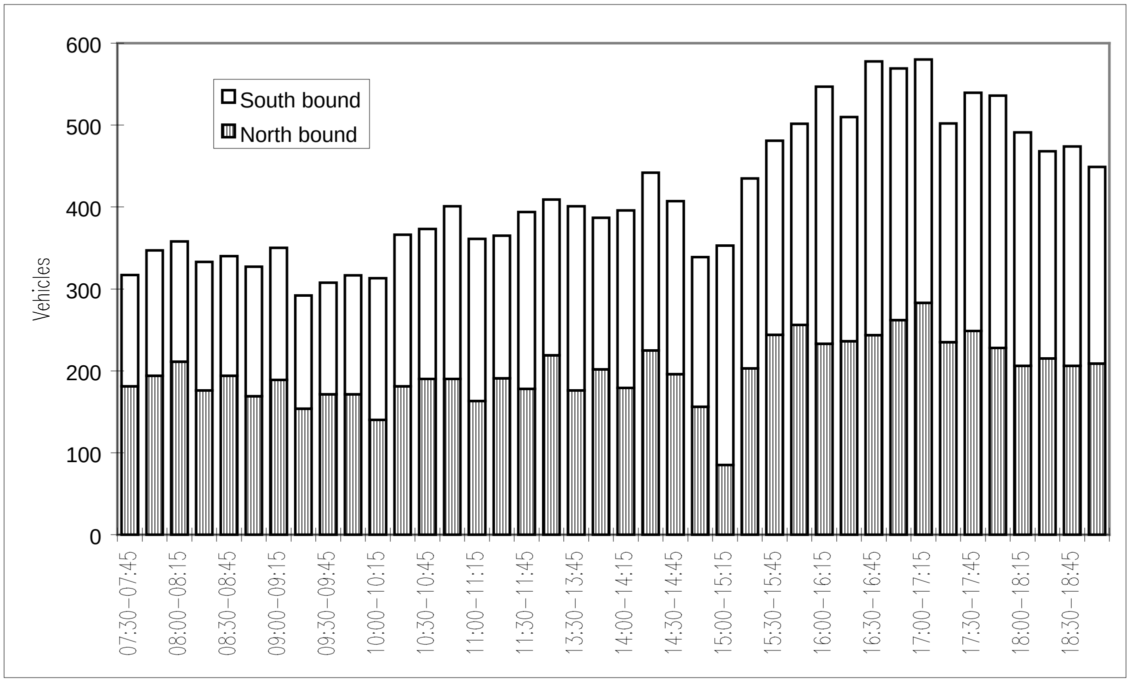

Figure 6. 11 Distribution of Average Traffic Volume (15 minutes) on Weekdays

Table 6-4 Hourly Traffic Volumes on Mainline

Time period	North bound			South bound			Total
	Lane-1	Lane-2	Subtotal	Lane-1	Lane-2	Subtotal	
07:00-08:00	250	125	375	164	125	289	664
08:00-09:00	462	288	750	376	232	608	1358
09:00-10:00	404	282	686	352	228	580	1266
10:00-11:00	**440**	**261**	**701**	**501**	**251**	**752**	**1453**
11:00-12:00	**473**	**278**	**751**	**526**	**252**	**778**	**1529**
13:00-14:00	251	127	378	247	163	410	788
14:00-15:00	**454**	**302**	**756**	**561**	**267**	**828**	**1584**
15:00-16:00	**418**	**370**	**788**	**625**	**357**	**983**	**1771**
16:00-17:00	567	408	975	768	461	1229	2204
17:00-18:00	547	448	995	702	461	1163	2158
18:00-19:00	476	360	836	625	421	1046	1882

6.3.2 Traffic Volume at Access Points

Traffic volumes at each access point were counted in 5-minute time intervals and were then grouped into 15-minute and hourly time intervals. Two typical access types were chosen in this section, two gas stations (Merit and Exxon) with corresponding access point numbers of N1, N2, N3, N4, N5 and N6, and one restaurant (Burger King) with corresponding access point numbers of S9 and S10. The results are summarized in Figures 6.12 and 6.13 for the gas stations and restaurant, respectively.

