ABSTRACT

IMPACT OF ACCESS POINTS ON MULTILANE HIGHWAY ACCIDENTS

by
Tao Qu

This thesis presents an analysis of reported accidents on multilane highways and regression models that identify the primary explanatory variables that have a significant effect on accident rates midblock to signalized intersections. The analysis was based on traffic and reported accident data provided by New Jersey DOT. The access points per mile and the accident rates per million-vehicle-miles-traveled were analyzed based on a large number of roadway sections which were selected from five NJ State routes. Comparative accident analysis related with traffic and roadway geometric characteristics were performed. The analysis showed that approximately 30% of accidents occurred between intersections, which were primarily attributed to the presence of access points. Among these, about 80% of the accidents were caused by a vehicle moving straight through on the mainline and a turning vehicle from/to an access point. Although nonlinear models show good fit, none of the coefficients of the variables show significant t-statistic values. It can be concluded that no good regression models among those tested provide good estimation of accident rates for multilane highways. A field study was conducted and presented several quantitative variables of speed reduction, delay and percentages of affected vehicles at access points.

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IMPACT OF ACCESS POINTS ON MULTILANE HIGHWAY ACCIDENTS

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This thesis is dedicated to
my family and friends
who have supported me throughout this work

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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 access points, midblock to signalized intersections on accident rates. This thesis presents an analysis of accident rates on multilane highways and the development of regression models that identify the primary explanatory variables that have a significant effect on accident rates midblock to signalized intersections. First, a brief introduction to access management is presented.

1.1 Access Management

Multilane highways are located in suburban communities leading to central cities or along high-volume rural corridors that connect main cities. They usually have four to six lanes, which may be divided or undivided by medians. Traffic signals are usually spaced at two miles or less, and traffic volumes typically range from 15,000 to 40,000 vehicles per day. Although multilane highways are not completely access controlled, they have greater control on the number of access points per mile than two-lane highways. Both property owners and roadway users have the right of reasonable access to the multilane highway system, freedom of movement, safety, and efficient expenditure of public funds. While the demand for access increases, the road accidents increase significantly and the system's operational efficiency and integrity degrades. An acceptable level of safety and operational efficiency are two of the main goals of multilane highway operation and access management. One of the techniques used by access management is the allocation of access permits to improve the economic productivity while limiting the impact on the safety and operational efficiency of the roadway.

In NCHRP report 348 (1992), access management was established as a response to the problems of speed reduction, capacity loss, and increasing accident rate along the roadways. Typical issues that access management is responsible for include access points of gas stations, convenience stores, malls and city blocks. It intends to solve the conflicts between the mainline traffic movement and the access functions. It calls for efforts in research and significant improvements in access control and design to preserve the functional integrity and operational viability of the road system. Access management is the process that provides or manages access to land development while simultaneously preserving the flow of traffic on the surrounding road system in terms of safety, speed, and capacity needs. A set of systematic approaches of balancing the access and mobility requirement are provided in this section.

The access management program mainly involves:

- Establish an access classification system,
- Define the allowable access level and access spacing for each class of highway,
- Set up a mechanism for granting variances when reasonable access can not be provided, and
- Develop a means for enforcement of the program.

Main techniques for managing access points include the application of the established traffic engineering, roadway design, and planning principles that:

- Limit the number of conflicts,
- Separate basic conflict areas,
- Reduce interference with through traffic due to turns into or out of a site,
- Provide sufficient spacing between at-grade intersections,
- Maintain progressive speeds along highways, and
- Provide adequate on-site storage areas.

The method of Access Code is another technique that is currently adopted by several states such as New Jersey, Florida and Colorado. A comprehensive access code can provide a supportable, predictable, and systematic basis for making and enforcing access decisions.

The allowable kinds of access between activity centers and mainline cover a broad spectrum. In NCHRP Report 348 (1992), seven levels of access have been defined for application to any state, county, or local road systems. Due to safety considerations, the access levels range from full access control (freeways) to partial access control (local and collector streets and frontage roads). Access level 1 for uninterrupted flow applies to limited access highways, and levels 2 through 7 govern "controlled access" highways. The access classification is shown in Table 1.1.

Table 1. 1 Access Classification System

Access Level	Description of Allowable Access	Roadway Classification	General Roadway Design Features
Level 1	Access at Interchanges Only (Uninterrupted Flow)	Freeway	Multi-lane, Median
Level 2	Access at Public Street Intersections or at Interchanges Only (Uninterrupted Flow)	Expressway	Multi-lane, Median
Level 3	Right Access Only (or Access at Interchange) (Uninterrupted Flow)	Strategic Highways	Multi-lane, Median
Level 4	Right and Left Turn with Left Turn Lane In and Out Required (Interrupted Flow-Both Directions)	Principal Highways	Multi-lane, Median
Level 5	Right and Left Turn with Left Turn Lane In and Out Required (Interrupted Flow-Both Directions)	Other Highways	Multi-lane or 2-lane
Level 6	Right and Left Turn In and Out with Left Turn Lane Optional-In and Out (Uninterrupted Flow-Both Directions)	Collector	2-lane
Level 7	Right and Left Turn In and Out (Safety Requirements Only)	Local/Frontage Road	2-lane

Source: Access Management Guidelines for Activity Centers, NCHRP Report 348

In reference to the latest videotape of an overview of access management produced by FHWA in May 1997, six major benefits are sited that could be obtained in a transportation system by practicing access management techniques, as follows:

1) Provide substantial reduction in accident costs,
2) Maintain the efficient movement of people and goods,

3) Preserve the public investment in transportation infrastructures,
4) Reduce the need to build more roadways,
5) Protect the value of private investments,
6) Enhance the environment and economy of communities.

These benefits coincide with the goals of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). Research in access management can play a key role in reaching the ISTEA goals for management systems, environmental impacts, and metropolitan planning.

1.2 Objectives

The primary objectives of this thesis are:

1) Statistical analysis of accidents on multilane highways in the state of New Jersey,
2) Development of regression models identifying the principal explanatory variables that are related to accident rates occurring midblock to signalized intersection of multilane highways,
3) Summarize the results of a field study on the operational characteristics of a section of multilane highway.

1.3 Thesis Outline

This thesis is comprised of seven chapters. Chapter 1 presents an introduction to access management and outlines the specific objectives of this thesis. Chapter 2 provides a literature review on accident studies related to multilane highways. Chapter 3 presents the problem definition and the methodology followed in this study. Chapter 4 outlines the data collection procedure. Chapter 5 presents the corresponding analysis and the primary results. Chapter 6 summarizes the field study conducted on a section of NJ State Route 27. Chapter 7 presents the conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the main literature related to accident rates 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 significant impact on 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 is also well studied. 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 as great 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 was not well studied. 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 can 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, accidents also increase. 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 with the independent variable of the ADT. The main critic 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: (see Persaud and Mucsi

(1995)), first, the estimation of accidents usually requires the use of the relationship between accidents and the measure of traffic volume, traditionally the Average Annual Daily Traffic (AADT), referring to. But if this relationship was nonlinear, the AADT based models would be unsuitable for the use in estimating safety during portions of a day, for example, specific hours, peak periods, and night. This makes it necessary to use hourly or sub-hourly volumes as one of the independent variables. The second reason, for the aforementioned discrepancy, is that most of the early studies use 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. But, 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 the 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 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. Indeed, 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 not only can they be applied to a specific case, but also they can be applied to various types of entities.

2.2 Impact of Access Points on Accident Rate

The safety impacts 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%. 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

PROBLEM DEFINITION AND METHODOLOGY

3.1 Problem Definition

Two of the primary goals of transportation agencies is the improvement of the safety and the operational efficiency of the highway system. A major category of the highway system are the multilane highways, which are generally located in urban and suburban areas. They either connect two cities an urban area with a suburban area, or a suburban area to another suburban area. The increase in development along multilane highways is a major issue of the State DOTs in the U.S. as well as in other countries. 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 accident causes at the vicinity of signalized intersections, only limited studies have dealt with the accident causes due to access points between signalized intersections for multilane highways. These access points are either unsignalized intersections, driveways, or direct access to various type of facilities such as gas stations, restaurants, residences, etc.. The state of New Jersey requested that a study be undertaken which would identify the major causes of accidents at six selected state routes between signalized intersections.

The principal hypothesis is that the access points of multilane highways located between signalized intersections may be a significant source of accidents. Underlying this hypothesis are the specific geometric, traffic flow and weather characteristics of the access points and the roadway sections which are the primary causes of the accidents occurring at these sections of the multilane highways. Specifically the following categories are identified for analysis 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 reported accidents occurred on multilane highways for sections between signalized intersections. The next section presents the methodology followed for this analysis.

3.2 Methodology

In this research, six principal highways are 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 unavailability, Route 82 was eliminated from the study. This study covers multilane highway sections totaling about 175.8 miles, consisting of 4-lane and 2-lane sections. All geometric elements, traffic volume and accident types pertaining to driveways were taken into consideration. First an analysis of the accidents occurred on a set of New Jersey State multilane highways is conducted. Then a regression analysis is undertaken to identify the relationship between accident rates and a set of independent variables.

Two key terms, access density and accident rate, are used through the process of the study, which are defined as follows:

- Access density is the number of access points per mile (abbreviated in #/mile) on a road section in each direction, refer to equation (1), which is obtained by dividing the number of access points with the corresponding section length. 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

- Accident rate is the number of accidents occurred per million vehicle miles traveled (in #/MVM) on a road section in each direction, refer to equation (2), which is calculated by dividing the number of accidents occurred in each direction with the AADT and length of the road section.

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

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.

3.2.1 Accident Analysis Procedure

A statistical analysis of accidents occurring on New Jersey State multilane highways was conducted on Route 21, 27, 28, 33, and 35. The analysis was conducted by route, direction of traffic and category of accidents. Specifically, the following elements were taken into consideration:

1. Accident location

All accident records were categorized into two types of locations: at signalized intersections and between intersections. The emphasis of this research is on the accidents occurred between signalized intersections. However, the statistical analysis provides a comparison of the proportion of the type of accidents occurred at signalized intersections and between intersections.

2. Collision type

The following collision types are identified: same direction rear collision, same direction side collision, turn collision, object obstacles, overturn, head-on, strike parked vehicle or pedestrian. Some of them may be due to the impact of access points, such as a turn 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 turning left from an access point, or vehicle-1 being parked while vehicle-2 turning right into an access point. The left-turn and right-turn accidents, if occurred on the road sections (not at intersections), are directly relative with the vehicles turning in/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 determined.

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.

The Microsoft Access and Excel software were used for the analysis of the various data. As a database management tool, Access can provide efficient queries and other powerful functions to process large amount of data. The various statistical techniques and worksheet calculation functions provided by Excel was found satisfactory for the needs of this data analysis.

3.2.2 Regression Analysis Procedure

The dependent variable identified in this regression analysis is the accident rate. The following elements were considered as potential independent variables:

- Traffic volume:
    - Traffic volume on main roads,
    - Traffic volume on driveways,
    - Conflict volume.
- Geometric factors of access points:
    - Access classification,
        - Residential,
        - Gas station,

    - ➢ Activity center,
  - ♦ Access point density (spacing): number of access point per mile,
  - ♦ Left turn control (permitted or not).
- Geometric factors:
  - ♦ Number of lanes,
  - ♦ Shoulder (with or without),
  - ♦ Median (with or without).
- Traffic control factors
  - ♦ Speed limit.

In order to conduct an unbiased regression analysis, a careful classification of roadway sections with uniform characteristics was necessary. The analysis resulted in sections ranging from 0.3 to 2.0 miles of length. Several iterations were conducted in finalizing the appropriate sections.

Accidents due to accessing vehicles are usually the result of the conflict between the mainline traffic and the entering/exiting traffic at access points. For two-lane highways, the conflicting traffic is the sum of the mainline traffic and the traffic to/from the access points, which includes both left-turn and right-turn vehicles. For four-lane highways, the conflicting traffic is composed of the accessing traffic and part of the mainline traffic, which includes the traffic in lane-1[1] and part of the traffic in lane-2.[2] The percentage of the traffic in lane-2, which is part of the conflicting traffic, can only be estimated through a field study. This percentage is a function of the driving

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[1] Lane-1 is the lane that provides access from the highway or arterial to the access driveways on the right,
[2] Lane-2 is the lane left of Lane-1.

characteristics of the drivers either exiting directly from lane-2 to the driveway or entering into lane-2 from the driveway, including both left-turn and right-turn vehicles. The geometric factors may also have a significant impact on accident rates. Therefore, the analysis was carried out by classifying the roadway sections based on common geometric characteristics, such as shoulder or no shoulder, presence of median and access classification. Furthermore, traffic control factors such as the speed limit and left turn control (e.g. no left turn) were taken into consideration in the classification of the roadway section.

Access densities and accident rates were computed by section, and comparative analysis was conducted by using the access density versus the accident rate diagrams along the mileposts. Tentative statistical regression models between access densities and accident rates were developed by grouping the study sections according to the geometric and traffic characteristics.

Based on the data availability for the analysis, year 1994 was chosen as the study year. Every case study was based on the data of year 1994. Out of the six New Jersey State highways, Routes 21, 27, 28, 33 and 35 were taken into consideration for the analysis. Route 82 was excluded due to the incompleteness of the corresponding data stated earlier.

3.2.3 Field Study

The field study was conducted on the Union County Liden Section of NJ State Route 27, which was one of 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 by using traffic counters. A video camera was used to record the speed measurements in a test vehicle. This survey covered both AM/PM peak periods and off-periods for the five weekdays from Monday to Friday.

CHAPTER 4

DATA COLLECTION

The principal data collected included access point information, reported accidents, roadway geometric and traffic conditions, which were provided by the NJ Department of Transportation. The data collected focused on 4-lane and 2-lane highways and covered the four years from 1991 to 1996. Six New Jersey State highways were considered: Routes 21, 27, 28, 33, 35 and 82. The roadway geometric data were extracted from the New Jersey state-line diagrams. The geometric data include the number of lanes, shoulder, median, intersections, functional class, and speed limit. The traffic volumes were also obtained from the state-line diagrams. The milepost, the points of the geometric changes and their locations could easily be identified on the state-line diagrams, with error differences of less than 0.001 miles.

The information on access points was extracted from videotapes provided by NJDOT. The specific video monitor was set in the front of the test vehicle and recorded the milepost, date, time, vehicle speed and the right side of the roadway. By viewing the videotapes utilizing the slow motion function of the VCRs, the access type and location could be identified. The error difference is within the range of 0.001 miles, which was considered adequate for the scope of this study. The access point information has been extracted from the seven video tapes including Routes 21, 27, 28, 33, 35, 82 for years 1991, 1992, 1993, 1994 and 1995.

All the accidents referred to throughout this study are the reported accidents on these routes. Based on previous studies, it is expected that the reported accidents are only a fraction of the total. The reported accident records were provided by the Office of Telecommunications and Information, Department of the Treasury through NJDOT, in a diskette containing data from reports MACLSTRT-1 and MACLSTRT-2 for the years 1989 through 1994, except for 1990. The accident database is contained in self-extracting files, which include: the route number, milepost, location, collision type, vehicle direction, vehicle type, and vehicle action. They also contain data on weather, surface, light, time, date, number of persons killed and injured, etc. The accident data were converted into a Microsoft Access data format from the original format of the data sets provided by NJDOT.

Traffic volume data were obtained by accessing the NJDOT database system through their computerized Bulletin Board.

The data collected are summarized as follows:

- Reported accident data (MACLSTRT-1 and MACLSTRT-2); Years 1989, 1991, 1992, 1993, 1994,
- NJ state-line diagrams (1996),
- Access point information (7 videotapes from years 1991 to 1995),
- AADT data from 1992 to 1996 for the selected routes under investigation (NJDOT Bulletin Board).

CHAPTER 5

ACCIDENT ANALYSIS AND RESULTS

5.1 Accident Analysis in General

In this study, the reported accident analysis is based on a NJDOT data file "Detail of Motor Vehicle Accidents On Mileposted Highways In Route & Milepost Order", which is also known as "MACLSTRT-2". The accident records retrieved for this study cover the period from January 1, 1994 to December 31, 1994. The routes in this study include Routes 21, 27, 28, 33 and 35. Each reported accident record in MACLSTRT-2 includes the following information: collision types, vehicle directions, vehicle type, vehicle actions, weather conditions, road surface conditions, light conditions, month/date, day of week, hour, vehicle contribution circumstances, and the location of accidents (at intersections / between intersections). In each reported record, the number of injured and killed are also recorded.

The research objective of this study is to conduct an analysis of the impact of access driveways on accidents, the accidents occurred at signalized intersections are beyond the scope of this study. The accident records in MACLSTRT-2 are classified into two groups:

1) Section-accidents: accidents occurred between signalized intersections are defined as section-accidents and,

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

Although intersection-accidents are not the primary concern of this study, they are included for comparison purposes.

In this section a comparison study is conducted between intersection-accidents and section-accidents for each route by collision types, vehicle actions, weather conditions, road surface conditions, light conditions, month, day of week, hour and vehicle contribution circumstances. In the collision type comparison, collision types are divided into same-direction-rear, same-direction-side, left turn collisions, collision with objects, overturn, strike parking vehicle, pedestrian, angle collision, head-on, and other collision types. For each of these subgroups, the percentage (same-direction-rear, same-direction-side, left turn collisions, collision with objectives, overturn, strike parking vehicle, pedestrian, angle collision, head-on, and other collision) is calculated for both section-accidents and intersection-accidents, and a comparison bar chart is drawn for each of the subgroups.

5.1.1 Accident Analysis by Location

The percentage of section-accidents as part of the total number of accidents occurring on all routes (Route 21,27, 28, 33, and 35) and the percentage of section-accidents per route are presented in Figures 5.1 and 5.2, respectively.

As seen from the figures, the percentage of section-accidents is approximately 30% for all routes, with the exception of Route 21. Route 21 is not taken into consideration

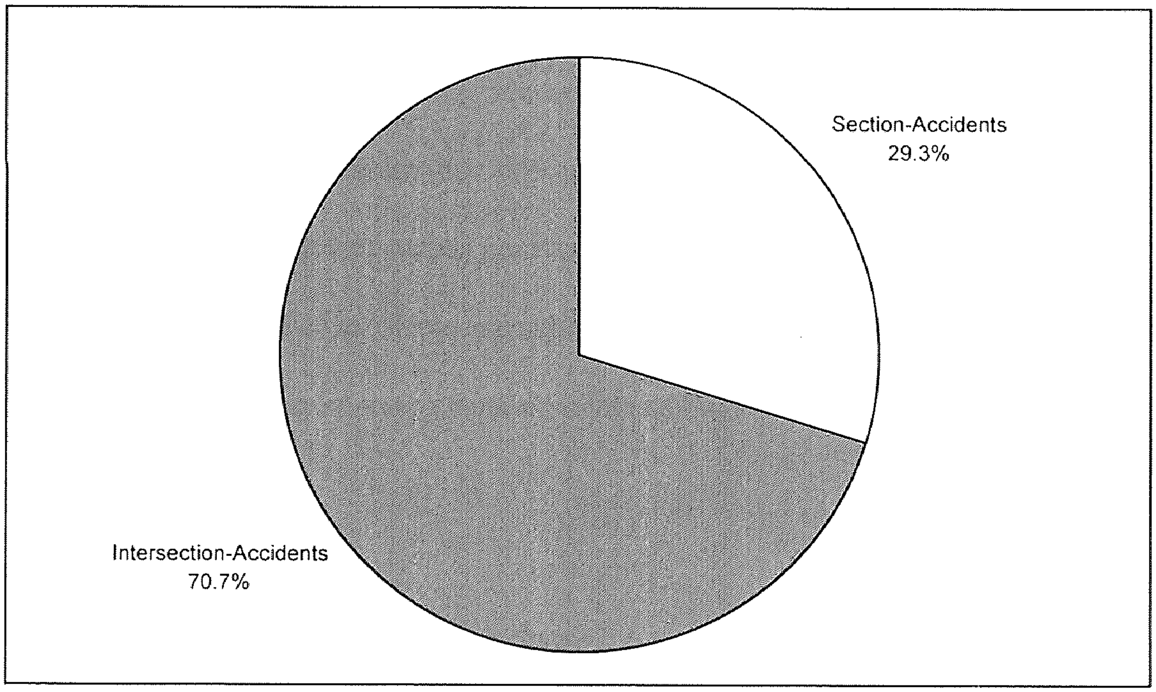

Figure 5. 1 Percentage of Section-Accidents as Part of the Total Accidents of all Routes (Routes 21, 27, 28, 33 and 35); 1991-1994

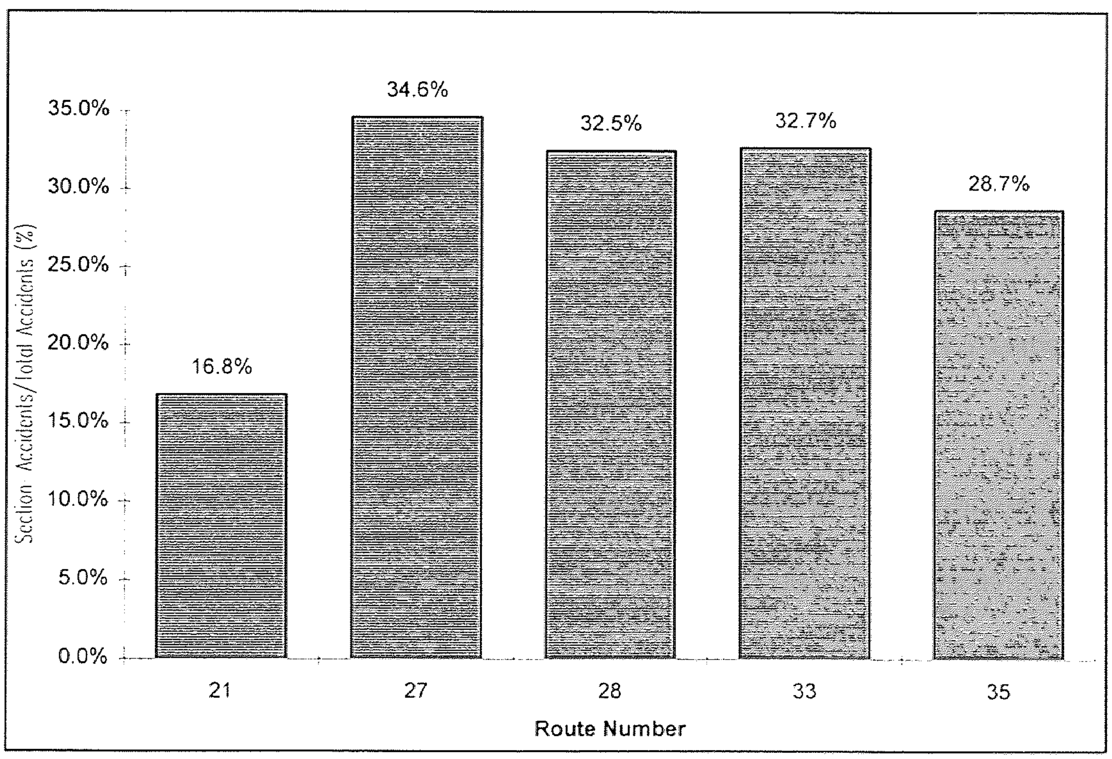

Figure 5. 2 Percentage of Section-Accidents (Section-Accidents/ Total accidents) vs. Route Number

because of its small sample size. These values indicate that the majority (about 70%) of accidents occurred at signalized intersections, and only about 30% of the accidents occurred between intersections. The 30% accidents could be caused either by vehicles entering or exiting midblock access points or by vehicles passing through the road segment. The number of accidents occurring in the vicinity of access points can only be identified with the help of access location information, which is addressed later in this report.

5.1.2 Accident Analysis by Collision Type

In this section, a comparison of section-accidents and intersection-accidents is conducted based on collision types. In MACLSTRT-2, collision types are divided into the following categories: same direction rear collision (SAME DIR-REAR), same direction side collision (SAME DIR-SIDE), left turn collision (LEFT TURN), collision with objectives (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 percentages of the types of collisions are summarized in Table 5.1 and a series of bar charts.

The percentages of left turn collisions and angle collisions of intersection-accidents are higher that those of section-accidents (See Figures 5.3 and 5.8, respectively). This observation can be justified by the fact that more left turning movements occur at intersections in comparison to those occurring between intersections.

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%

Table 5.1 (Continued)

Route #	Collision Type	Section-accidents	Intersection-accidents	Total
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%

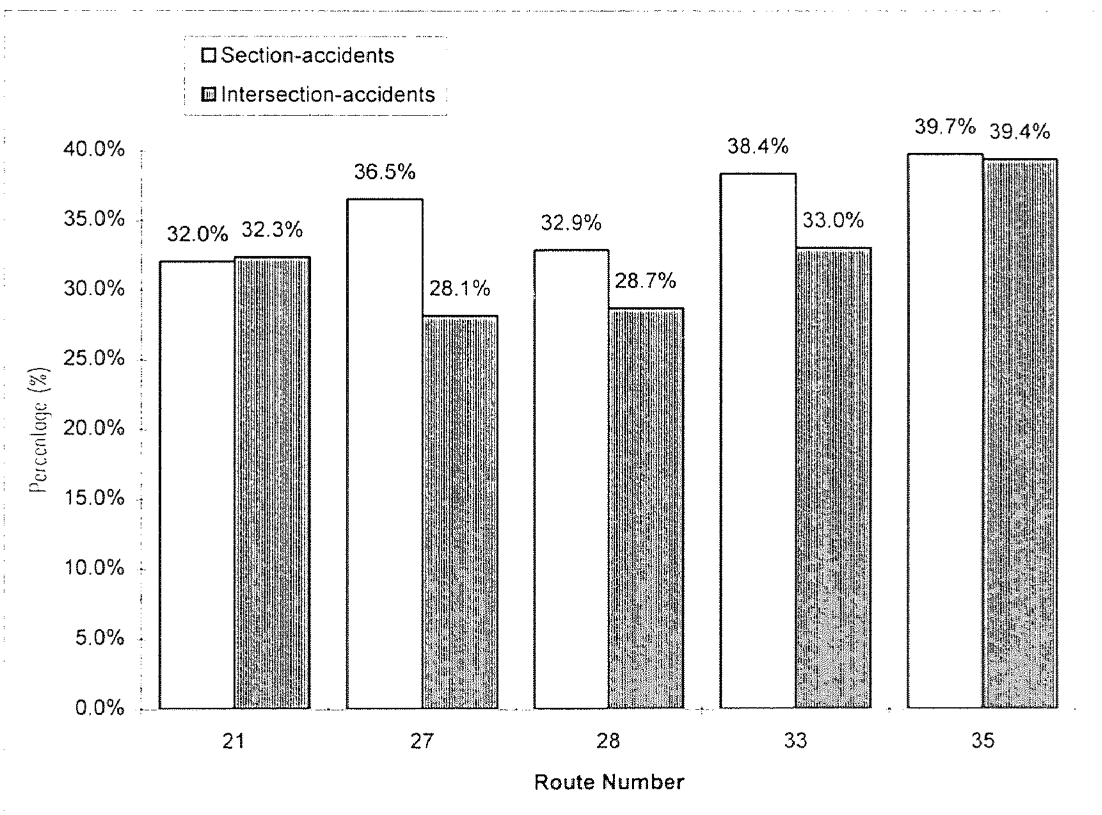

Figure 5. 3 Same Direction Rear Collision — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

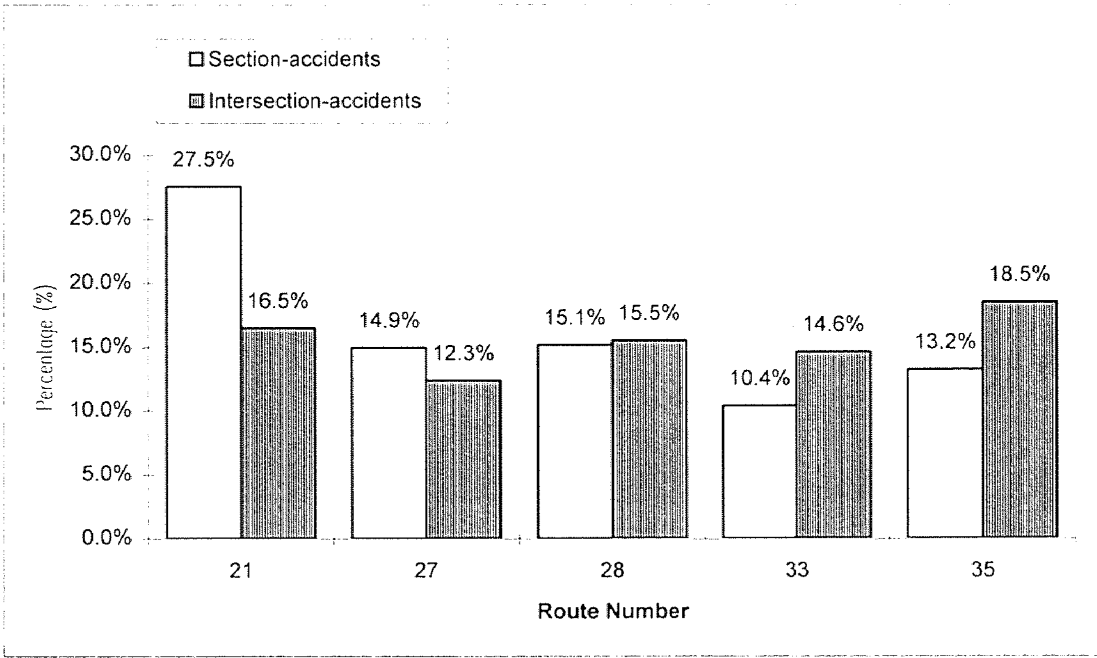

Figure 5. 4 Same Direction Side Collision — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

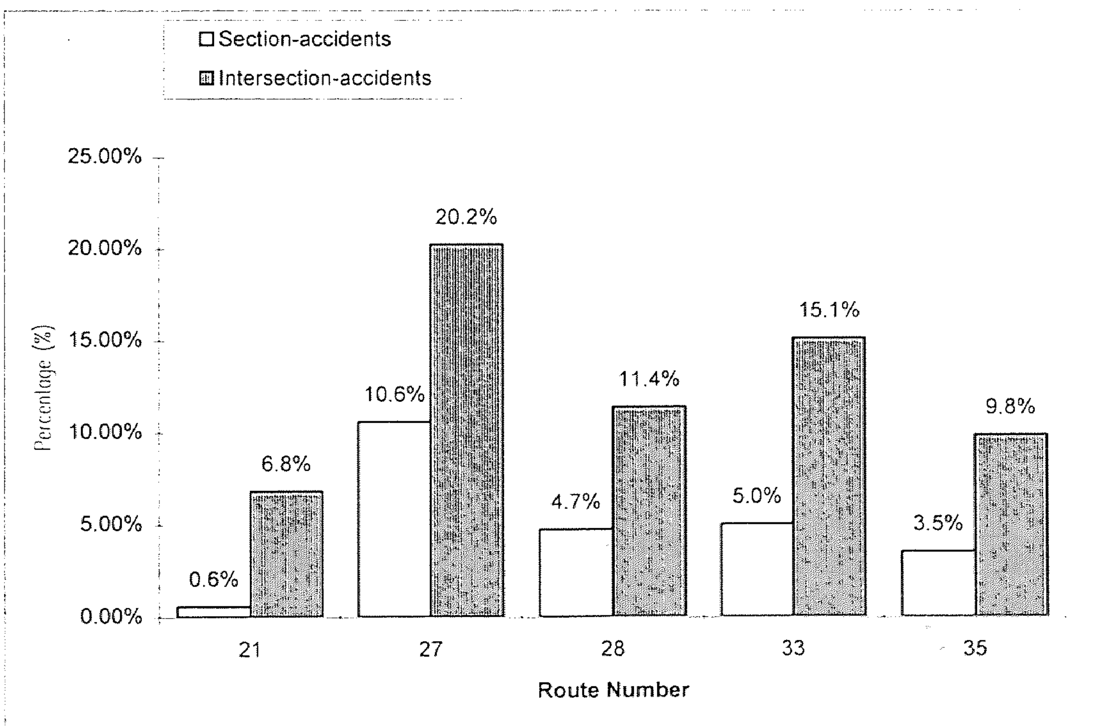

Figure 5. 5 Left-turn Collision — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

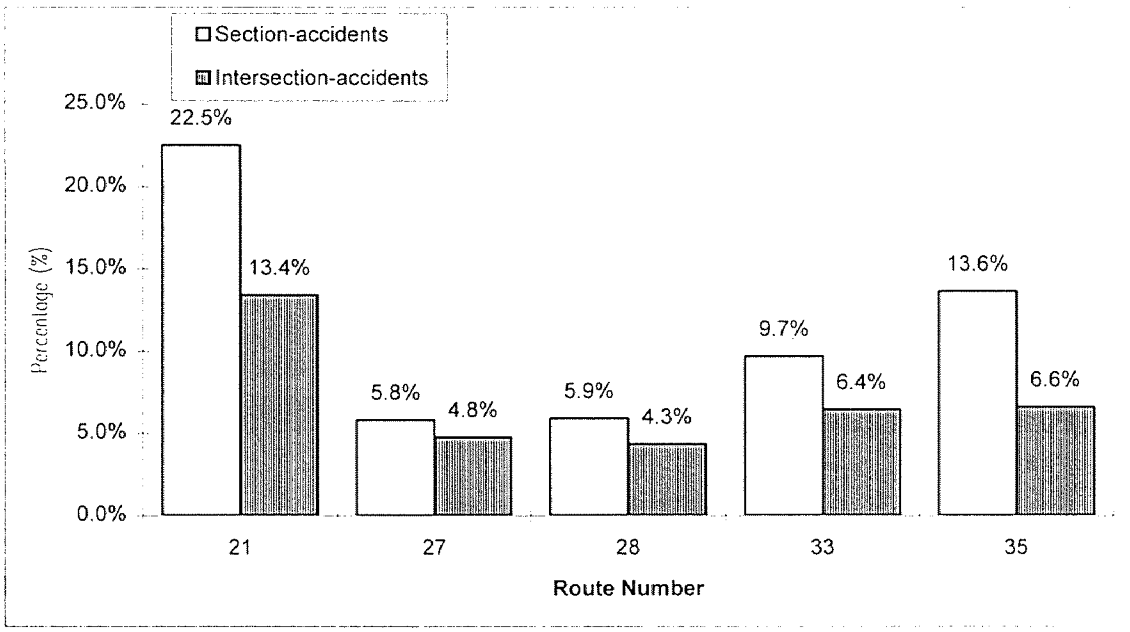

Figure 5. 6 Collisions with Objects — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

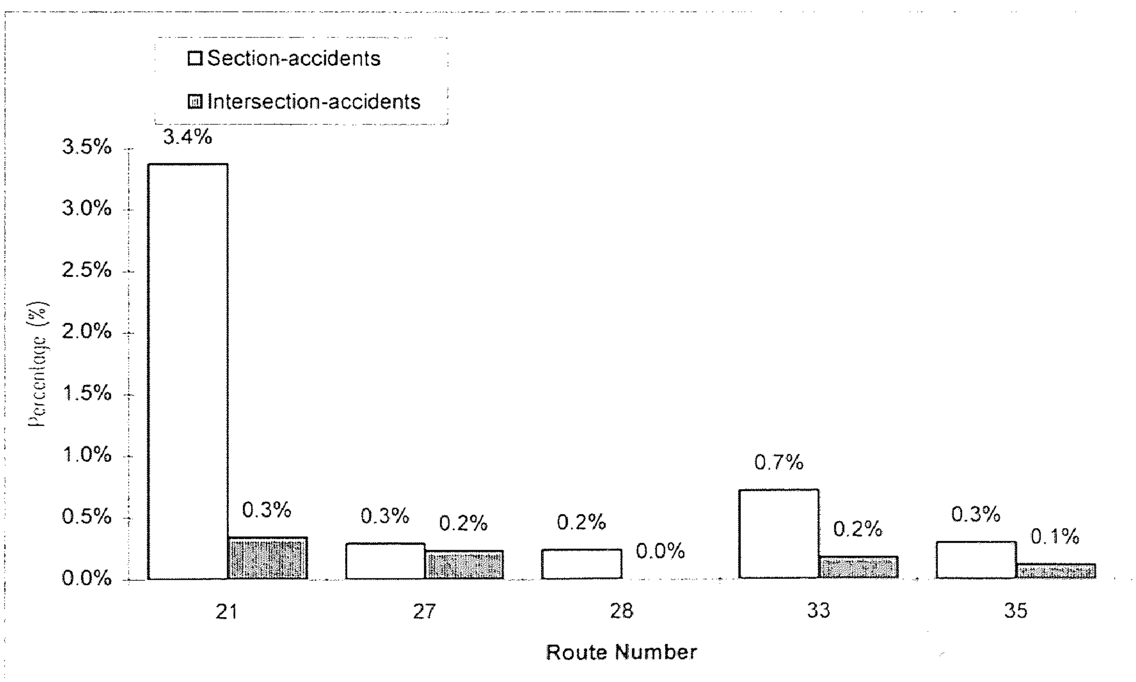

Figure 5. 7 Overturn Collision — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

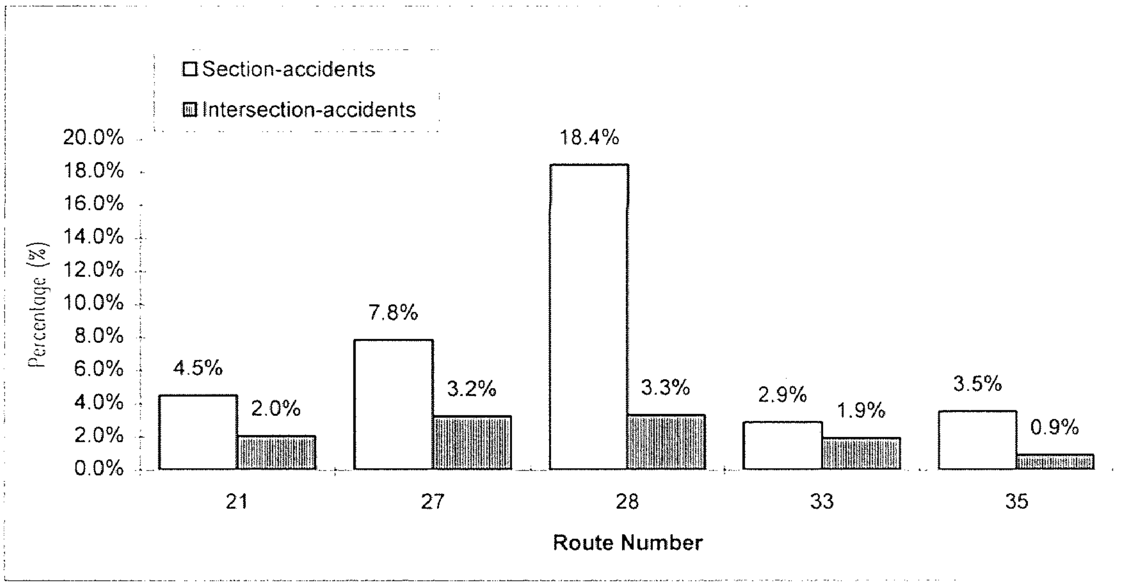

Figure 5. 8 Strike Parking Vehicle Collision — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

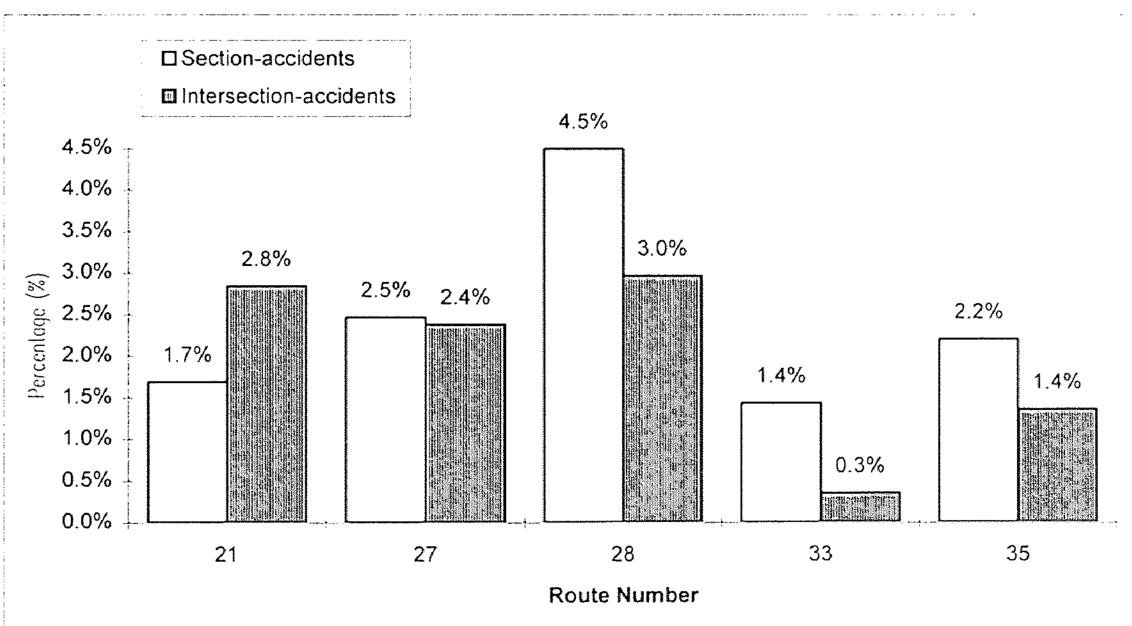

Figure 5. 9 Pedestrian Collision — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

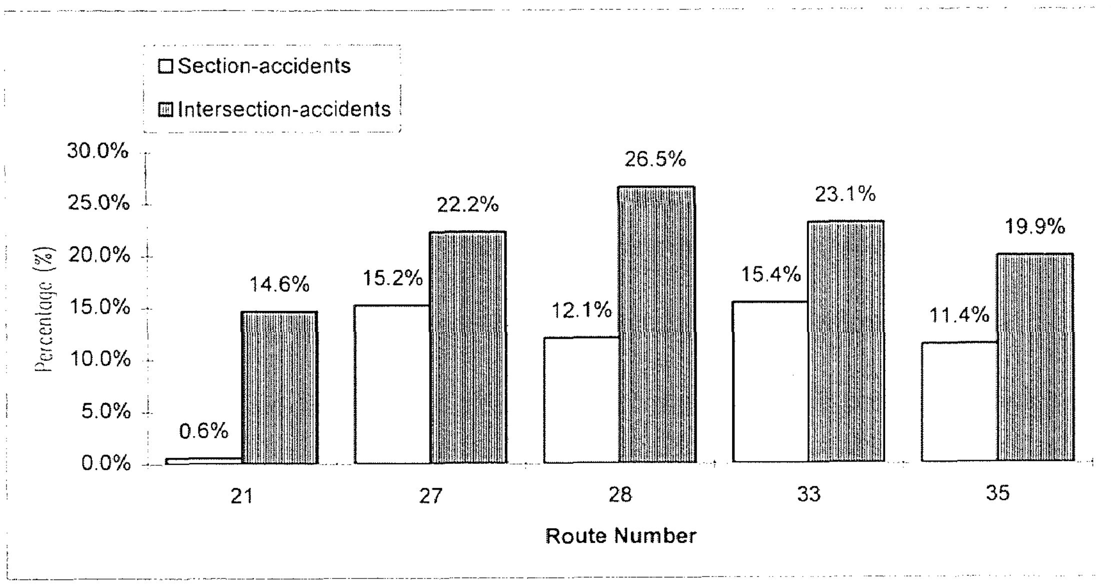

Figure 5. 10 Angel Collision — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

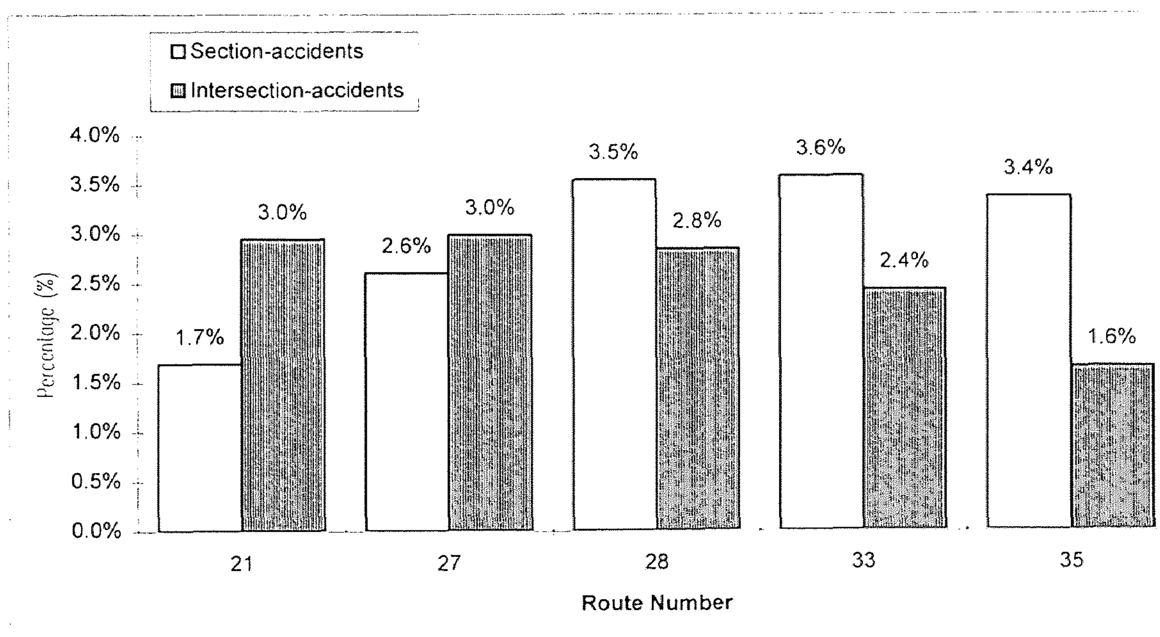

Figure 5. 11 Head-on Collision — Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

The majority of midblock access driveways have no physical left-turn restrictions, although most of the left-turning movements are illegal. In some multilane highways, the median acts as a barrier to physical left-turn movements. The higher percentage at intersections involving angle collisions may be attributed to the presence of a higher number of conflicting movements at intersections than between intersections.

The percentages of collisions with objects, over turns and strike parking vehicles of intersection-accidents are lower than those of section-accidents (see Figures 5.6 - 5.8) The occurrence of accidents between intersections and at intersections may be attributed to the following causes:

- Collision with object accidents: The concentration of drivers rises as they approach a signalized intersection that may explain the lower percentage observed. In contrast, the absence of any traffic control device between intersections reduces the alertness of the drivers. The concentration of the drivers as they drive between intersections maybe reduced due to the presence of various distractions such as pedestrians, restaurants, gas stations, etc.
- Strike parking vehicle accidents: Parking maneuvers increase the conflict points along the roadway. Driver inattention to vehicles which want to park, in combination with insufficient spacing between the leading and the following vehicles are the primary causes of these types of accidents. Again, the expected alert increase of drivers at the vicinity of signalized intersections may explain the relative lower accident percentages observed versus the section accident percentages (see Figure 5.8).

- Head-on collision accidents: The occurrence of these accidents may be attributed to driver aggressiveness entering into the lanes of the opposing traffic. The results here are mixed for the different routes examined.
- Collisions with pedestrians: The occurrence of these accidents at signalized intersections may be attributed to both drivers and pedestrians. The occurrence of these accidents between intersections may primarily be attributed to pedestrians trying to cross the highway or arterial, or standing/walking near the curb. However, driver inattention and speeding may also contribute to these accidents. With the exception of Route 21, signalized intersection accidents exhibit lower accident percentages than the corresponding section accident percentages.