As seen from the figures, for the gas stations, the hourly traffic volume at access points varies significantly each day. For example, at N5, it could be as high as 45 vehicles per hour on Monday and as low as 5 vehicles per hour on Thursday. Although there is no obvious trend in the daily distribution of access volumes, drivers are more likely to fill gas on Monday, Tuesday and Friday rather than on Thursday. People are more likely to go to Burger King on Mondays rather than on Wednesday, Thursday and Friday. It is noted that this is a limited study that may not indicate the actual daily patterns for either of the two access points.

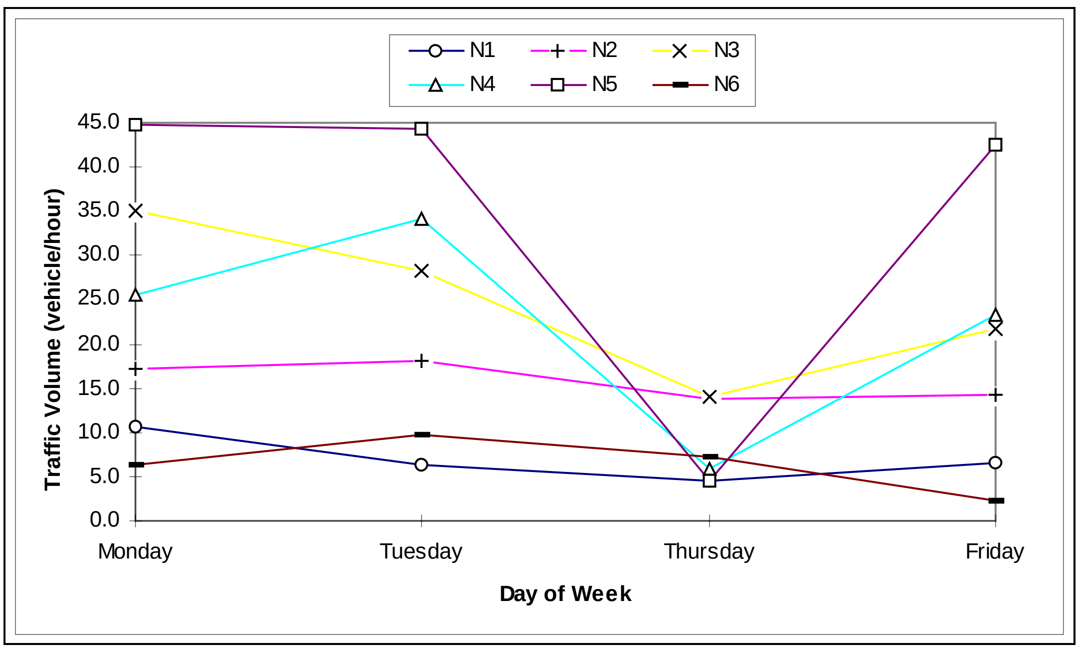

Figure 6. 12 Hourly Traffic Volume vs. Weekdays at Access Points of Gas Stations

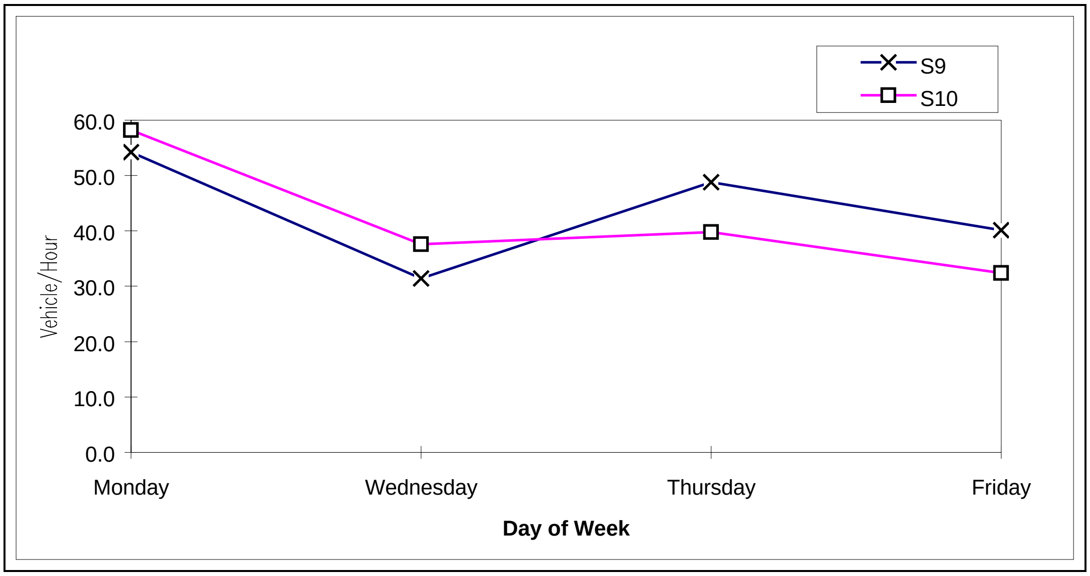

Figure 6. 13 Hourly Traffic Volume vs. Weekdays at Access Points of Restaurant (Burger King)

6.3.3 Impact Analysis of Turning Movements at Access Points

To study the impact of access traffic on the traffic operation on main roadways, turning vehicles were grouped according to types of maneuver (entering and exiting), turning movements (left turn and right turn), impact on other vehicles (impact and no impact), and time periods (peak hour, and off-peak hour). The analysis was conducted for 3 days, and the results are presented in Table 6-5.

Comparing the results of the entering vehicles with those of the exiting vehicles, the percentage of left turning entering vehicles having an impact on other vehicles is higher than the percentage of left turning exiting vehicles for both peak and off-peak hours: 24% versus 15% (peak hour), and 19% versus 10% (off-peak hour), respectively. This indicates that drivers are more cautious in a left turning maneuver exiting from an access point. In contrast, the percentage of the left turning entering vehicles without impact on other vehicles is lower than the percentage of the left turning exiting vehicles for both peak and off-peak hours: 14% versus 17% (peak hour), and 15% verus 21% (off-peak hour), respectively.

Table 6-5 Percentage of Turning Movements Impacting on Other Vehicles

Turning Movement	Left-turning		Right-turning	
	Impact	No impact	Impact	No impact
Entering (Peak hour)	24%	15%	6%	55%
Entering (Off-peak)	19%	16%	8%	57%
Exiting (Peak hour)	14%	16%	8%	62%
Exiting (Off-peak)	10%	21%	13%	56%

The percentage of right turning vehicles without impact on other vehicles is above 50%. In contrast, the percentage of right turning vehicles with impact on other vehicles is much lower. These results indicate that the right turning vehicle action has the least impact on other vehicles from all the other vehicle movements.

The percentage of peak hour left turning vehicles with impact on other vehicles is higher than that of off-peak hours for both entering and exiting cases. In contrast, the percentage of peak hour left turning vehicles without impact on other vehicles is lower than that of off-peak hour for both entering and exiting vehicle actions. This indicates that with increasing traffic volume on the mainline, the left turning movements have a higher impact on other vehicles.