5.1.3 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. In MACLSTRT-2 accident records, the actions of both vehicles are recorded. As long as any one of the two vehicles is in left-turn or right-turn actions, the accident is considered as a left-turn accident or a right-turn accident, respectively, (see Figure 5.12).

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

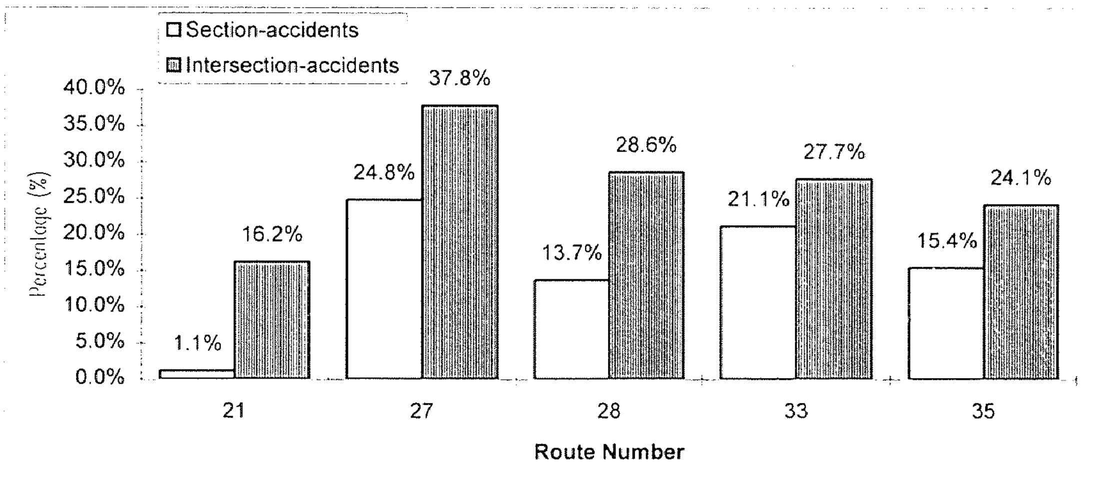

Figure 5. 12 Left-turn Accidents—Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

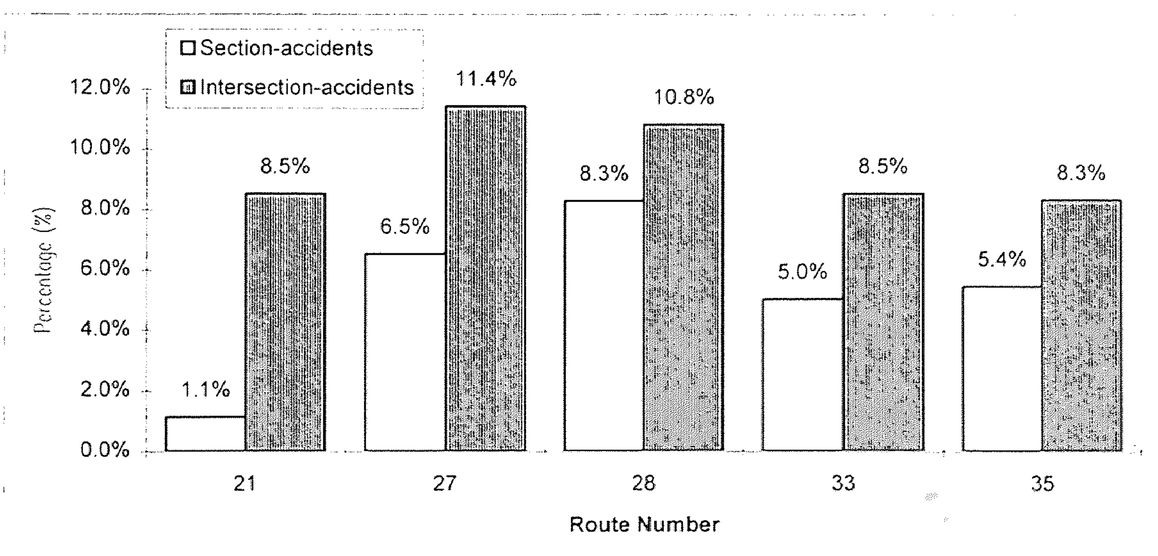

Figure 5. 13 Right-turn Accident—Section-Accidents (%) and Intersection-Accidents (%) vs. Route Number

It is noted that section-accidents caused by turning vehicles occur when vehicles enter or exit midblock access points, (see Figure 5.14).

The percentage of section-accidents caused by turning vehicles ranges between 21% and 31%, with the exclusion of Route 21. This implies that 21-31% of section-accidents is caused by vehicles entering or exiting access points.

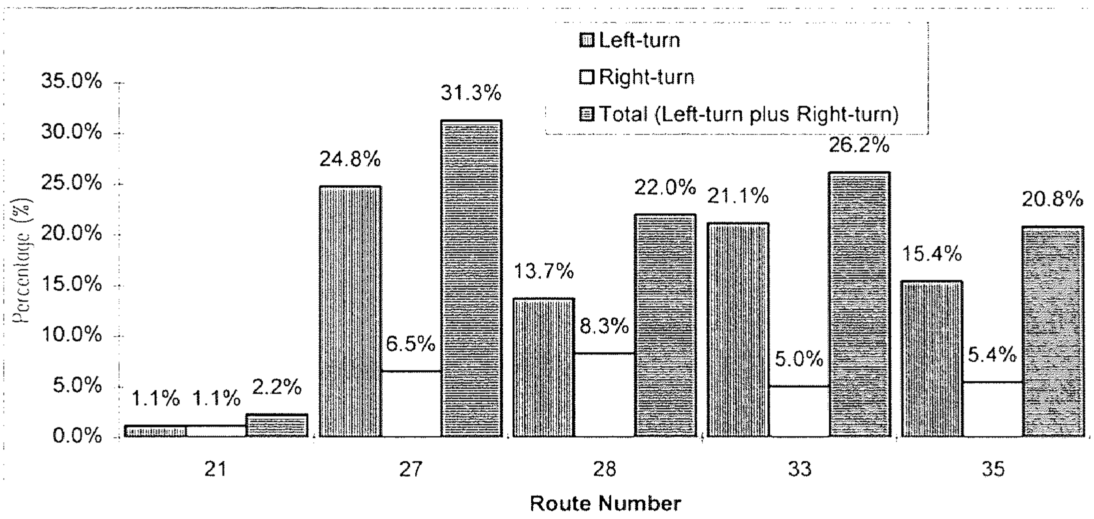

Figure 5. 14 Percentage of Section-Accidents Caused by Turning Vehicles vs. Route Number

5.1.4 Section-Accident Analysis by Turning Action

All section-accidents involved with turning vehicles are identified as access related accidents. In this section, section-accidents caused by turning vehicles are divided into left-turn accidents and right-turn accidents, which refer to the accidents with either of the two vehicles in left turning or right turning actions. Then, left turn accidents are divided into the types of going through plus left-turn, parked plus left-turn, stopped plus left-turn, right-turn plus left-turn, and type of others. Right turn accidents are divided in the same way except that the second vehicle being in right turning action. The results are summarized in Figures 5.15 and 5.16 for the left-turn and right-turn accidents, respectively.

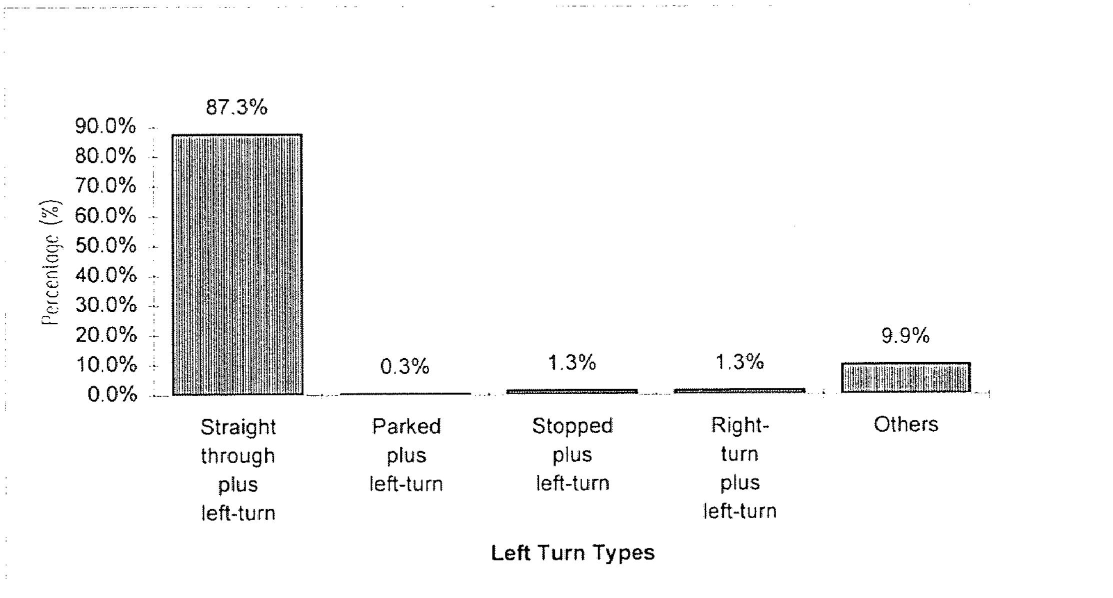

Figure 5. 15 Left-turn Section-Accidents Percentage by Type

Figures 5.15 and 5.16 indicate that the majority of section-accidents involved with turning vehicles are caused by a straight through vehicle (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 accidents respectively. This result implies that a large portion of access related accidents are caused by a vehicle moving straight through on the main road and a vehicle entering or exiting an access point.

5.1.5 Accident Analysis by Vehicle Contribution Circumstance

In database MACLSTRT-2, vehicle contribution circumstances are 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 5.17.

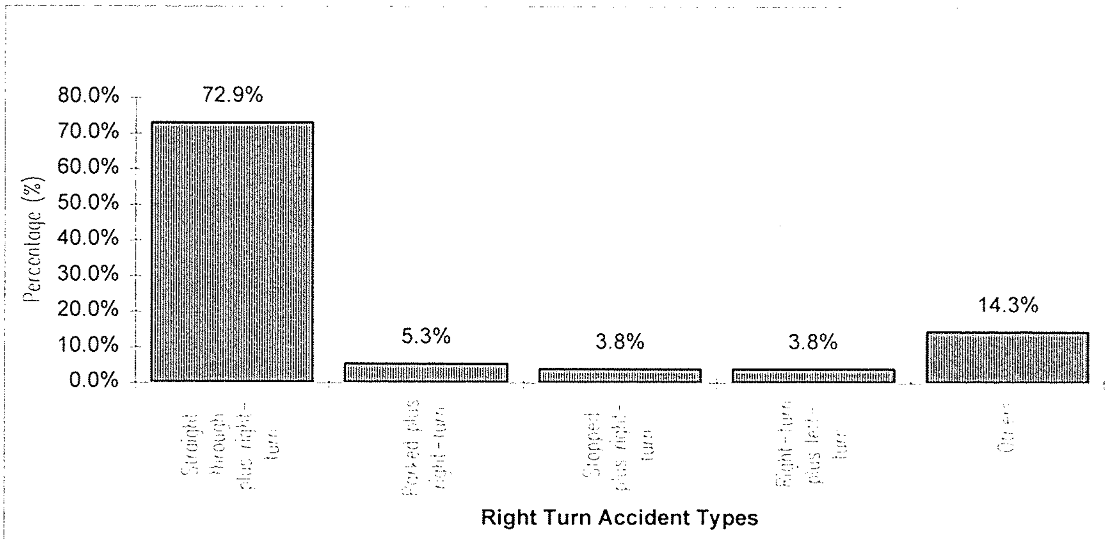

Figure 5. 16 Right-turn Section-Accident Percentage by Type

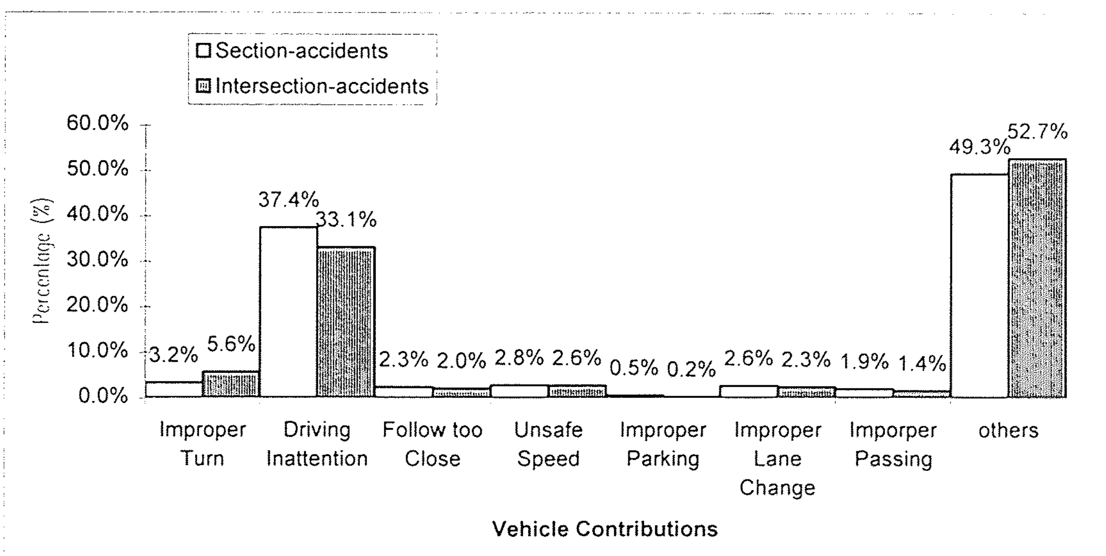

Figure 5. 17 Percentage of Section-Accidents (%) and Intersection-Accidents (%) by Vehicle Contribution Circumstances

5.1.6 Accident Analysis by Weather Condition

The weather conditions can be 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 is conducted by calculating the percentage of accidents reported under different weather conditions for each route. See Figures 5.18 to 5.20.

As seen from Figures 5.18 and 5.19, clear and rain weather conditions do not show any apparent difference between section-accidents and intersection-accidents. It is noted though that for Routes 21 to 35, intersection-accidents exhibit a much higher accident occurrence percentage than the corresponding section-accidents. It is observed in Figure 5.20, for all the routes, that the percentages of section-accidents reported are higher than those of intersection-accidents.

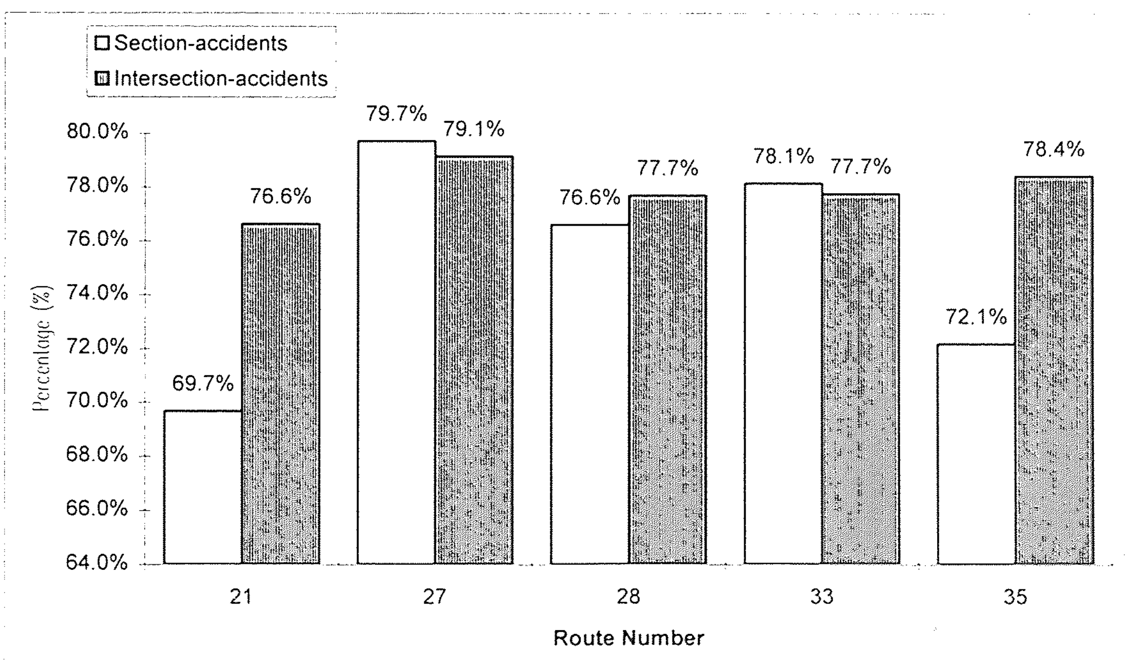

Figure 5. 18 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Clear Weather Conditions

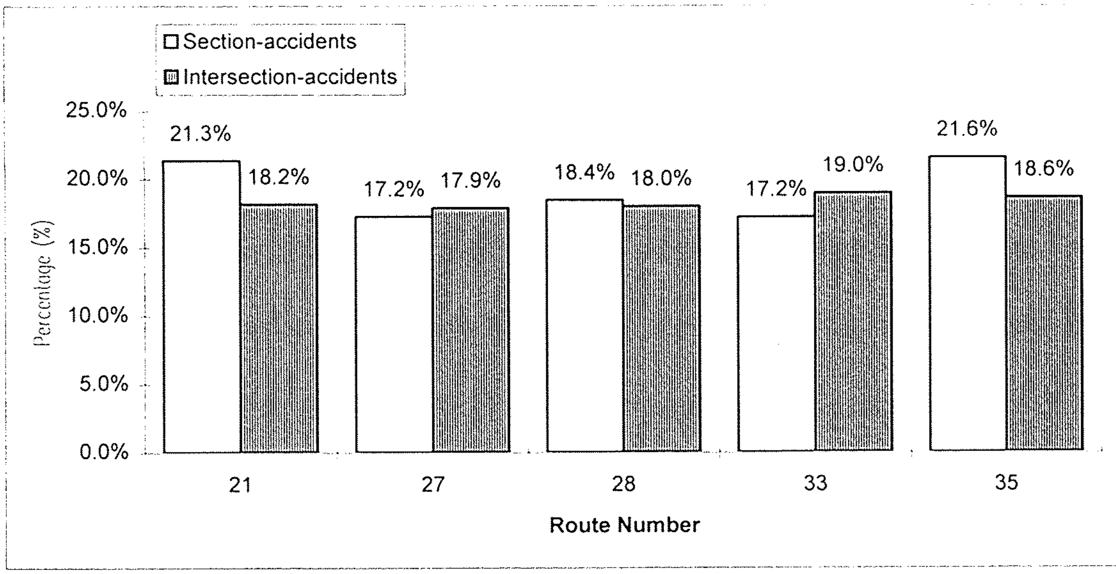

Figure 5. 19 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Rain Weather Conditions

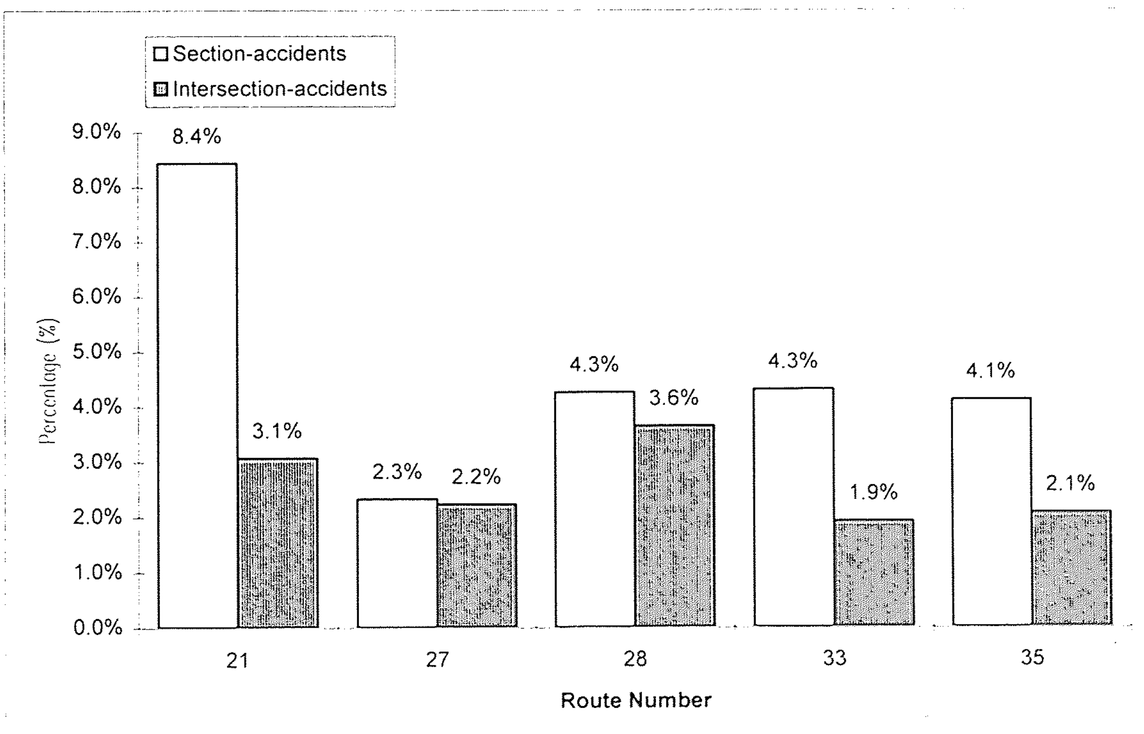

Figure 5. 20 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Snow Weather Conditions

5.1.7 Accident Analysis by Surface Condition

Surface conditions are very important in safety analysis, since a substantial number of accidents occur when the roadway surface is in bad condition. Surface conditions are closely related to weather conditions, however they are not identical. A bad weather may only last for one day, but bad surface conditions may last for several days even after the bad weather is gone. Based on the information in MACLSTRT-2, surface conditions are grouped into dry, wet, snow and ice. This classification parallels the classification of weather conditions that include clear, rain, and snow. The percentages of accidents for different surface conditions were calculated both for section-accidents and intersection-accidents. The results are presented in Figures 5.21, 5.22 and 5.23, for dry, wet, snow and ice pavement surface conditions, respectively.

The results of the accidents under dry surface conditions (Figure 5.21) show no apparent difference between section-accidents and intersection-accidents. Under wet surface conditions (Figure 5.22), 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, the percentages of section-accidents are higher than the percentages of intersection-accidents. The results of the surface condition analysis are consistent with those of weather condition analysis.

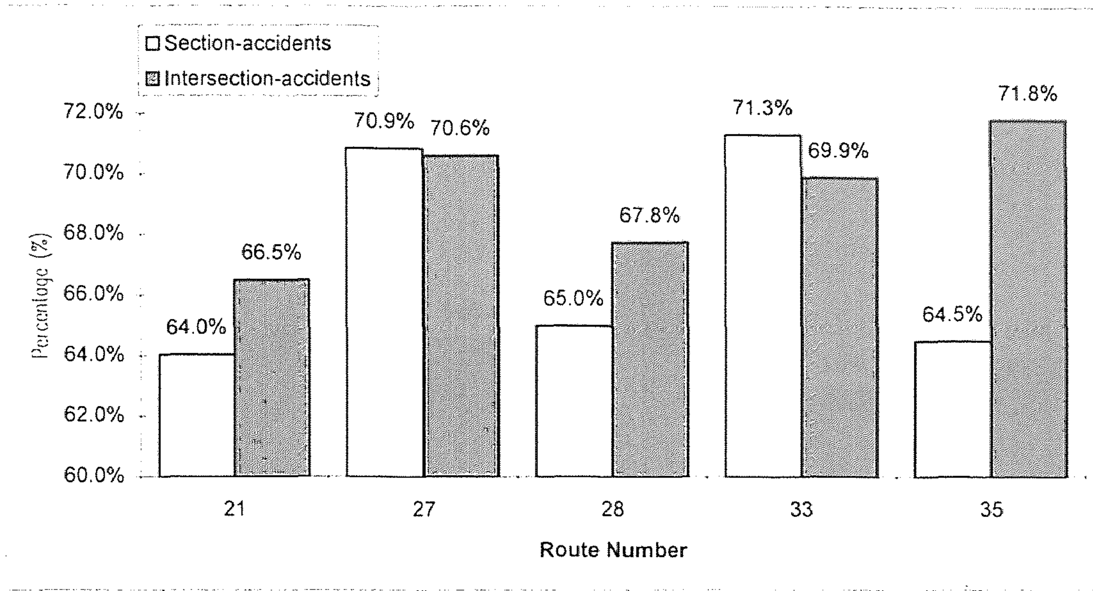

Figure 5. 21 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Dry Pavement Surface Conditions

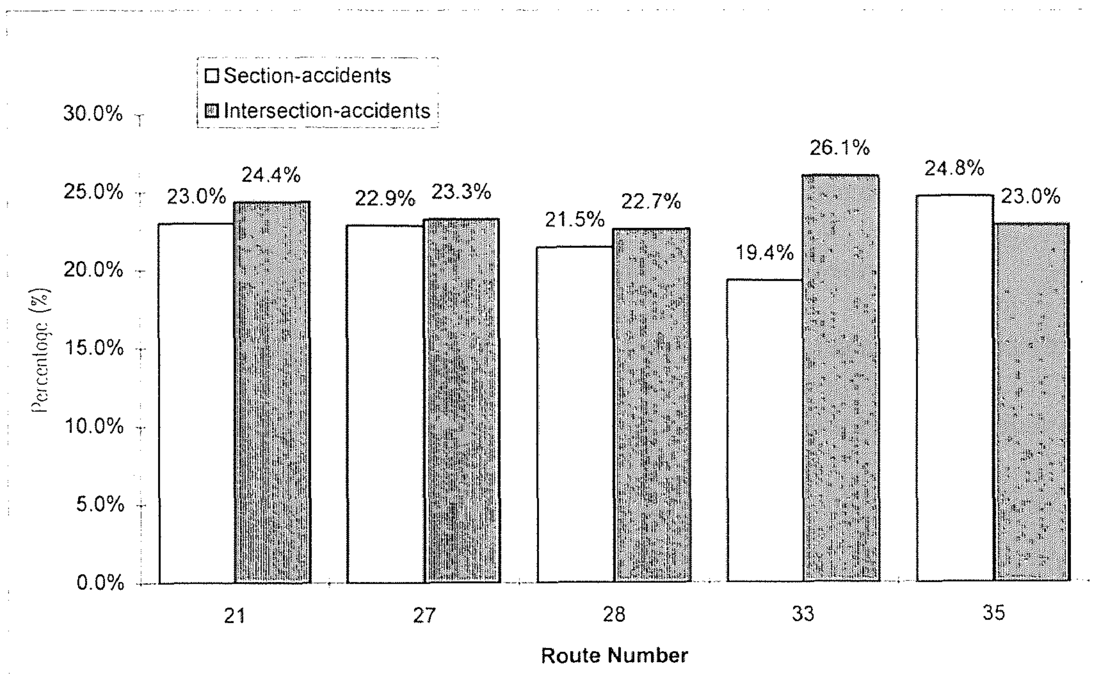

Figure 5. 22 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Wet Pavement Surface Conditions

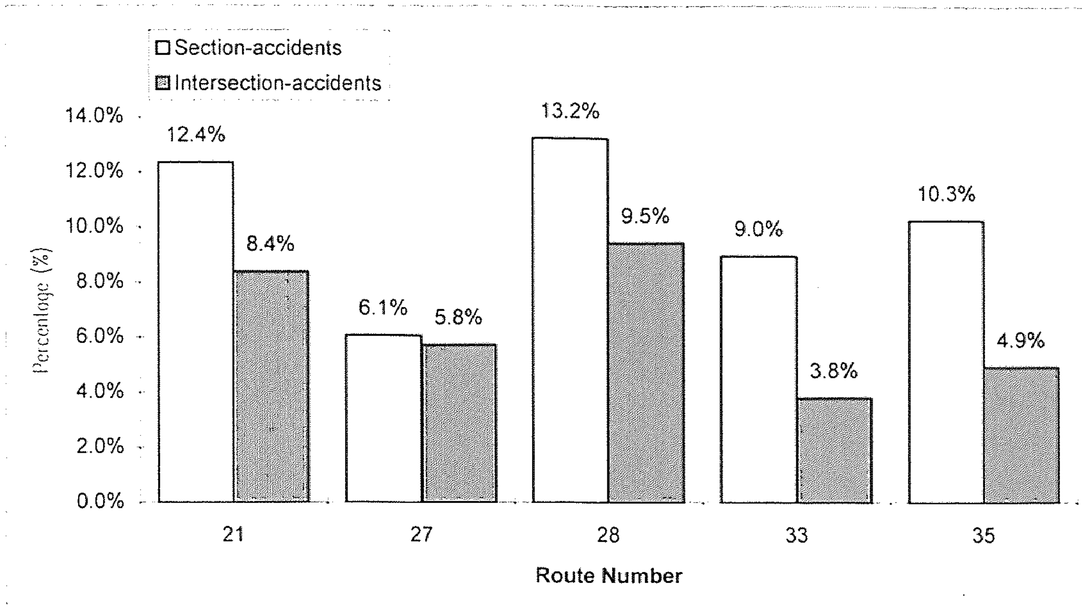

Figure 5. 23 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Snow and Ice Pavement Surface Conditions

5.1.8 Accident Analysis by Light Condition

Light conditions are 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 5.24, 5.25, and 5.26, respectively.

As seen from Figures 5.24, 5.25, and 5.26, the majority of accidents occur during day light conditions. With the exception of Route 21, which is not typical because of its small sample size, over 70% of all the accidents occur in day light conditions. The percentages of accidents occurring in dark light conditions range between 20% and 30%. Day light and dark light conditions do not show any significant difference on the patterns of section-accidents and intersection-accidents.

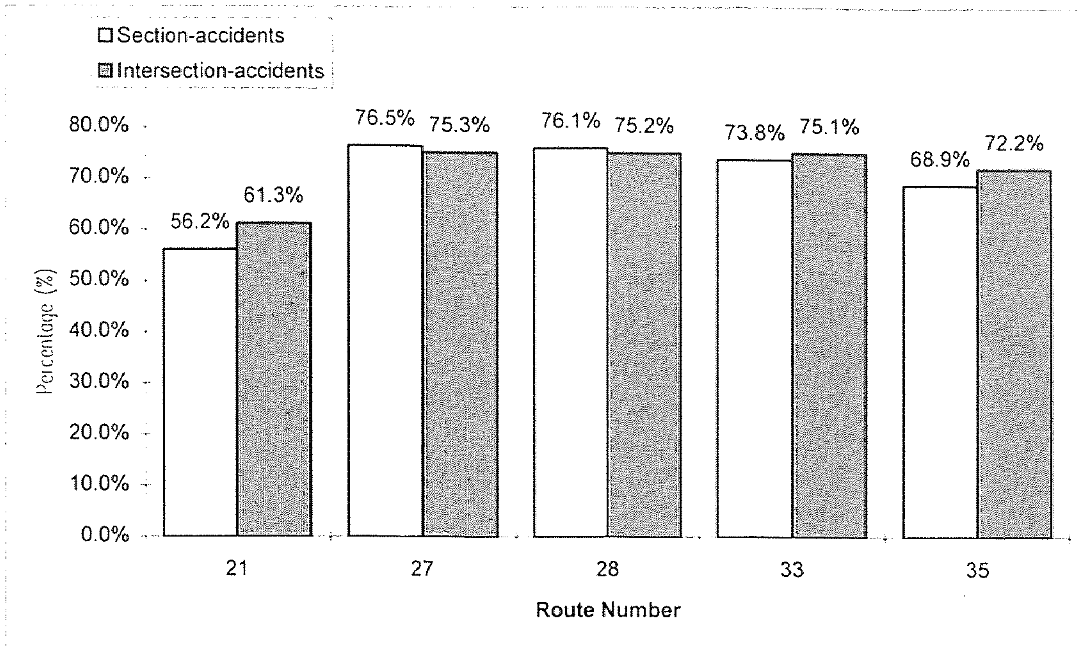

Figure 5. 24 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Daytime Conditions

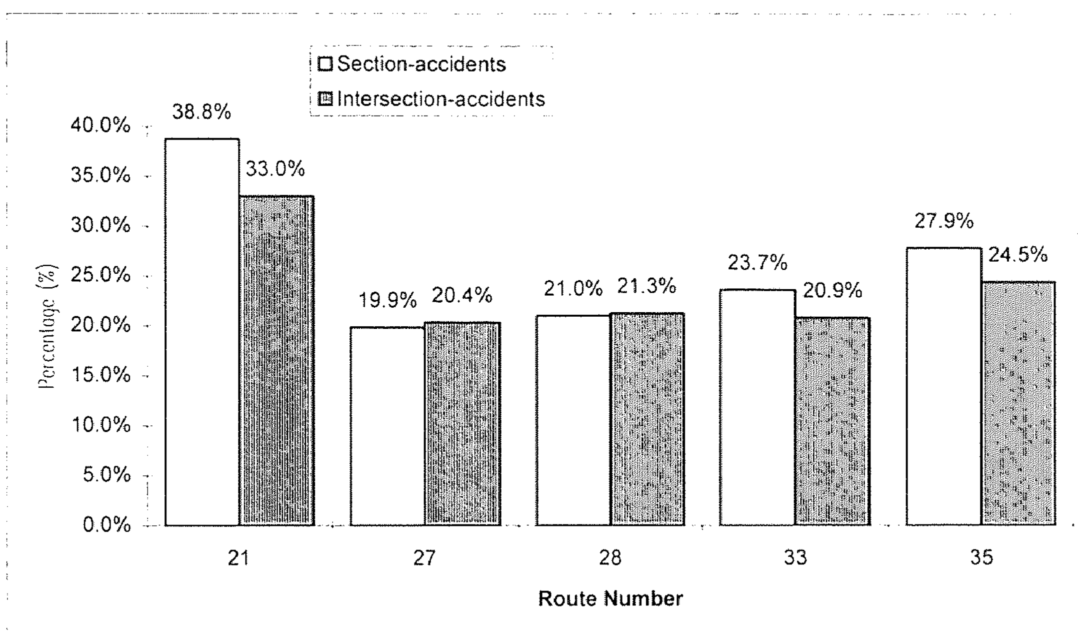

Figure 5. 25 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Dark Conditions

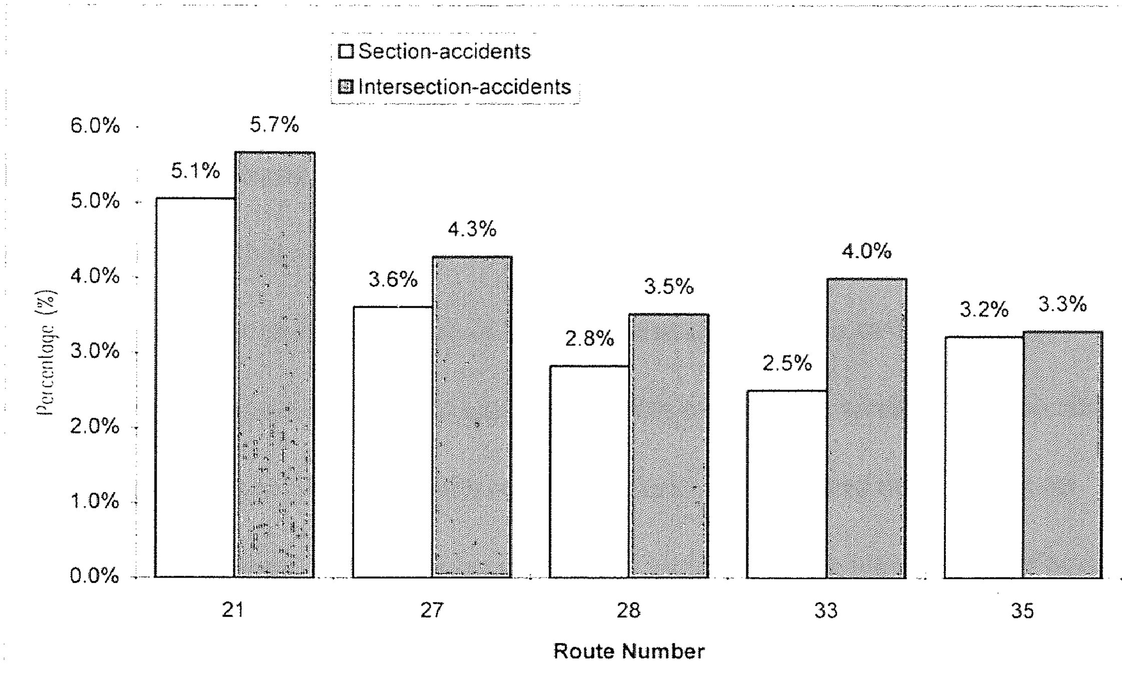

Figure 5. 26 Percentage of Section-Accidents (%) and Intersection-Accidents (%) under Dawn and Daybreak (DNDK) Conditions

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

In this section, accidents are analyzed by month, day of week, and hour, and the results are presented in Figures 5.27, 5.28, 5.29 and 5.30, respectively.

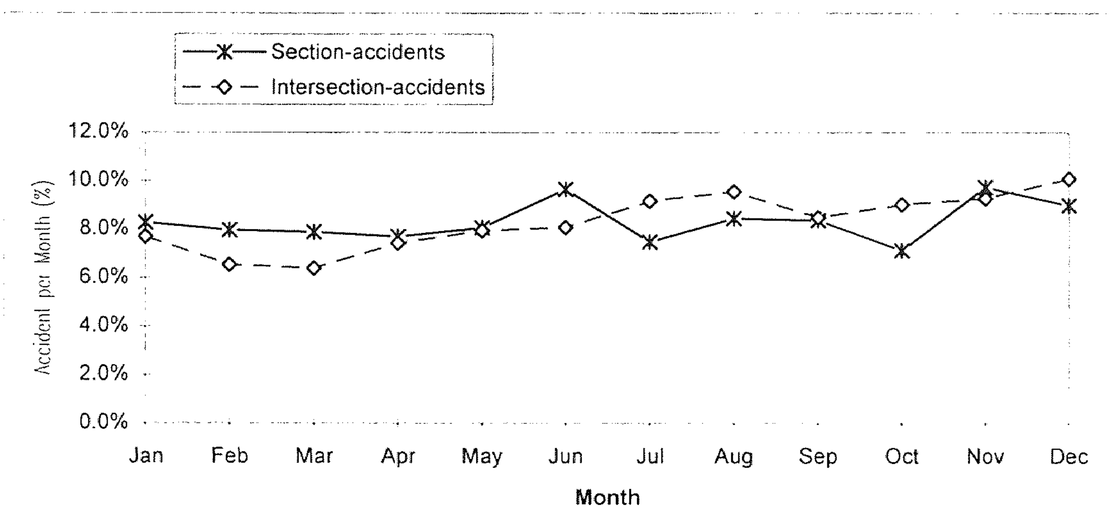

Figure 5. 27 Accident Percentage for all Routes vs. Month

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

The accident analysis by day of the week was divided into two categories, weekdays and weekends. The accident occurrences of different weekdays do no show any significant differences between each other. Similarly, the accident occurrences on Saturdays and Sundays also show no substantial variations. The percentages of accidents occurred on weekdays and weekends were calculated for both section-accidents and intersection-accidents, and the results are shown in Figures 5.28 and 5.29 for each category, respectively.

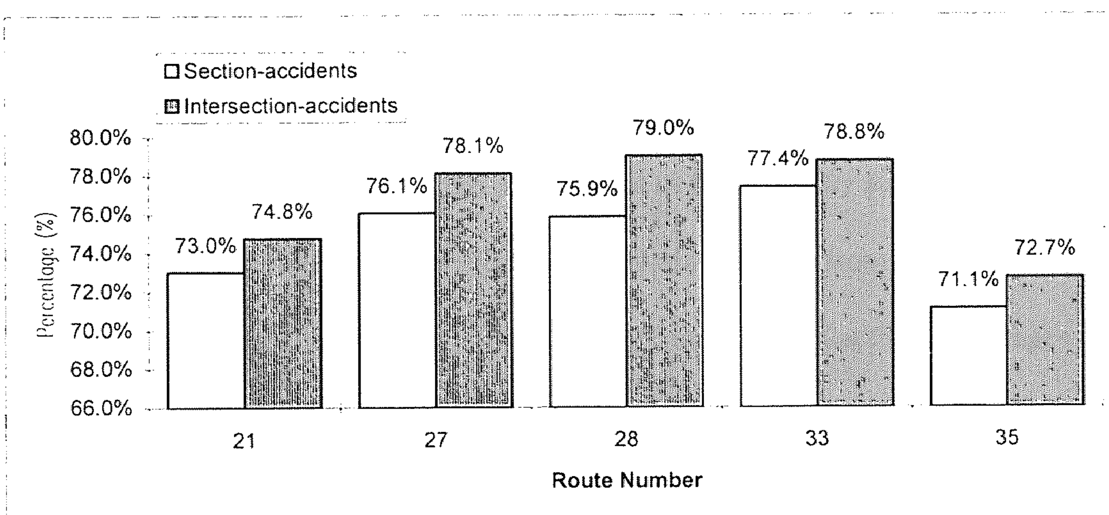

Figure 5. 28 Percentage of Section-Accidents (%) and Intersection-Accidents (%) on Weekdays vs. Route Number

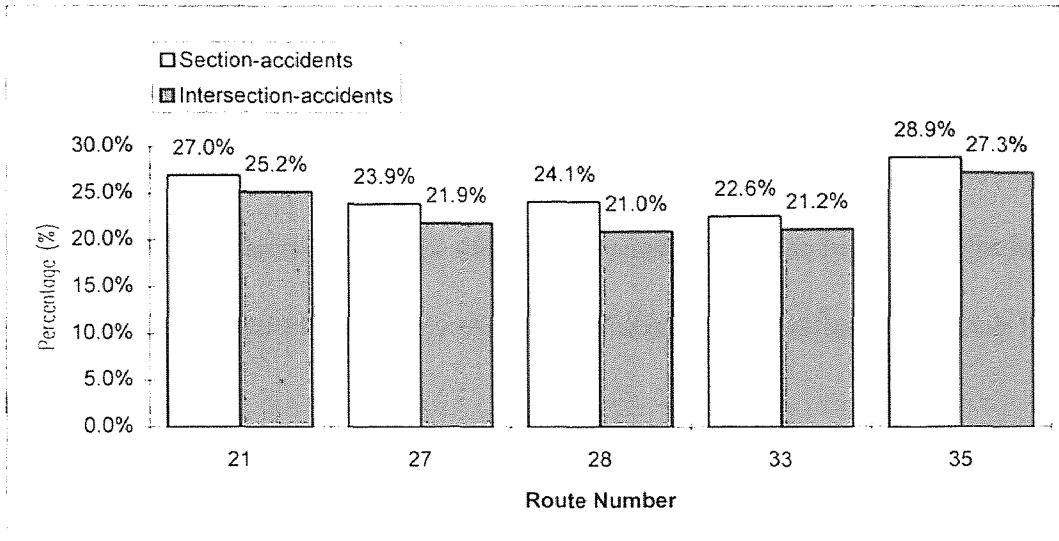

Figure 5. 29 Percentage of Section-Accidents (%) and Intersection-Accidents (%) on Weekends vs. Route Number

The percentages of weekday and weekend accidents were then combined into a single database for both the section-accidents and intersection-accidents. The average accident probabilities for the weekdays and weekends were found to be 71% and 29%, respectively.

As observed in Figure 5.28, the percentages of the weekday section-accidents range from 71% to 77%, while for intersection-accidents the range is from 73% to 79%. The percentages of intersection-accidents on weekdays are higher than the percentages of section-accidents. On the other hand, the distribution of accidents on weekends shows an opposite pattern, the percentage of weekend section-accidents are higher than those of intersection-accidents. The hourly accident distributions is shown in Figure 5.30.

The hourly distribution patterns of section-accidents and intersection-accidents are very similar. The lowest accident rate occurs between 4:00am to 5:00am, and then it starts to climb continuously. Between 5:00pm to 6:00pm, the accident rate reaches its peak, and then starts to decline until the period of 4:00am to 5:00am, where the next cycle starts. The high accident rates in the period of 3:00pm to 6:00pm are consistent with the afternoon peak traffic. However, in the morning peak hour (for most routes, it is within the period of 7:00am to 11:00am), the accident rates are not as high as might have been expected. The period of the least occurrence of accidents is the early morning from 4:00am to 6:00am.

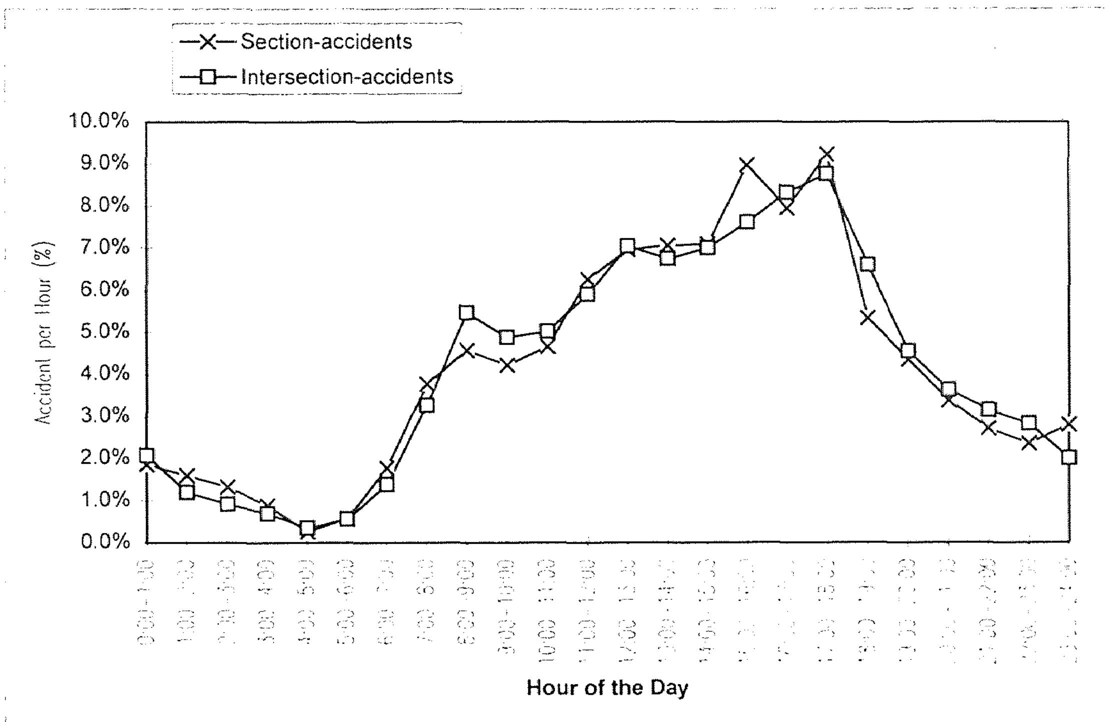

Figure 5. 30 Accident Percentage (%) versus Hour of the Day

5.2 Relationship between Access Points and Accidents

Filtering the reported accidents which occurred at intersections out, the relationship between accidents and access points is analyzed for each route. The relationships between accidents caused by turning traffic and access points are also analyzed along the milepost for each route. Although trials for identifying the types of access points have been conducted, the milepost can not provide a reliable base in identifying the correlation between accident location and the corresponding access point. Therefore, a classified analysis of the relationship between the three types of access points, commercial access, gas stations, and residential access, and accidents could not be carried out.

A trend between access density and accident rate seems to exist, as shown in Figures 6.31 to 5.38. However, there are some locations where the trend breaks down such as: Route 27, milepost 0.0 to 3.0, 5.1 to 11.0; Route 28, milepost 2.4 to 3.9, 5.1 to 6.0, etc. This indicates that while there is a trend between the accident rates and access densities, it is not necessary that this is the only reason for the occurrence or not of accidents at specific locations. Some of these factors are analyzed in the next section.