CHAPTER 7
CONCLUSIONS AND RECOMENDATIONS

The primary research objective of this project was to identify the impact of mid-block access point on accident rates on multilane highways/arterials in the state of New Jersey. Accident, access, geometric and traffic volume data were collected from the documents and data files provided by NJDOT. Both graphical and formal statistical analysis were conducted based on the collected data. In addition, a field study was undertaken on a 0.6-mile highway section on Rt. 27 near Linden New Jersey. The objective of the field study was to identify the basic operational characteristics of a typical multilane highway section in New Jersey, in terms of speed and traffic volume at the mainline and at the access points.

7.1 Conclusions

The major conclusions of this study are:

- Accident rates were found to follow a lognormal distribution.
- AADT, access density, median, shoulder, speed limit, and intersection spacing were found to have a significant impact on accident rates. The impact of the number of lanes was not as significant as the above factors.
- Regression models developed for cases of 4-lane highway with shoulder, 2-lane highway without shoulder, and 4-lane highway with median can be used with caution to predict the occurrence of accidents. For other cases, including 4-lane highway without shoulder, 4-lane highway without median, 2-lane highway with shoulder, and 2-lane highway without median, no acceptable regression models were found.
- Approximately 30% of the reported accidents were mid-block section-accidents, which were primarily caused by the presence of access points. Seventy (70%) of all reported accidents occurred at signalized intersections.
- Left turn collision and angle collision reported accidents were shown to be proportionally higher at signalized intersections in comparison to the corresponding proportion observed between signalized intersections. In contrast, collisions with objects, over turns, strike parking vehicles and same direction rear collisions reported between signalized intersections were proportionally higher than those reported at signalized intersections.
- Left-turn and right-turn vehicle actions exhibited a higher proportion of accidents at signalized intersections than between signalized intersections.
- Midblock section-accidents were reported to be primarily caused by vehicles entering and exiting mid-block access points. 70-80% of the section-accidents were caused by a vehicle moving straight through on the mainline and a turning vehicle from/to an access point.
- The analysis of vehicle contribution accident indicated that improper turnings were the primary reason for accidents occurring at intersections than accidents between intersections. The driving-inattention category experienced a higher proportion among section-accidents rather than intersection-accidents.
- Neither clear and rain weather conditions nor dry and wet roadway surface conditions exhibited any difference on the patterns of section-accidents and intersection-accidents.