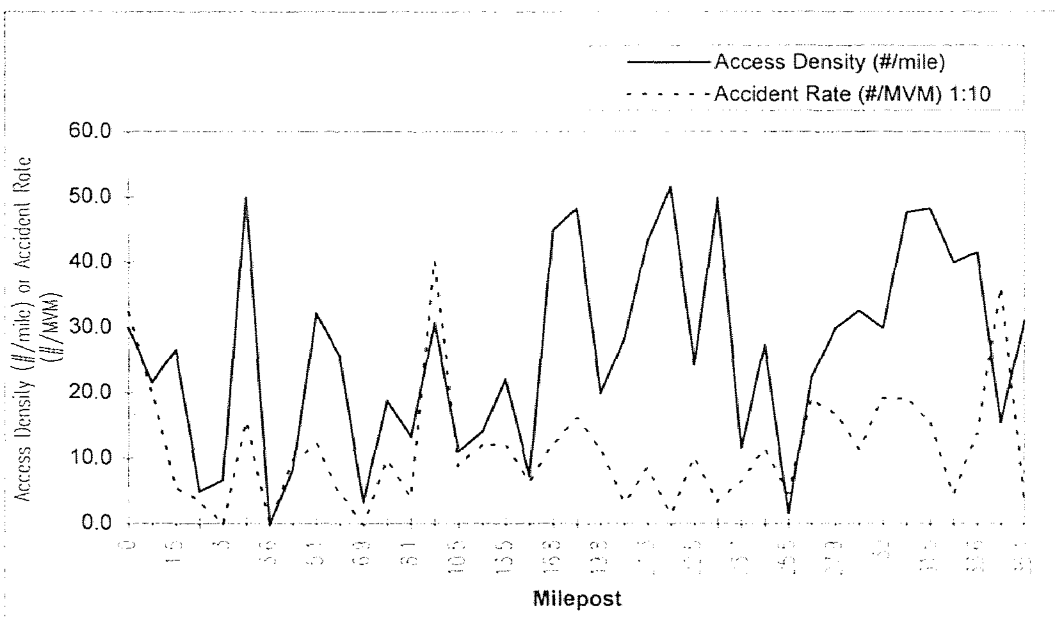

Figure 5. 31 Accident Rate and Access Density vs. Milepost on Route 27 (Northbound, 1994)

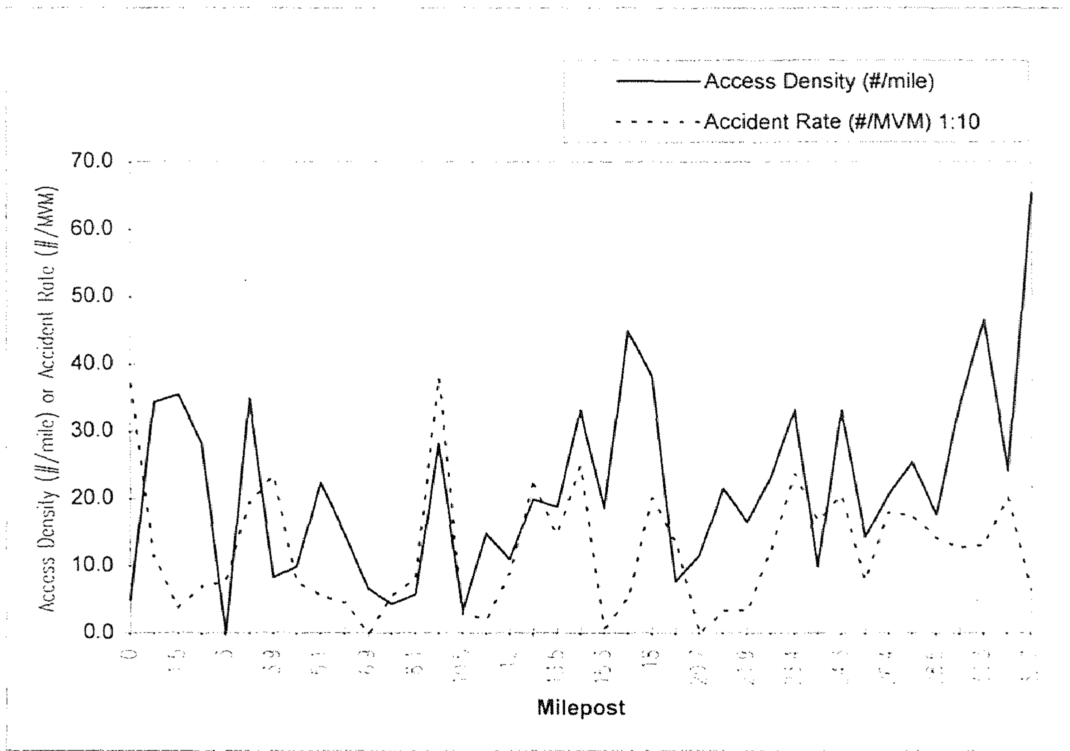

Figure 5. 32 Accident Rate and Access Density vs. Milepost on Route 27 (Southbound, 1994)

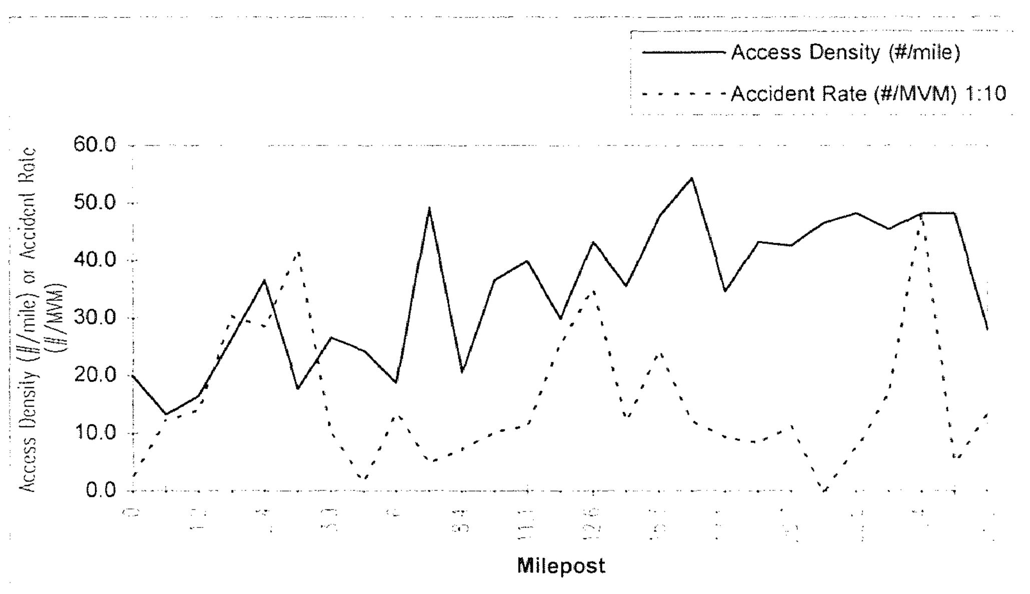

Figure 5. 33 Accident Rate and Access Density vs. Milepost on Route 28 (Eastbound, 1994)

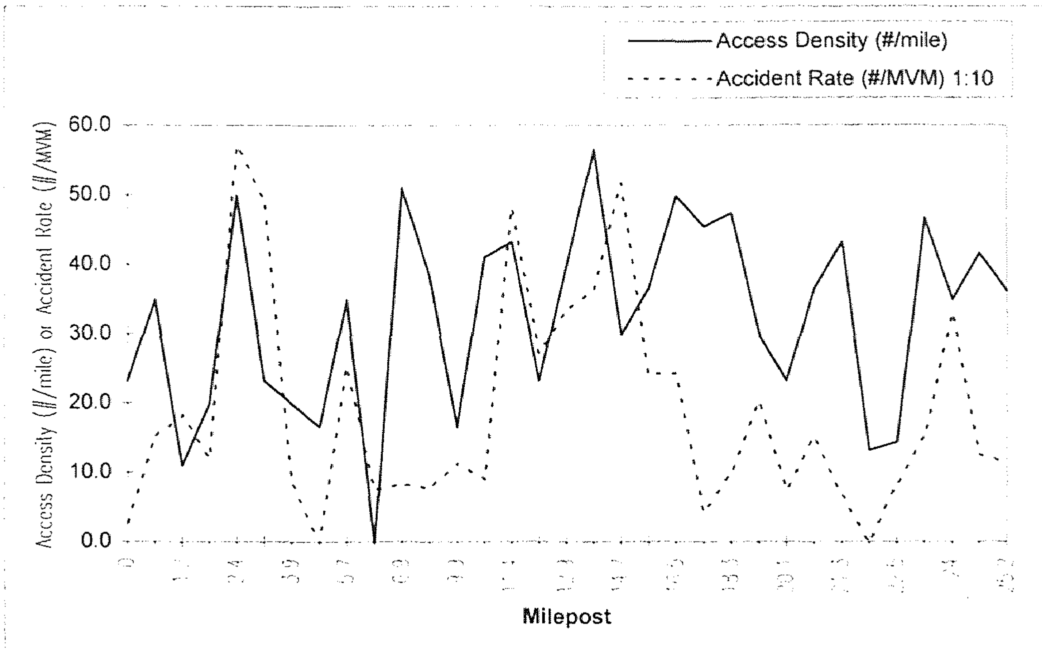

Figure 5. 34 Accident Rate and Access Density vs. Milepost on Route 28 (Westbound, 1994)

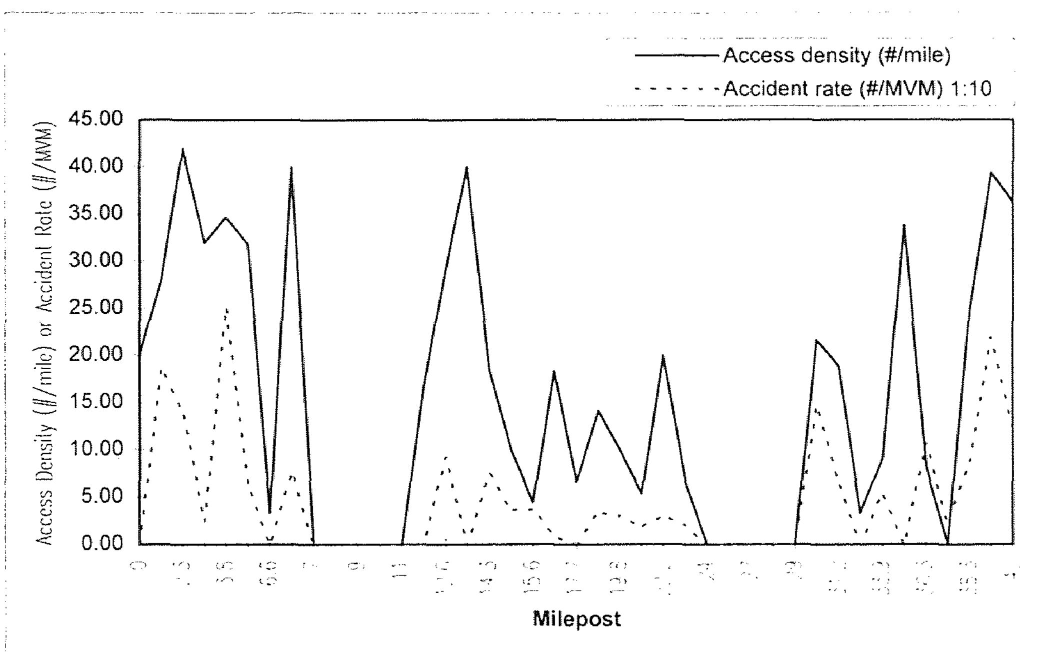

Figure 5. 35 Accident Rate and Access Density vs. Milepost on Route 33 (Eastbound, 1994)

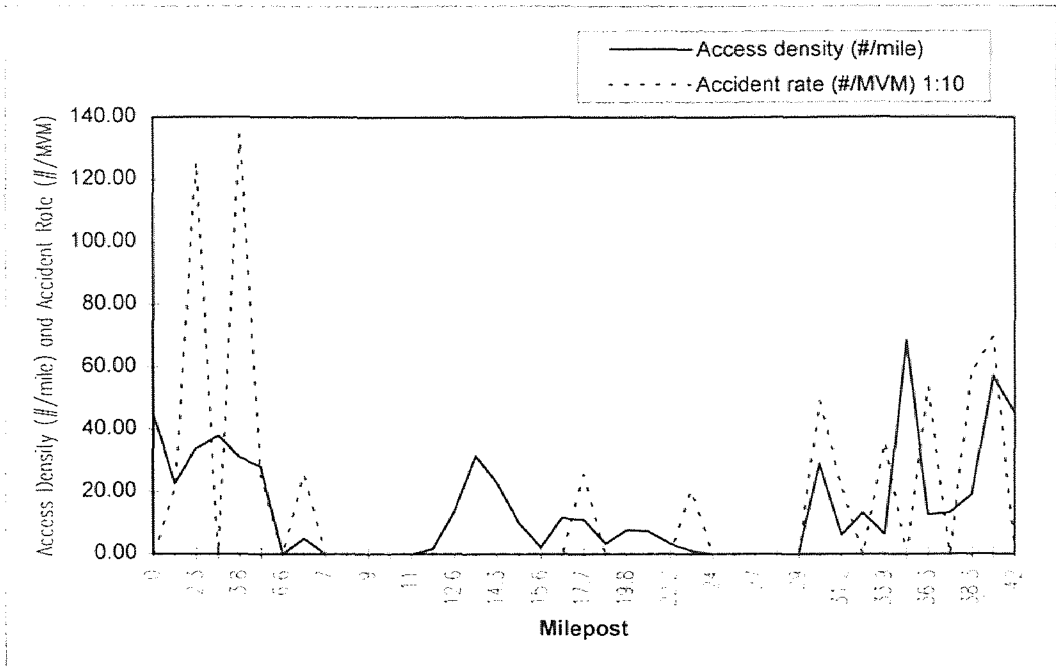

Figure 5. 36 Accident Rate and Access Density vs. Milepost on Route 33 (Westbound, 1994)

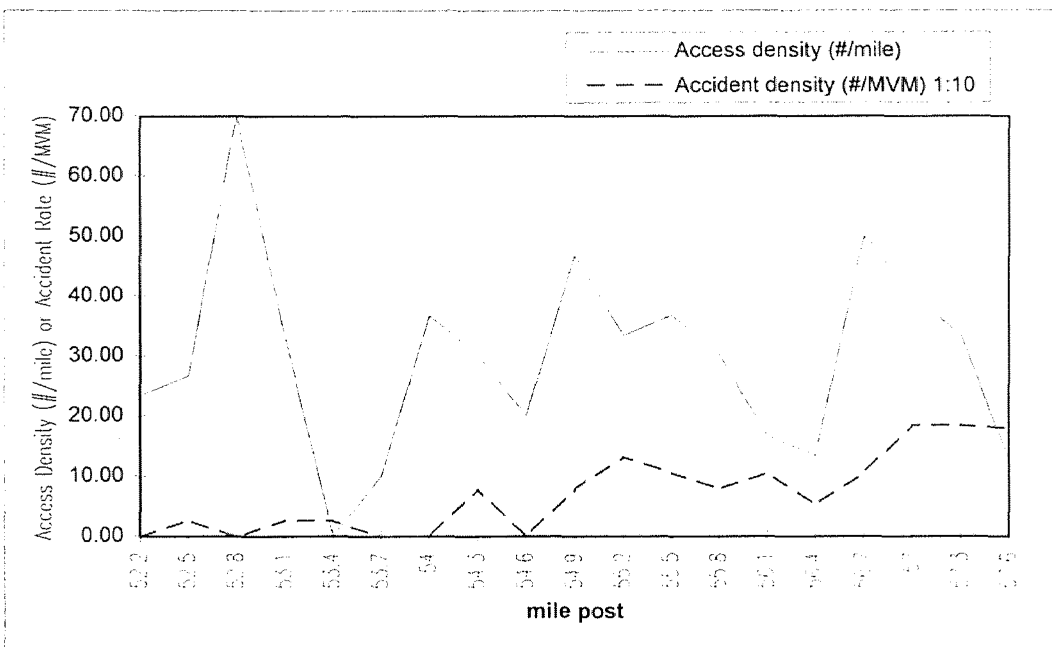

Figure 5. 37 Accident Rate and Access Density vs. Milepost on Route 35 (Northbound, 1994)

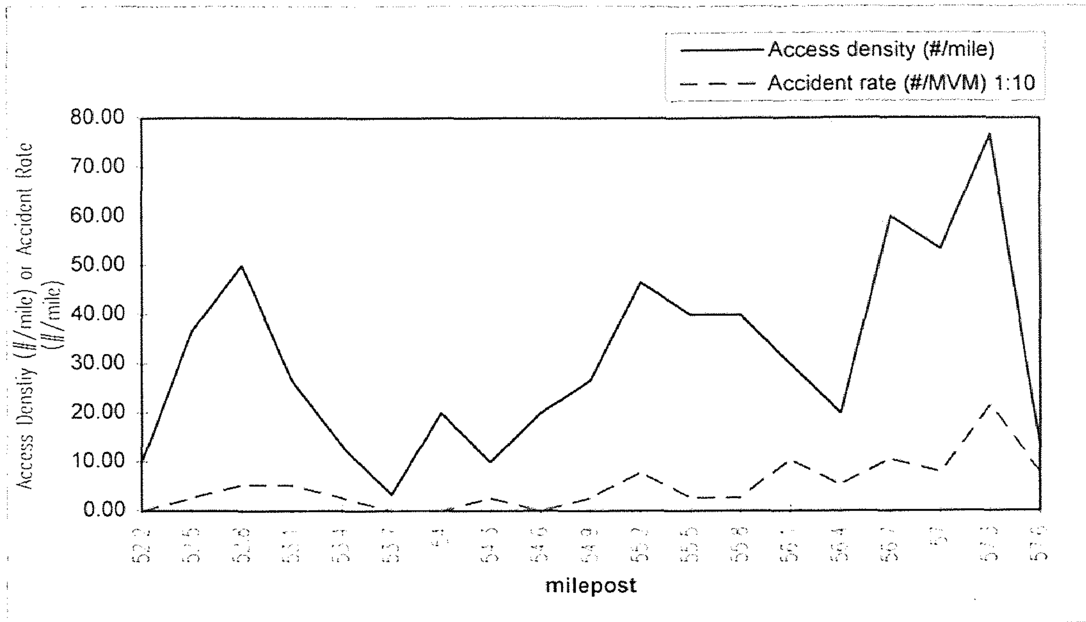

Figure 5. 38 Accident Rate and Access Density vs. Milepost on Route 35 (Southbound, 1994)

In order to examine the overall relationship of accident rates and access densities of all routes under this study (Route 27, 28, 33 and 35), the access densities were divided into to six groups: 0-10, 10-20, 20-30, 30-40, 40-50, and >50 (#/mile). The corresponding bar chart is shown in Figure 5.39.

This indicates that the relationship between the accident rate and access density is nonlinear. The average accident rate increases rapidly up to an access density of 20 access points per miles. From the third group (20-30 #/mile), the increasing trend begins to slow down, and at the fifth group (40-50 #/mile), the average accident rate reaches its peak. After that, the average accident rate declines.

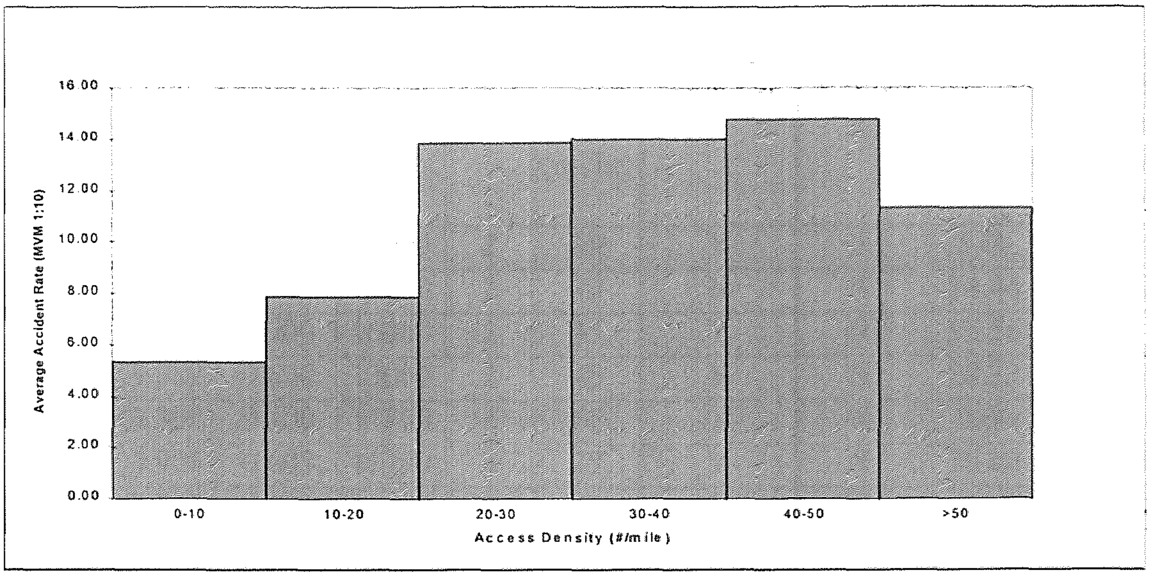

Figure 5. 39 Average Accident Rate (MVM 1:10) vs. Access Density (#/mile)

5.3 Accident Analysis by Geometric Classification

To estimate the impact of access points on road section accidents, geometric factors and traffic factors have also been taken into consideration. All four routes, NJ State Routes 27, 28, 33 and 35, have been separated into 200 study sections based on geometric and traffic conditions. The access densities and accident rates in each direction have been calculated for these sections. The accidents occurred at intersections were excluded from this analysis. The geometric features, traffic conditions and speed limits were identified from the state-line diagrams and traffic volume records. Each study section has the following characteristics: length, start /end point in milepost, number of lanes, median, shoulder, speed limit and AADT (Annually Average Daily Traffic). The study road sections were grouped into a Microsoft Access database (see Appendix C), as presented in Table 5.2.

Table 5. 2 Sample Access Database of Study Road Sections

Start	End	Length (mile)	AADT	Lane	Speed Limit (mi/hr)	Shoulder	Median	Access Density (#/mile)	Accident Rate MVM (1:10)
0.000	0.600	0.600	16000	2	30	Y	N	5.00	37.10
0.600	1.500	0.900	16000	2	30	N	N	34.44	11.42
1.500	2.400	0.900	16000	2	45	Y	N	35.56	3.81
2.400	3.000	0.600	13000	2	45	Y	N	28.33	7.02
3.000	3.300	0.300	11700	4	45	Y	N	0.00	7.81
3.300	3.900	0.600	11700	2	35	Y	N	35.00	19.51
3.900	4.500	0.600	11700	2	45	Y	N	8.33	23.42
4.500	5.100	0.600	11700	2	45	Y	N	10.00	7.81
5.100	6.300	1.200	20000	2	50	Y	N	22.50	5.71
6.300	6.900	0.600	20000	2	50	Y	N	15.00	4.57

5.3.1 Number of Lanes

The average access densities, accident rates and the variances for two-lane and four-lane highways are shown in Table 5.3.

Table 5. 3 Comparison between Two-lane and Four-lane Highway Accident Rates

Highway type	Road sections	Average access density		Average accident rate	
		(#/mile)	Variance	(MVM 1:10)	Variance
Two-lane	115	26.23	217.03	13.13	153.82
Four-lane	85	26.44	280.56	9.13	72.20

The average access densities are basically the same, but the average accident rate of two-lane highways is higher than that of four-lane highways by 44 percent. The t-test showed that there is a statistically significant difference between the accident rate of two-lane highways and that of four-lane highways (see Appendix A).

5.3.2 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 accident rates, access densities and the variances are summarized in Table 5.4. The average access densities of highways without shoulders are greater than that of highways with shoulders. The average accident rates for two-lane highway sections without shoulders exhibit higher percentage that the sections with shoulders. However, the reverse is true for four-lane highways. The t-test showed that there was a statistically significant difference between the average accident rate of two-lane highways with shoulder and that of two-lane highways without shoulder. The t-test showed that there was no statistically significant difference between the average accident rate of four-lane highways with shoulder and that of four-lane highways without shoulder.

Table 5. 4 Comparison between Highways with Shoulders and Highways without Shoulders on Accident Rates

Highway type	Road sections	Average access density		Average accident rate	
		(#/mile)	Variance	(MVM 1:10)	Variance
2-lane with shoulder	71	21.74	204.88	11.22	123.92
2-lane without shoulder	44	33.47	154.81	16.22	190.32
4-lane with shoulder	48	22.45	263.68	9.60	90.78
4-lane without shoulder	37	31.21	263.25	8.58	50.68

5.3.3 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. It generally is used to improve the traffic flow operations of the highways. There are 27 road sections with median and 58 sections without median. The t-test (see Appendix A) shows that there is a significant difference between the average accident rate of highways with median and that of highways without median. The same is true for the average access density, (see Table 5.6).

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

Highway type	Road sections	Average access density		Average accident rate	
		(#/mile)	Variance	(MVM 1:10)	Variance
Four-lane with median	27	41.24	54.96	19.48	198.35
Four-lane without median	58	33.10	201.48	11.06	61.58

5.3.4 Speed Limit

The speed limit of the NJ State highways studied ranges from 25 mile per hour to 55 mile per hour. Table 5.7 shows the number of road sections, access densities, accident rates and variances computed corresponding to each speed limit.

Table 5. 6 Average Access Density and Accident Rate by Speed Limit

Speed Limit (mile/hour)	Road sections	Average access density		Average accident rate	
		(#/mile)	Variance	(MVM 1:10)	Variance
25	6	22.39	190.60	1.25	7.10
30	18	33.40	219.66	13.01	178.43
35	49	34.16	155.91	15.33	145.75
40	34	34.01	208.00	13.77	73.05
45	29	16.31	150.20	7.04	44.72
50	36	17.08	168.24	8.29	67.96
55	18	8.53	27.48	2.83	3.25

As shown in Figure 5.40, both the average accident rate and average access density reach their peaks around the speed limit of 35 mile per hour, and simultaneously remain at relatively low levels at both ends of the speed limits. Speed limits of 25, 45, 50 and 55 mph show smaller average accident rates than the corresponding accident rates of 30, 35 and 40 mph. The similar patterns observed in Figure 5.40 imply some significant relationships among the average accidents rates, access points and speed limits.

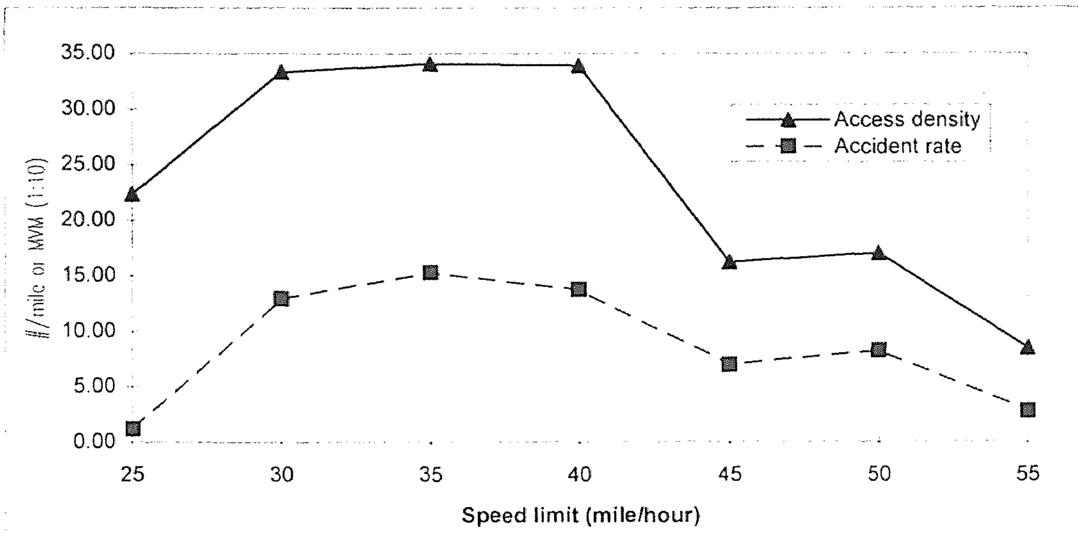

Figure 5. 40 Accident Rate and Access Density vs. Speed Limit

5.3.5 Traffic Volume

All road sections were grouped into 9 categories based on traffic volume ranges of AADT in intervals of 2000 vehicles per day. The average access densities, accident rates and variances are listed in Table 5.9.

As shown in Figure 5.42, the lines of access density and accident rate vary in a similar pattern, which might imply a correlation between access points and accidents. However no obvious trend is observed to the accident rate as the traffic volume increases.

Table 5. 7 Comparison of Access Density and Accident Rate by AADT

AADT (vpd)	Road sections	Average access density		Average accident rate	
		(#/mile)	Variance	(MVM 1:10)	Variance
0-10000	14	38.97	138.18	32.75	174.26
10000-12000	15	17.85	243.60	10.67	171.28
12000-14000	25	26.67	324.10	8.88	54.93
14000-16000	34	23.20	129.57	13.42	117.23
16000-18000	23	32.00	235.36	12.55	112.00
18000-20000	24	22.24	174.17	9.19	40.92
20000-22000	27	23.58	175.91	11.11	106.60
22000-24000	6	9.44	32.35	3.30	4.98
24000-26000	12	27.18	214.56	7.80	49.05
>26000	20	36.60	314.57	7.21	35.29

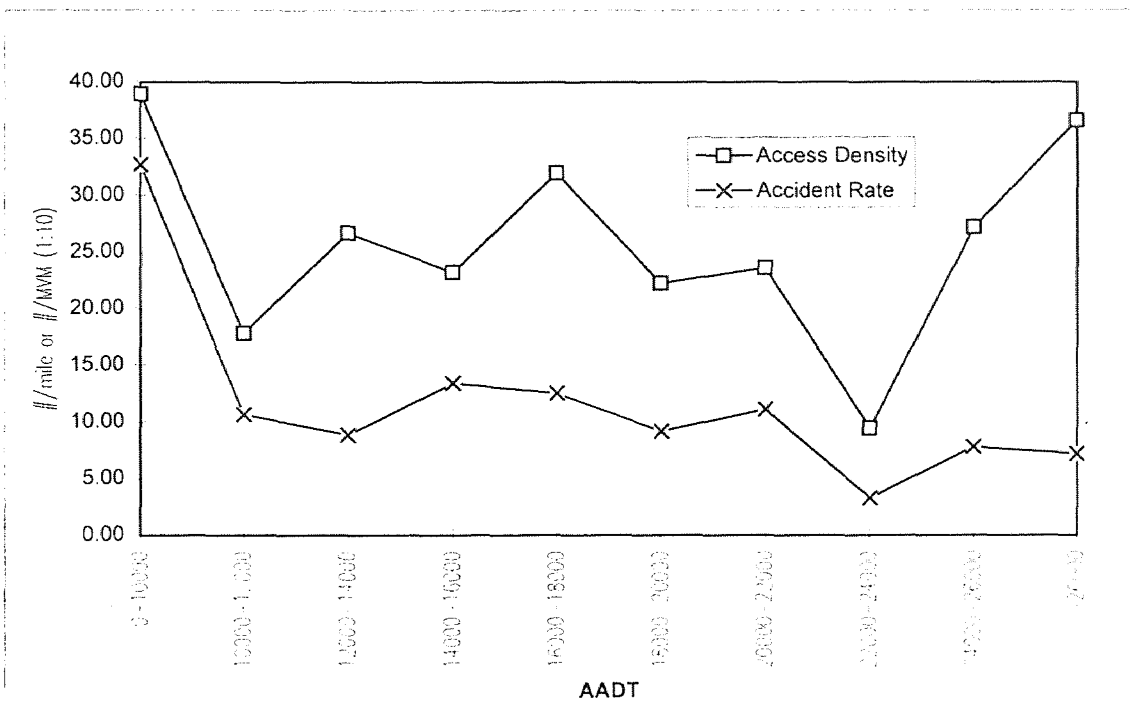

Figure 5. 41 Accident Rate (#/MVM 1:10) and Access Density (#/mile) vs. AADT (vpd)

5.4 Regression Model Analysis

Since there was a statistically significant difference between the accident rate of two-lane highways and the accident rate of four-lane highways, two groups of regression models were developed and analyzed.

The regression models were developed based on the ranges of roadway section length, which were grouped in the length of 0-0.3 miles, 0.3-0.6 miles, 0.6-0.9 miles, 0.9-1.2 miles, 1.2-1.5 miles, and above 1.5 miles. The independent variables considered were speed limit, traffic volume (AADT) and access density. Shoulder was also taken into consideration. The dependent variable used was the accident rate (number of accidents per million vehicle miles traveled, in 1:10). The detailed results of the regression analysis are shown in Appendix B. The sample database used for the analysis is shown in Appendix C.

5.4.1 Two-Lane Highway Regression Models

The two-lane highway regression models were based on a sample size of 115 roadway sections. For each range of roadway length, both linear models and nonlinear models were developed, except the nonlinear model for the range of 0.3 miles due to limited sample size (see Table 5.10). R squares showed a good fit for the nonlinear model with length greater than 1.5 miles. In general the R squares of the nonlinear models indicated better fit than linear models, however only a few of them show a good fit. For two-lane highways, the models of the highways with/without shoulder confirm the previous conclusion that they belong to different populations. The linear regression model 4 with shoulder exhibit very low fit (R^2 =0.0980), and the linear regression model 5 without shoulder exhibits a better fit (R^2 =0.5436). The nonlinear regression model 4 with shoulder exhibits very low fit (R^2 =0.2677), and the nonlinear regression model 5 without shoulder exhibits a better fit (R^2 =0.5707).

Table 5.8 Two-lane Highway Regression Models

Model	Length (miles)	Equation	R^2
Linear 1	0.3	$Y = 2.5610 + 0.3052X_1 - 0.0009X_2 + 0.2155X_3$	0.8141
Linear 2	0.6	$Y = 43.6586 - 0.3059X_1 - 0.0012X_2 + 0.0935X_3$	0.2980
Linear 3	0.9	$Y = 70.7597 - 0.6471X_1 - 0.0015X_2 - 0.2220X_3$	0.4294
Linear 4 (shoulder)	0.9	$Y = 24.8702 - 0.3712X_1 + 0.0001X_2 - 0.1006X_3$	0.0980
Linear 5 (no shoulder)	0.9	$Y = 91.5866 - 0.6825X_1 - 0.0029X_2 + 0.2430X_3$	0.5436
Linear 6	1.2	$Y = -26.0668 + 0.5300X_1 - 0.0003X_2 + 0.4317X_3$	0.2298
Linear 7	>1.5	$Y = 11.4828 + 0.1061X_1 - 0.0006X_2 + 0.2716X_3$	0.2502
Nonlinear 1	0.3	N/A	N/A
Nonlinear 2	0.6	$Y = 139.2991 - 3.1753X_1 + 0.0374X_1^2 - 0.0055X_2 + 0.0000002X_2^2 - 0.6182X_3 + 0.0140X_3^2$	0.4541
Nonlinear 3	0.9	$Y = 191.0309 - 4.9683X_1 + 0.0579X_1^2 - 0.0086X_2 + 0.0000002X_2^2 + 0.5040X_3 - 0.0095X_3^2$	0.6132
Nonlinear 4 (shoulder)	0.9	$Y = 141.2106 - 6.6364X_1 + 0.0768X_1^2 - 0.0001X_2 + 0.00000001X_2^2 + 0.4255X_3 - 0.0083X_3^2$	0.2677
Nonlinear 5 (no shoulder)	0.9	$Y = -49.4611 + 108437X_1 - 0.1845X_1^2 - 0.0104X_2 + 0.0000003X_2^2 + 0.2805X_3 - 0.0058X_3^2$	0.5707
Nonlinear 6	1.2	$Y = 37.2859 + 3.4168X_1 - 0.0335X_1^2 - 0.0165X_2 + 0.0000005X_2^2 + 1.6288X_3 - 0.0206X_3^2$	0.4014
Nonlinear 7	>1.5	$Y = -165.5240 + 18.6628X_1 - 0.2377X_1^2 - 0.0211X_2 + 0.0000007X_2^2 + 0.0263X_3 - 0.0097X_3^2$	0.8683
Shoulder	$Y = 5.9749 + 0.2415X_3$		0.0964
No shoulder	$Y = 11.8310 + 0.1310X_3$		0.0140

Where, Y represents accident rate (#/MVM in 1:10), X_1 represents speed limit (mph), X_2 represents AADT (vpd), X_3 represents access density (#/mile).

5.4.2 Four-Lane Highway Regression Models

The four-lane highway regression models were based on the 85 roadway sections. For each range of roadway length, both linear models and nonlinear models were developed, (see Table 5.11). R squares showed that the linear model for the range of 0.3 miles and the nonlinear model for the range of 0.3 miles, 0.9 miles, 1.2 miles and above 1.5 miles provide a good fit. Almost all the R squares of nonlinear models indicated better fit than linear models. Both models for four-lane highways with shoulder and without shoulder did not provide good fits.

Table 5.9 Four-lane Highway Regression Models

Model	Length (miles)	Equation	R^2
Linear 1(All sections)		$Y = 4.8374 + 0.2264X_3$	0.1587
Linear 2 (Shoulder)		$Y = 4.8103 + 0.2133X_3$	0.1321
Linear 3(No shoulder)		$Y = 3.6027 + 0.1593X_3$	0.1318
Linear 4	0.3	$Y = 110.3518 - 2.6985X_1 + 0.0014X_2 - 0.6621X_3$	0.6761
Linear 5	0.6	$Y = 8.0700 + 0.1412X_1 - 0.0006X_2 + 0.2662X_3$	0.1978
Linear 6	0.9	$Y = 44.1752 - 0.6903X_1 - 0.0002X_2 - 0.0318X_3$	0.5513
Linear 7	1.2	$Y = 45.3003 - 0.6265X_1 - 0.0003X_2 + 0.1118X_3$	0.4686
Linear 8	>1.5	$Y = 13.0964 - 0.1792X_1 - 0.0001X_2 + 0.2683X_3$	0.5213
Nonlinear 1	0.3	$Y = 393.9541 - 14.0693X_1 + 0.1466X_1^2 - 0.0071X_2 + 0.0000002X_2^2 + 0.3731X_3 - 0.0160X_3^2$	0.7172
Nonlinear 2	0.6	$Y = -43.9996 - 1.2420X_1 + 0.0116X_1^2 + 0.0101X_2 + 0.0000003X_2^2 - 0.7258X_3 + 0.0133X_3^2$	0.3754
Nonlinear 3	0.9	$Y = 27.5700 - 0.6205X_1 - 0.0024X_1^2 + 0.0017X_2 - 0.0000001X_2^2 - 0.0933X_3 - 0.0003X_3^2$	0.5998
Nonlinear 4	1.2	$Y = -39.2109 + 2.5544X_1 - 0.0357X_1^2 + 0.0010X_2 - 0.0000001X_2^2 + 0.3454X_3 - 0.0069X_3^2$	0.6992
Nonlinear 5	>1.5	$Y = 30.1359 + 2.7293X_1 - 0.0341X_1^2 - 0.0094X_2 + 0.0000003X_2^2 + 0.3160X_3 - 0.0020X_3^2$	0.6940

Where, Y represents accident rate (#/MVM in 1:10), X_1 represents speed limit (mph), X_2 represents AADT (vpd), X_3 represents access density (#/mile).

There is no linear relationship between accident rates and access density for two-lane highways. A higher relationship between accident rates and access density for four-lane highways, but R squares do not show good fit.

Although nonlinear models show good fit, none of the coefficients show significant t-statistic values. It can be concluded that the regression models shown do not produce robust predictions of accident rates on two-lane highways.

Although nonlinear models show good fit, none of the coefficients show significant t-statistic values. It can be concluded that the regression models shown do not produce robust predictions of accident rates on four-lane highways.

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 is about 0.6 miles long with two lanes in each direction and without any median. The study involved taking traffic counts and speed measurements. Traffic volumes both at access points and on main road were counted by using traffic counters. A video camera was used to tape the speed indication from the odometer of a test vehicle. This survey covered both AM/PM peak periods and off-peak periods for five weekdays from Monday to Friday. The objective of the speed study was to record the operational characteristics of a multilane highway section.

6.1 Data Collection

Two kinds of data collection which include traffic speed measurement and traffic volume counts were performed during the field study. 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; there are 31 points

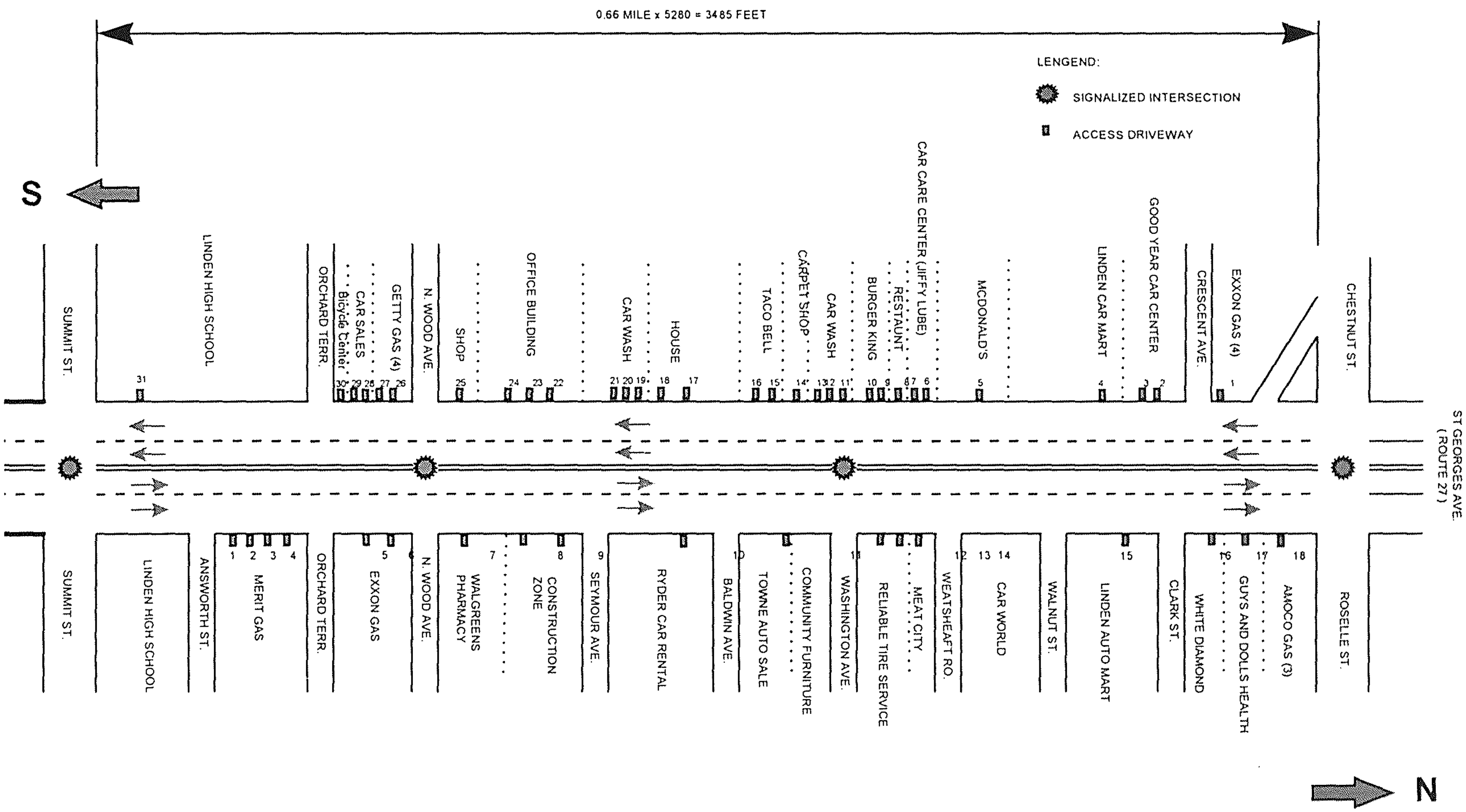

Figure 6.1 Basic Information of the Study Roadway Section of Linden, NJ State Route 27

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.

6.1.2 Traffic Data Collection

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 5-6 adjacent access points. Data was collected on three mornings from 07:00 to 12:00, and three afternoons from 14:00 to 19:00. The data collected is divided into the traffic volume of the main roadway on both directions and the traffic volume at 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 a tally sheet (Table 6.1) include left turning vehicles which have impact on other vehicles, left turning vehicles which have no impact on other vehicles, right turning vehicles which have impact on other vehicles, and right turning vehicles which have 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, average speeds are reported for the trips which were not affected by the vehicles entering or exiting access points. The average speeds were calculated for both lane-1and lane-2 for the southbound and northbound streets, respectively. The speed of northbound lane-1 ranges from 24 to 31 miles per hour, averaging to 29 miles per hour. The values for northbound lane-1 ranges from 19 to 34 miles per hour, averaging to 30 miles per hour. The speed of southbound lane-1 ranges from 20 to 31 miles per hour, averaging to 27 miles per hour. The speed for southbound lane-2 ranges from 18 to 36 miles per hour, and averaging to 30 miles per hour. The average speeds affected by vehicle turning are presented in Figures 6.2 and 6.3.

The average speed 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 (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, signals have a higher impact on speed than access points.