However, under snow weather conditions, or when the road surface was covered with snow or ice, there was a distinct difference between the proportion observed on section-accidents and the corresponding intersection-accidents.

- The proportion of weekday intersection-accidents was found to be higher than that of weekend intersection-accidents, whereas the weekend section-accidents exhibited a higher proportion than the weekday section-accidents.
- In the hourly accident distribution analysis, the 4:00-5:00 AM hourly period exhibited the lowest accident percentage. Correspondingly, the evening traffic peak period between 5:00 to 6:00 PM exhibited the highest percentage of accident rates.
- The accident rate and access density showed similar patterns to speed limit increases.
- Through a limited field study, speed reduction, delay, and the percentage of affected vehicles due to turning movements to/from access points were identified as the main variables in the estimation of the impact of access points on multilane highway accidents.
- Approximately 25% of the entering/exiting vehicles from/to access points has impact on mainline traffic within this study section. Left turning movements have greater impact on mainline traffic than right turning movements. For left turning movements, the entering traffic has more impact on mainline vehicles than the exiting traffic.
- Accident rates and access densities are follow similar patterns along the sections' milepost, although inconsistencies were observed on some sections. This implies that while the high access density is one of the important contributing factors to the occurrence of accidents between intersections, it is not a necessary one.

7.2 Recommendations

One of the most important questions in access management is what should be the spacing between access points that would optimize the traffic flow and improve traffic safety. The limitation of the data that were available for this study did not permit this study from reaching any definitive conclusion towards this question. Specifically, the following data may contribute towards a better understanding of the traffic operation and accident occurrence for these types of highway facilities: sub-hourly traffic volumes both at the mainline and access points, the speed profile along the roadway, the speed distribution for each section, detailed geometric characteristics, the trip generation characteristics of the various generators along the roadways, speed limit law enforcement, as well as the acceleration and deceleration along each section.

A limited field study was conducted to identify the impact of access points on the traffic operations of the highway. A more comprehensive study should be conducted with the main goal of developing a simulation model, which can capture the microscopic traffic flow characteristics of multilane highways between signalized intersections. The present version of CORSIM can not represent access points closely spaced together accurately. Such a simulation model will establish a tool for traffic impact analysis for access management. Furthermore, the simulation model should also be able to emulate the occurrence of accidents, which is a non-trivial task due to the unavailability of the pertinent data.

The analysis was conducted on a limited number of NJ State highways. A more comprehensive study should be undertaken to include all the NJ state highways, which can then be followed by a nationwide study that would identify the similarities and/or differences of different states.

Develop an Access Management Information System (AMIS) using a Geographic Information System (GIS) platform in conducting accidents analysis and traffic impact analysis on multilane highways. This could include links in conducting microscopic simulation analysis using a variation of CORSIM.

The present 1994 Highway Capacity Manual concentrates on capacity under normal conditions in establishing the level of service. Its treatment on the impact of access points on capacity is non-adequate. It should onclude explicitely, the impact of the number of left turns and right turns from the mainline to the access points and from the access points to the maniline, which was illustrated with the field study. In addition, other variables could be introduced, which would include the effect of accidents on the level of service of a roadway, such as:

- Number of accidents per mile,
- Number of fatal accidents per mile,
- Total delay due to accidents per mile,
- Benefit/Cost ratio per mile; should include the cost per accident, and the cost per time delay.

In essence the new manual will need to change to become the Highway Level of Service Manual or the Highway Benefit/Costs Analysis Manual. Capacity analysis will then become a part of this more comprehensive manual.

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DISCLAIMER

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