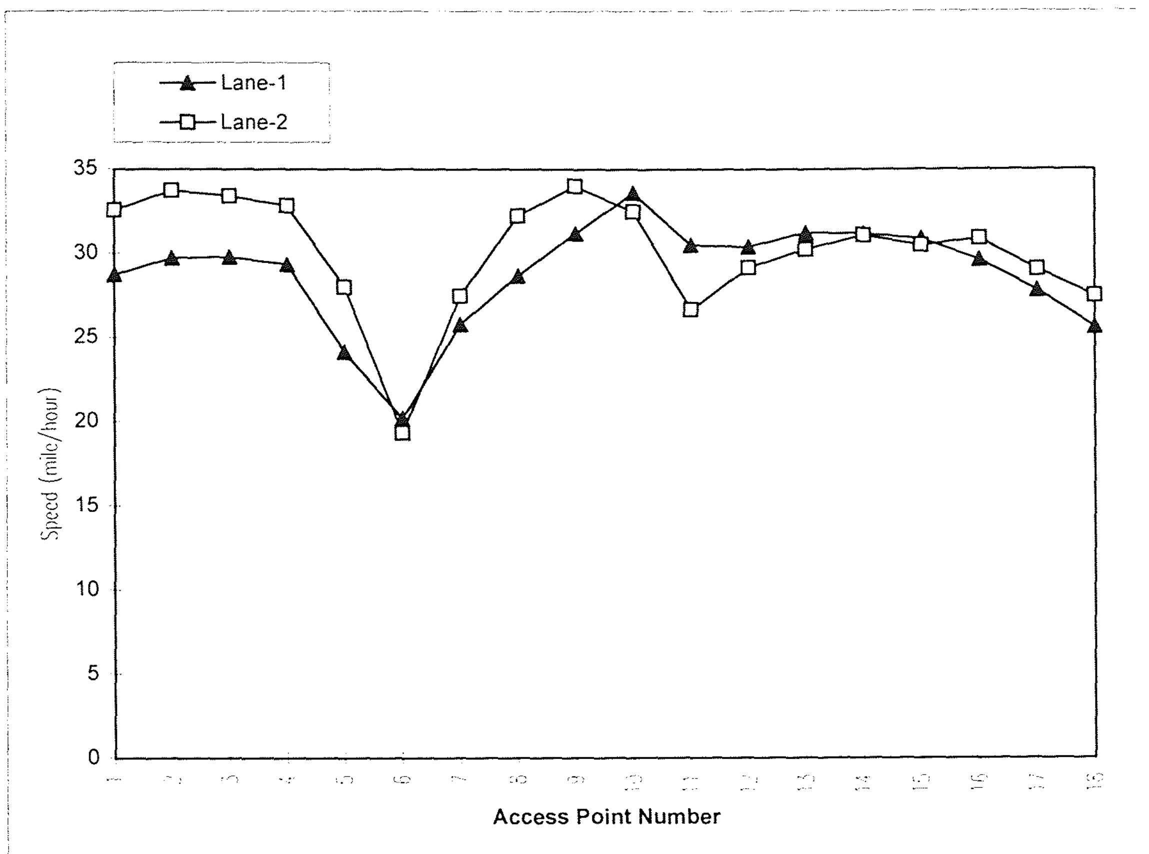

Figure 6. 2 Vehicle Speed Not Affected vs. Access Point Number (Northbound)

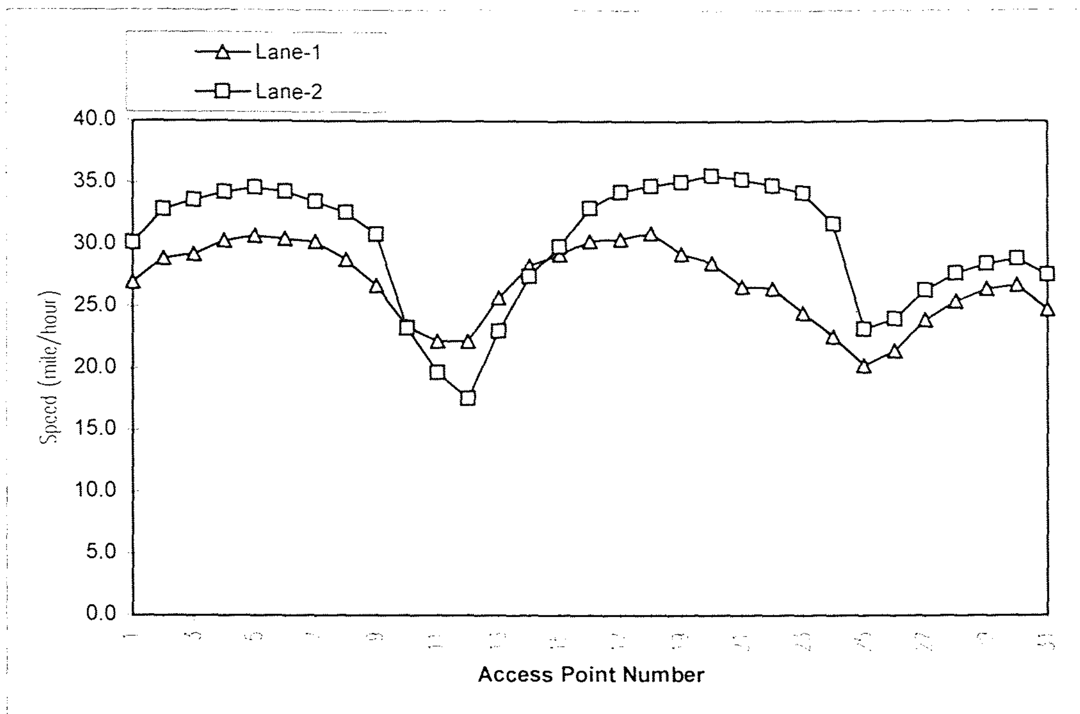

Figure 6. 3 Vehicle Speed Not Affected vs. Access Point Number (Southbound)

6.2.2 Average Speed Affected by Vehicle Turns into Access Points

In this section, the analysis of speed affected by vehicle turns into access points is presented.

1. Speed affected by entering movements into the access points

For entering movements, 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.

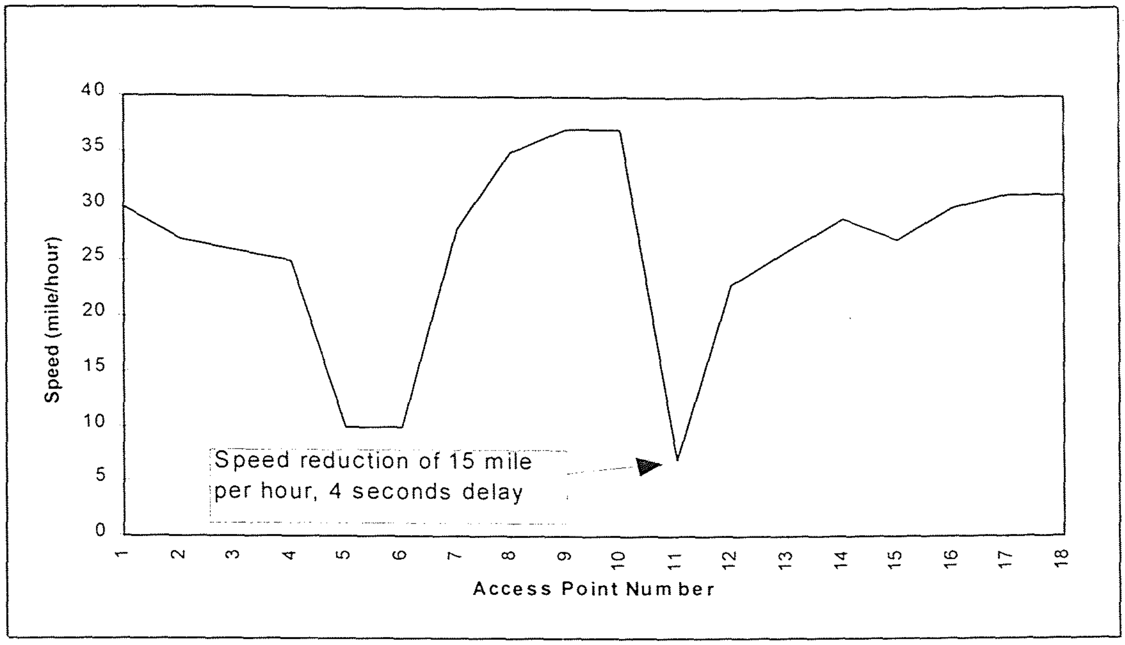

Figure 6. 4 Speed of Lane-2 Affected by Opposite Direction Left-turn Movements vs. Access Point Number

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.

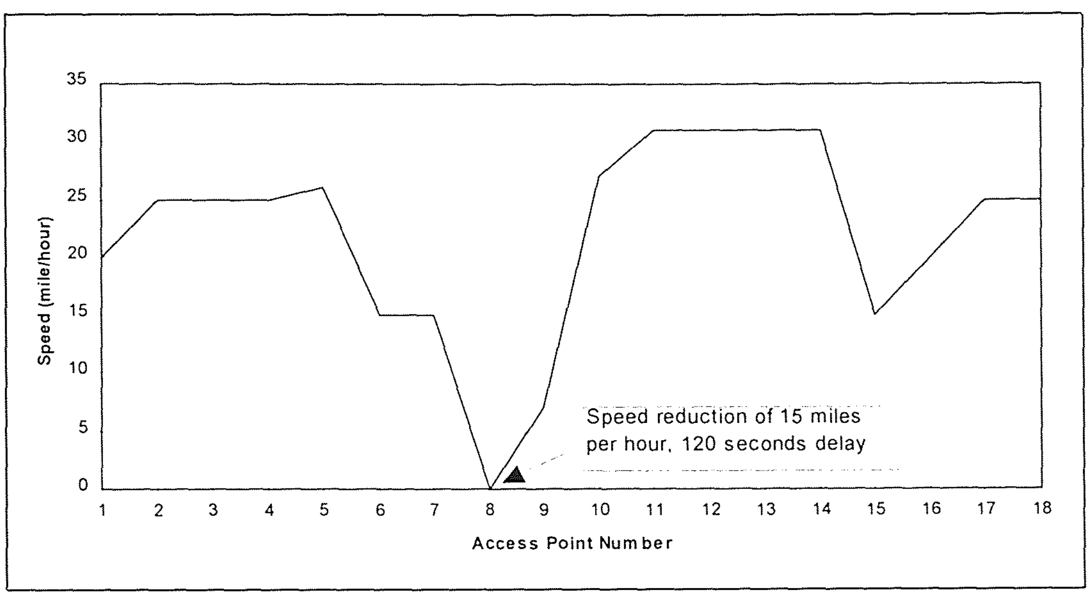

Figure 6. 5 Speed of Lane-2 Affected by Same Direction Left-turn Movements vs. Access Point Number

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.

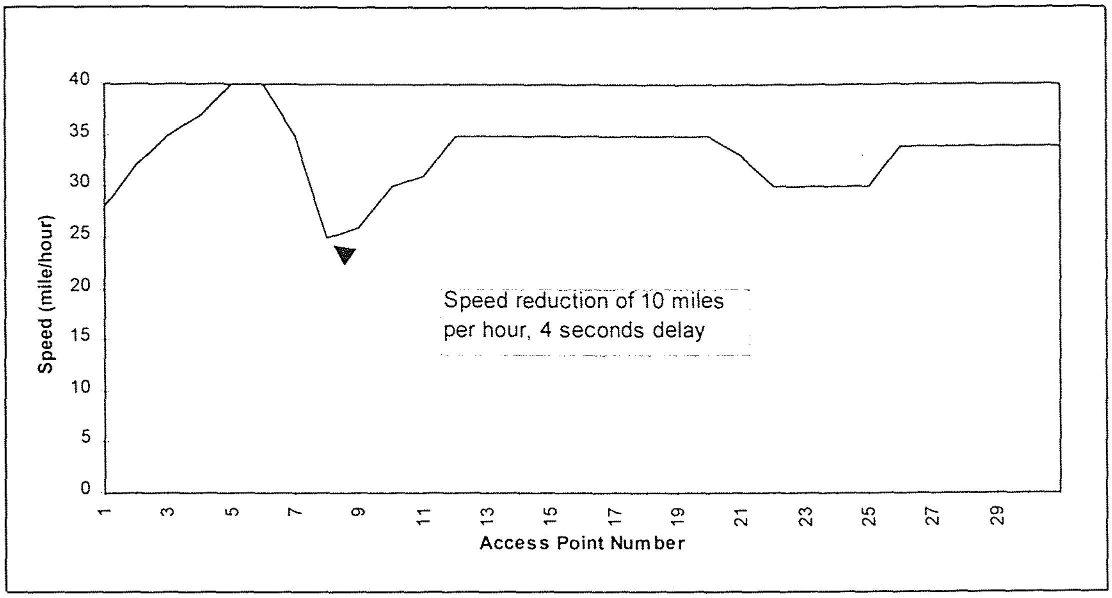

Figure 6. 6 Speed of Lane-1 Affected by Same Direction Right-turn Movements vs. Access Point Number

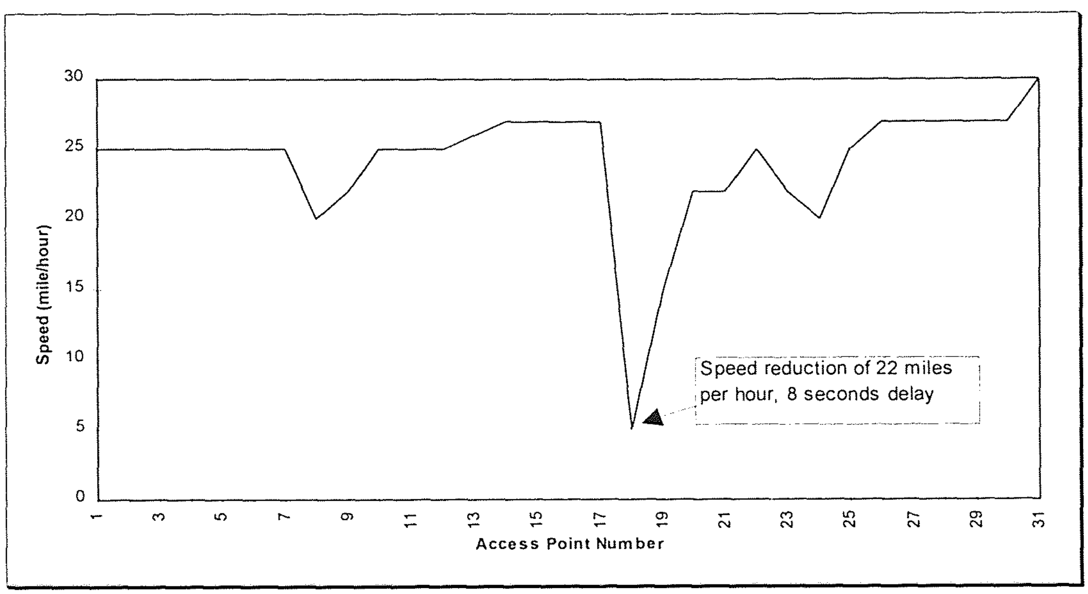

Figure 6. 7 Speed of Lane-1 Affected by Same Direction Left-turn Movements vs. Access Point Number

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

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.

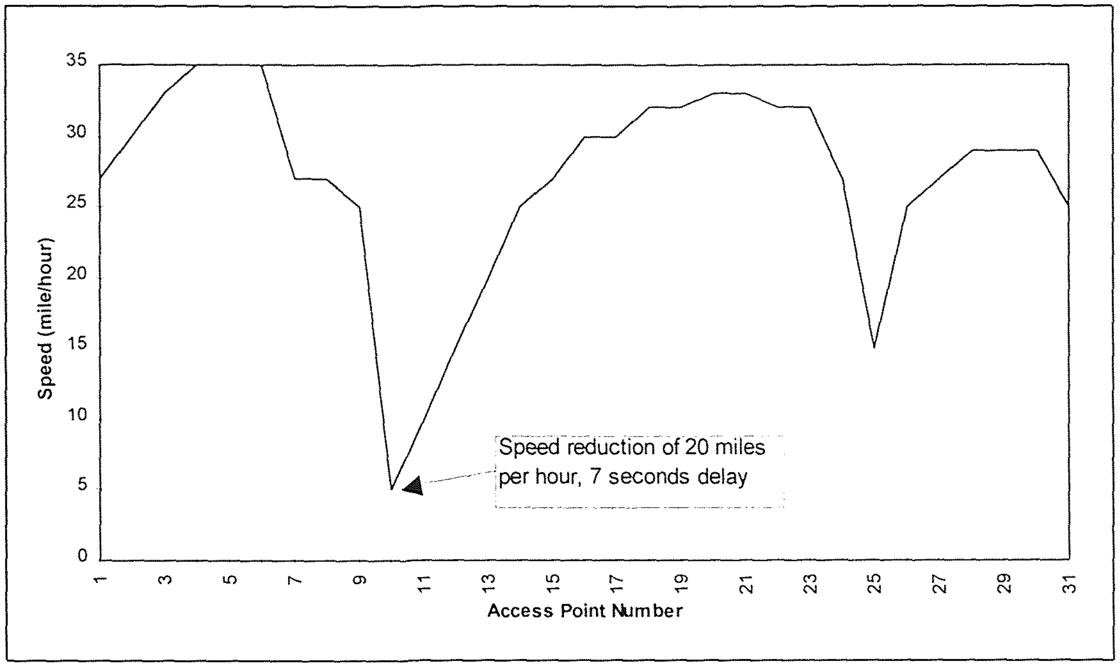

Figure 6. 8 Speed of Lane-1 Affected by Opposite Direction Left-turn Movements vs. Access Point Number

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:

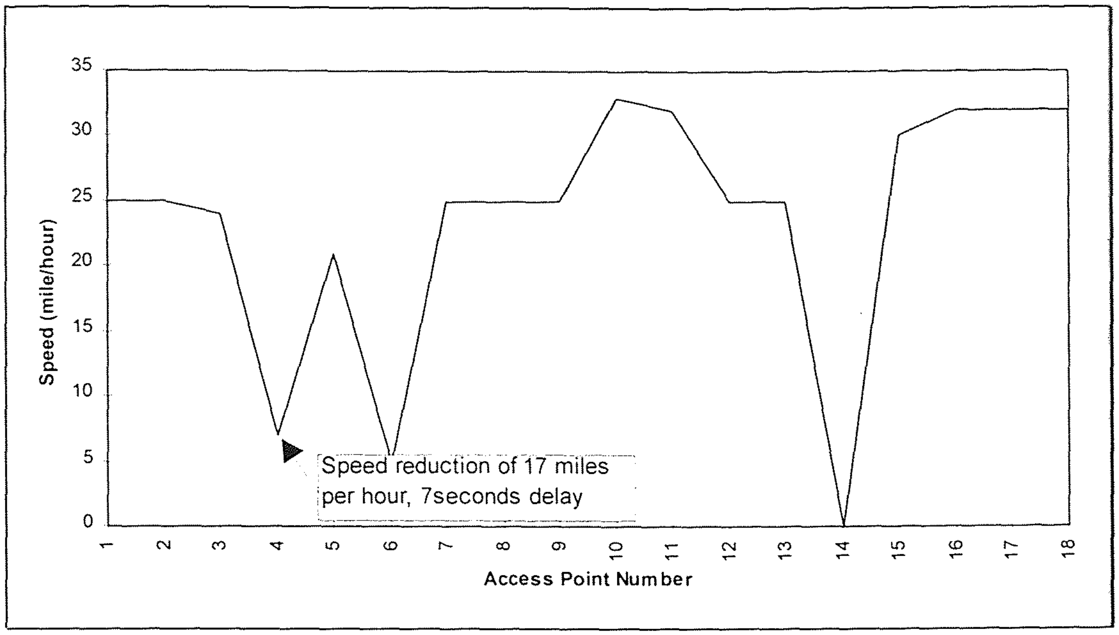

Figure 6. 9 Speed Affected by Left-turn Exiting Movements vs. Access Point Number

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

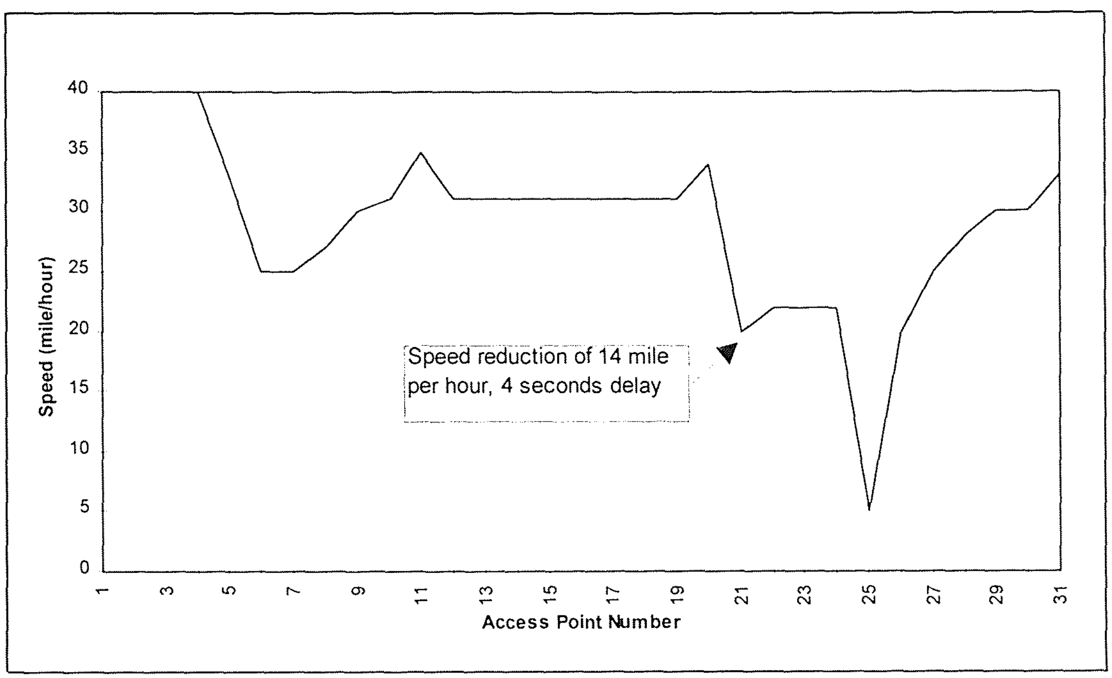

Figure 6. 10 Speed Affected by Right-turn Exiting Movements vs. Access Point Number

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

The total number of test runs conducted were 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 of 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. In most cases, they would only make an exiting maneuver when they find an acceptable gap occurring on the main road. The impact of these exiting vehicles on through vehicles is not significant. For entering vehicles, the drivers are not as careful as those in the previous case. In this section, only the analysis of entering maneuvers is conducted. 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: 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 first three cases in the above ranking, same direction left-turning movement on lane-2, opposite direction left-turning movement on lane-1, same-direction right turning movements on lane-1, are consistent with intuition. The delay and speed reduction due to the opposite direction left turning movements on lane-2 is the lowest of all. This is 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 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 happens between 16:00 to 18:00 which is consistent to general belief. However, the morning peak hour happens between 10:00 to 12:00 AM instead of 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.

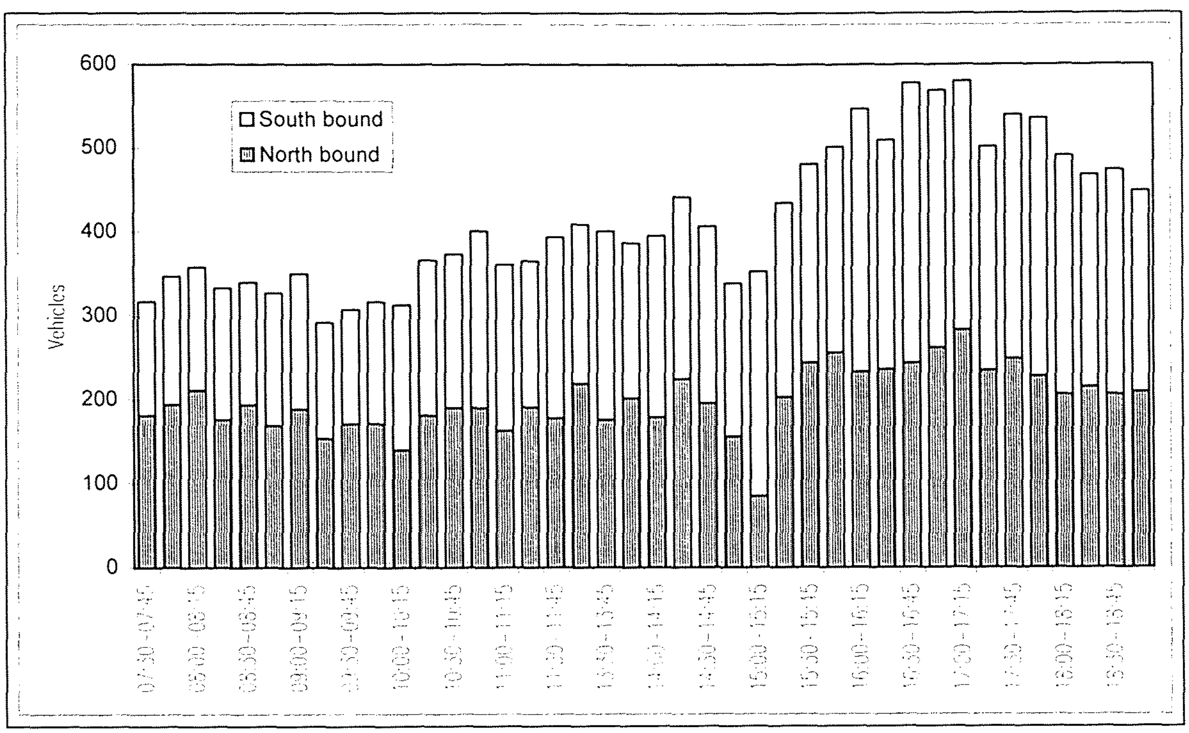

Figure 6. 11 Distribution of Average Traffic Volume (15 minutes) on Weekdays

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 which may not indicate the actual daily patterns for either access point.

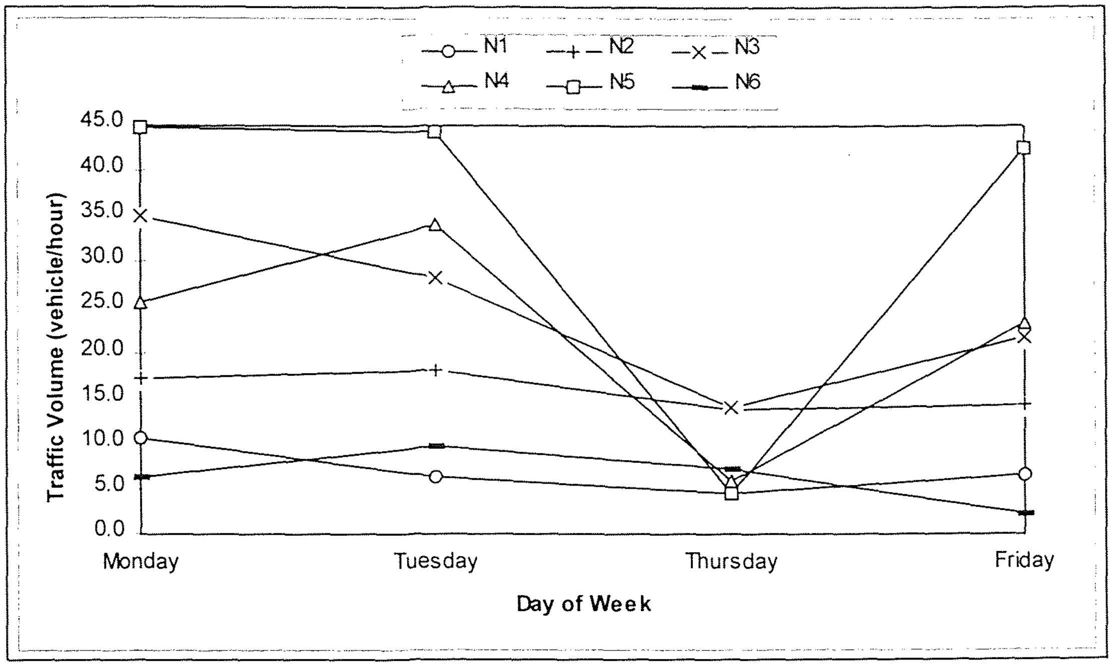

Figure 6. 12 Hourly Traffic Volume vs. Weekdays at Access Points of Gas Stations

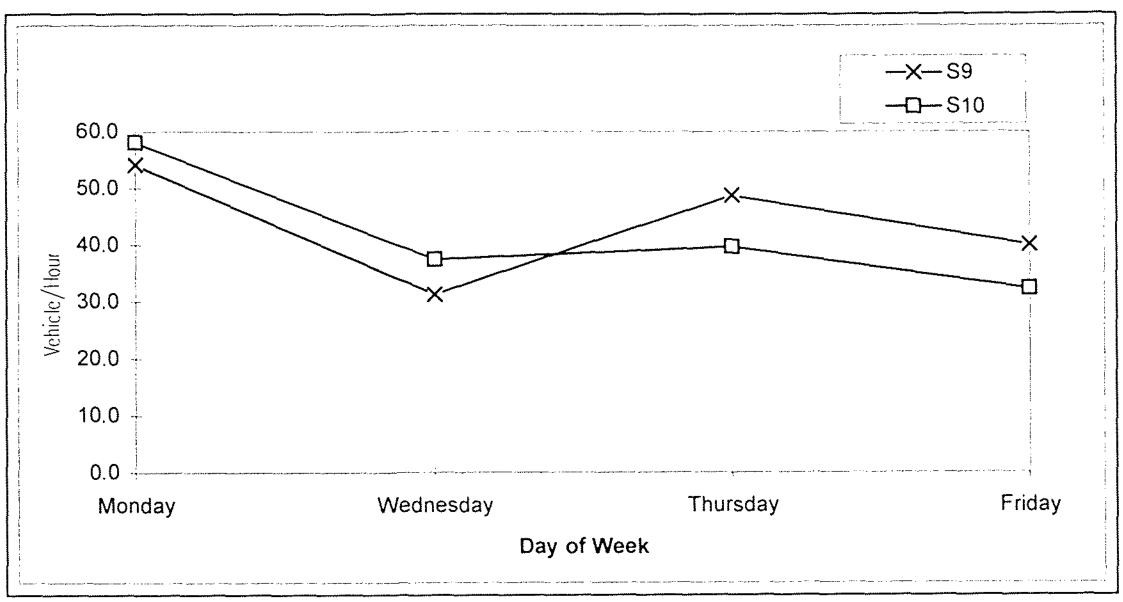

Figure 6. 13 Hourly Traffic Volume vs. Weekdays at Access Points of Restaurant (Burger King)

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 are 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% vs. 15% (peak hour), and 19% vs. 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% vs. 17% (peak hour), and 15% vs. 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

7.1 Summary

The primary objectives of this thesis were to identify the primary causes of accidents occurring on multilane highways mid-block to signalized intersections, and identify any relationships that may exist between the principal traffic flow weather and geometric characteristics and accident rates. This study concentrated on the impact of access points on multilane highway accidents on a selected set of New Jersey state highways, namely Routes 21, 27, 28, 33, 35 and 82. Due to data unavailability, Route 82 was eliminated from the study.

- A statistical analysis was conducted on reported accidents occurred on the selected test routes, traffic flow data and geometric characteristics based on data provided by NJDOT. The study covered a total of 175.8 miles of NJ state highways, consisting of both 4-lane and 2-lane sections. The accident data were extracted from reported accident record files (MACLSTRT-1 and MACLSTRT-2), the traffic flow data were obtained from the NJDOT Bulletin Board, the access point data were obtained from video tapes of the five selected NJ state routes, and the geometric data were extracted from state-line diagrams. The statistical analysis was divided into three parts:

1) A general analysis of reported accidents, which included a comparison of accidents occurred at signalized intersections (intersection-accidents) and between intersections (section accidents);

2) accident analysis based on geometric and traffic flow conditions; and
3) analysis of the relationship between accidents and access points, which included the development of regression models between accident rates and a number of different independent variables such as: access density, speed limit, AADT, and geometric factors.

In addition to the statistical analysis on accidents on state highways, a field study was undertaken where the main objective was to identify the basic operational characteristics of a section of a multilane highway in New Jersey. The field study was undertaken on a 0.6 mile section of NJ state route 27 in Linden New Jersey. The principal data collected were the speed variation on lane 1 and lane 2, which was obtained through the use of a test vehicle based on a total of 43 test runs, and traffic flow data at the mainline and at access points during a five weekday period.

The primary results and conclusions are presented next.

7.2 Conclusions

The major results of the analysis are summarized below:

- Approximately 30% of the reported accidents were midblock section-accidents, which were primarily caused due to the presence of access points. Seventy (70%) of the 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 exhibit a higher proportion of accidents at signalized intersections than between signalized intersections.
- Midblock section-accidents were mainly 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 diving-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 show any difference on the patterns of 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 proportion 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.

- In the hourly accident distribution analysis, 4:00-5:00 AM exhibits the lowest accident percentage. The evening traffic peak period between 5:00 to 6:00 PM exhibited the highest percentage of accident rates.
- The average accident rate of two-lane highways was higher than that of four-lane highways by 44 percent, while the average access densities were statistically the same. And the t-test showed that there was statistically significant difference between the accident rate of two-lane highways and that of four-lane highways.
- The t-test showed that there was a statistically significant difference between the average accident rate of two-lane highways with shoulder and that of two-lane highways without shoulder. The t-test showed that there was no statistically significant difference between the average accident rate of four-lane highways with shoulder and that of four-lane highways without shoulder.
- The accident rate and access density showed similar patterns as the 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 main variables in estimation of 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.

- There is no linear relationship between accident rates and access density for two-lane highways. Four-lane highways exhibit better linear relationships, but the R squares do not show good fit of the developed models.
- Although nonlinear models show good fit, none of the coefficients show significant t-statistic values. It can be concluded that the regression models shown do not produce robust predictions of accident rates on two-lane highways.
- Although nonlinear models show good fit, none of the coefficients show significant t-statistic values. It can be concluded that the regression models shown do not produce robust predictions of accident rates on four-lane highways.
- Although the data do not produce good fit, there is a very strong trend among the average accident rate and the average access density per section length. The high variability observed for each section length group however does not provide any high confidence in the trend observed.

7.3 Recommendations

This study presented some insights into the relation of access points to accident rates and the linear and nonlinear relationships were developed for the five NJ State highways. Further research should focus on the relationship between the accidents caused by turning traffic and the types of access points (e.g. gas station, restaurants, residential, other). Due to the limited accidents and access information in this study, the development of an accurate model which can capture the relationship between accidents caused by turning traffic and access points was not possible at this stage. A general model between the accidents and access points can not be developed for the purpose of accident evaluations, since too many factors are involved in the impact study of accidents.

In addition, 15-minute or hourly traffic flow rates were not available for the selected routes. A more detailed analysis should be conducted which would incorporated 15-minute and/or hourly traffic volume into the analysis of accidents between intersections.

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 that can become as a tool for traffic impact analysis for access management.

The analysis was conducted on NJ State highways. A nationwide study can be undertaken which 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. However, this is misleading and not comprehensive. Other variables should be introduced, which would include the effect of incidents on the level of service of a roadway. These additional variables could include:

- 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,
- Benefit/Cost ratio for new facility,
- Other

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 became a part of this more comprehensive manual.

APPENDIX A

HYPOTHESIS TESTING

Hypothesis testing was conducted for identifying if there were statistically significant differences among the accident rates of different type of highways. Three pairs of highways conducted are listed as below:

- Two-lane highways versus four-lane highways,
- Two-lane highways with shoulder versus two-lane highways without shoulder,
- Four-lane highways with shoulder versus four-lane highways without shoulder,

Based on 95% confidence interval, for the cases where the variances are unequal, the following t-test is conducted:

Test statistic value:

$$t' = \frac{\bar{x} - \bar{y} - \Delta_0}{\sqrt{\frac{s_1^2}{m} + \frac{s_2^2}{n}}}$$

Degree of freedom:

$$v = \frac{\left(\frac{s_1^2}{m} + \frac{s_2^2}{n}\right)^2}{\frac{(s_1^2/m)^2}{m-1} + \frac{(s_2^2/n)^2}{n-1}}$$

Alternative hypothesis	Re*jection region for approximate level* α *test*
$H_a : \mu_1 - \mu_2 > \Delta_0$	$t' \geq t_{\alpha,v}$
$H_a : \mu_1 - \mu_2 < \Delta_0$	$t' \leq -t_{\alpha,v}$
$H_a : \mu_1 - \mu_2 \neq \Delta_0$	*either* $t' \geq t_{\alpha,v}$ *or* $t' \leq -t_{\alpha,v}$

- Two-lane highway versus four-lane highway

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	12.9235	9.1422
Variance	150.0522	72.7736
Observations	114	124
Hypothesized Mean Difference	0.0000	
df	200.0000	
t Stat	2.7410	
P(T<=t) one-tail	0.0033	
t Critical one-tail	1.6525	
P(T<=t) two-tail	0.0067	
t Critical two-tail	1.9719	

Null hypothesis is rejected.

- Two-lane highway with shoulder versus Two-lane highway without shoulder

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	10.8537	16.3281
Variance	115.8712	194.2905
Observations	70	43
Hypothesized Mean Difference	0.0000	
df	72.0000	
t Stat	-2.2033	
P(T<=t) one-tail	0.0154	
t Critical one-tail	1.6663	
P(T<=t) two-tail	0.0308	
t Critical two-tail	1.9935	

Null hypothesis is rejected.

- Four-lane highway with shoulder versus four-lane highway without shoulder

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	9.6245	8.4634
Variance	92.1097	50.8718
Observations	67	56
Hypothesized Mean Difference	0.0000	
df	119.0000	
t Stat	0.7684	
P(T<=t) one-tail	0.2219	
t Critical one-tail	1.6578	
P(T<=t) two-tail	0.4438	
t Critical two-tail	1.9801	

Null hypothesis is not rejected.

- Four-lane highway with median versus four-lane highway without median

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	12.2000	7.0371
Variance	62.8003	108.4830
Observations	57	30
Hypothesized Mean Difference	0	
df	47	
t Stat	2.3770	
P(T<=t) one-tail	0.0108	
t Critical one-tail	1.6779	
P(T<=t) two-tail	0.0216	
t Critical two-tail	2.0117	

Null hypothesis is rejected.

APPENDIX B

REGRESSION ANALYSIS RESULTS

1. Linear Regression Analysis of Two-lane Highways

- Linear Model for Two-lane Highways: 0.3 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9023
R Square	0.8141
Adjusted R Square	0.5353
Standard Error	4.3446
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	165.3340	55.1113	2.9197	0.2654
Residual	2	37.7515	18.8757		
Total	5	203.0854			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.5611	15.4463	0.1658	0.8836	-63.8990	69.0211
Speed	0.3053	0.2610	1.1698	0.3626	-0.8176	1.4281
AADT	-0.0009	0.0006	-1.5037	0.2715	-0.0036	0.0017
Access Density	0.2155	0.1021	2.1108	0.1692	-0.2238	0.6547

1. The R square shows a good fit, but the sample size is too small to obtain any definitive conclusions.

- Linear Model for Two-lane Highways: 0.6 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.5459
R Square	0.2980
Adjusted R Square	0.2253
Standard Error	10.6877
Observations	33

ANOVA

	df	SS	MS	F	Significance F
Regression	3	1405.901	468.6337	4.1027	0.0153
Residual	29	3312.558	114.2261		
Total	32	4718.459			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	43.6586	15.3041	2.8527	0.0079	12.3582	74.9589
Speed	-0.3059	0.2869	-1.0662	0.2951	-0.8928	0.2809
AADT	-0.0012	0.0004	-3.1009	0.0043	-0.0019	-0.0004
Access Density	0.0935	0.1504	0.6215	0.5391	-0.2141	0.4010

1. The R square does not show a good fit,
2. The F-statistic shows that at least one coefficient of the model is not zero,
3. Only the coefficient of access density shows a significant t-statistic value.

- Linear Model for Two-lane Highways: 0.9 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6553
R Square	0.4294
Adjusted R Square	0.3844
Standard Error	10.8515
Observations	42

ANOVA

	df	SS	MS	F	Significance F
Regression	3	3367.988	1122.663	9.5339	0.0001
Residual	38	4474.664	117.7543		
Total	41	7842.652			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	70.7597	14.4838	4.8854	0.0000	41.4387	100.0806
Speed	-0.6471	0.3016	-2.1454	0.0384	-1.2577	-0.0365
AADT	-0.0015	0.0004	-3.7313	0.0006	-0.0023	-0.0007
Access Density	-0.2220	0.1426	-1.5570	0.1278	-0.5106	0.0666

1. The R square does not show a very good fit,

2. The F-statistic shows that at least one coefficient of the model is not zero,

3. None of the coefficients of the variables show a significant t-statistic value.

- Linear Model for Two-lane Highways with Shoulder: 0.9 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.3130
R Square	0.0980
Adjusted R Square	-0.0445
Standard Error	7.0800
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	103.428	34.4759	0.6878	0.5706
Residual	19	952.406	50.1267		
Total	22	1055.834			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	24.8702	15.5978	1.5945	0.1273	-7.7764	57.5169
Speed	-0.3712	0.2628	-1.4126	0.1739	-0.9212	0.1788
AADT	0.0001	0.0004	0.2441	0.8098	-0.0007	0.0009
Access Density	-0.1006	0.1334	-0.7538	0.4602	-0.3798	0.1787

1. The R square does not show a good fit,

2. The F-statistic shows that at all the coefficients of the model are zero,

3. None of the coefficients of the variables shows a significant t-statistic value.

- Linear Model for Two-lane Highways without Shoulder: 0.9 miles

Regression Statistics	
Multiple R	0.7373
R Square	0.5436
Adjusted R Square	0.4523
Standard Error	11.5074
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2365.633	788.5442	5.9548	0.0070
Residual	15	1986.319	132.4213		
Total	18	4351.952			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	91.5866	37.0496	2.4720	0.0259	12.6173	170.5559
Speed	-0.6825	1.1792	-0.5788	0.5713	-3.1958	1.8308
AADT	-0.0029	0.0007	-3.9425	0.0013	-0.0044	-0.0013
Access Density	-0.2430	0.2555	-0.9512	0.3566	-0.7875	0.3015

1. The R square does not show a very good fit, but better than the corresponding one with shoulder,
2. The F-statistic shows that at least one coefficient of the model is not zero,
3. None of the coefficients of the variables show significant t-statistic values.

- Linear Model for Two-lane Highways: 1.2 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.4794
R Square	0.2298
Adjusted R Square	0.1082
Standard Error	10.2141
Observations	23

ANOVA

	df	SS	MS	F	Significance F
Regression	3	591.434	197.1446	1.8897	0.1656
Residual	19	1982.219	104.3273		
Total	22	2573.653			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-26.0668	16.4512	-1.5845	0.1296	-60.4995	8.3659
Speed	0.5300	0.3623	1.4630	0.1598	-0.2282	1.2883
AADT	0.0003	0.0007	0.4228	0.6772	-0.0012	0.0017
Access Density	0.4317	0.2442	1.7676	0.0932	-0.0795	0.9428

1. The R square does not show a good fit,
2. The F-statistic shows that all the coefficients of the model are zero,
3. None of the coefficients of the variables show significant t-statistic values.

- Linear Model for Two-lane Highways: above 1.5 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.5002
R Square	0.2502
Adjusted R Square	-0.0711
Standard Error	11.5542
Observations	11

ANOVA

	df	SS	MS	F	Significance F
Regression	3	311.839	103.9463	0.7786	0.5422
Residual	7	934.503	133.5005		
Total	10	1246.342			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	11.4829	41.2674	0.2783	0.7889	-86.0990	109.0647
Speed	0.1061	0.4959	0.2140	0.8367	-1.0665	1.2787
AADT	-0.0006	0.0013	-0.4574	0.6612	-0.0036	0.0024
Access Density	0.2716	0.3046	0.8917	0.4022	-0.4486	0.9918

1. The R square does not show a good fit,

2. The F-statistic shows that all the coefficients of the model are zero,

3. None of the coefficients show significant t-statistic values.

2. Nonlinear Regression Analysis of Two-lane Highways

- Nonlinear Model for Two-lane Highways: 0.6 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6739
R Square	0.4541
Adjusted R Square	0.3282
Standard Error	9.9531
Observations	33

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	2142.791	357.1318	3.6051	0.0098
Residual	26	2575.668	99.0642		
Total	32	4718.459			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	139.2991	91.2224	1.5270	0.1388	-48.2114	326.8096
Speed	-3.1753	4.3519	-0.7296	0.4721	-12.1208	5.7702
Speed square	0.0374	0.0545	0.6853	0.4992	-0.0747	0.1494
AADT	-0.0055	0.0020	-2.7183	0.0115	-0.0096	-0.0013
AADT square	0.0000	0.0000	2.1758	0.0388	0.0000	0.0000
Access density	-0.6182	0.5203	-1.1882	0.2455	-1.6877	0.4512
Access density square	0.0140	0.0101	1.3798	0.1794	-0.0069	0.0349

1. The R square does not show a very good fit,

2. The F-statistic shows that at least one of the coefficients of the model is not zero,

3. None of the coefficients show significant t-statistic values.

- Nonlinear Model for Two-lane Highways: 0.9 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7831
R Square	0.6132
Adjusted R Square	0.5469
Standard Error	9.3093
Observations	42

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	4809.46	801.5767	9.2494	4.38E-06
Residual	35	3033.192	86.6626		
Total	41	7842.652			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	191.0309	67.9162	2.8127	0.0080	53.1534	328.9083
Speed	-4.9683	3.4059	-1.4587	0.1536	-11.8825	1.9460
Speed square	0.0579	0.0427	1.3567	0.1836	-0.0288	0.1446
AADT	-0.0086	0.0019	-4.5543	0.0001	-0.0125	-0.0048
AADT square	2.13E-07	5.61E-08	3.7948	0.0006	9.9E-08	3.27E-07
Access density	0.5040	0.4224	1.1931	0.2408	-0.3536	1.3615
Access density square	-0.0095	0.0059	-1.5927	0.1202	-0.0215	0.0026

1. The R square shows a good fit,
2. The F-statistic shows that at least one of the coefficients of the model is not zero,
3. None of the coefficients show significant t-statistic values.

- Nonlinear Model for Two-lane Highways with Shoulder: 0.9 miles

Regression Statistics	
Multiple R	0.5174
R Square	0.2677
Adjusted R Square	-0.0068
Standard Error	6.9513
Observations	23

ANOVA

	df	SS	MS	F	Significance F
Regression	6	282.696	47.1160	0.9751	0.4730
Residual	16	773.138	48.3211		
Total	22	1055.834			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	141.2106	82.0393	1.7213	0.1045	-32.7049	315.1261
Speed	-6.6364	3.8174	-1.7385	0.1013	-14.7289	1.4561
Speed square	0.0768	0.0466	1.6491	0.1186	-0.0219	0.1755
AADT	0.0001	0.0036	0.0174	0.9863	-0.0075	0.0077
AADT square	4.53E-09	9.02E-08	0.0503	0.9605	-1.9E-07	1.96E-07
Access density	0.4255	0.3615	1.1771	0.2564	-0.3408	1.1918
Access density square	-0.0083	0.0054	-1.5463	0.1416	-0.0198	0.0031

1. The R square does not show a good fit,
2. The F-statistic shows that all the coefficients of the model are zero,
3. None of the coefficients show significant t-statistic values.

- Nonlinear Model for Two-lane Highways without Shoulder: 0.9 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7555
R Square	0.5707
Adjusted R Square	0.3561
Standard Error	12.4773
Observations	19

ANOVA

	df	SS	MS	F	Significance F
Regression	6	2483.766	413.9610	2.6590	0.0705
Residual	12	1868.186	155.6821		
Total	18	4351.952			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-49.4611	0	65535.0	0.9863	-49.4611	-49.4611
Speed	10.8437	0	65535.0	0.9605	10.8437	10.8437
Speed square	-0.1845	0	65535.0	0.2564	-0.1845	-0.1845
AADT	-0.0104	0.0088	-1.1888	0.2575	-0.0295	0.0087
AADT square	2.75E-07	3.18E-07	0.8641	0.4045	-4.2E-07	9.67E-07
Access density	0.2805	1.4992	0.1871	0.8547	-2.9860	3.5470
Access density square	-0.0058	0.0206	-0.2821	0.7826	-0.0507	0.0391

1. The R square does not show a very good fit,
2. The F-statistic shows that all the coefficients of the model are zero,
3. None of the coefficients show significant t-statistic values.

- Nonlinear Model for Two-lane Highways: 1.2 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6336
R Square	0.4014
Adjusted R Square	0.1769
Standard Error	9.8125
Observations	23

ANOVA

	df	SS	MS	F	Significance F
Regression	6	1033.079	172.180	1.7882	0.1650
Residual	16	1540.574	96.286		
Total	22	2573.653			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	37.2859	74.6415	0.4995	0.6242	-120.9471	195.5189
Speed	3.4168	3.3306	1.0259	0.3202	-3.6438	10.4773
Speed square	-0.0335	0.0414	-0.8086	0.4306	-0.1213	0.0543
AADT	-0.0165	0.0114	-1.4469	0.1672	-0.0407	0.0077
AADT square	4.88E-07	3.31E-07	1.4749	0.1596	-2.1E-07	1.19E-06
Access density	1.6288	0.7354	2.2149	0.0416	0.0699	3.1878
Access density square	-0.0207	0.0138	-1.5021	0.1525	-0.0499	0.0085

1. The R square does not show a very good fit,

2. The F-statistic shows that all the coefficients of the model are zero,

3. None of the coefficients show significant t-statistic values.

- Nonlinear Model for Two-lane Highways: above 1.5 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9318
R Square	0.8683
Adjusted R Square	0.6707
Standard Error	6.4062
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	1082.187	180.3645	4.3950	0.0867
Residual	4	164.155	41.0388		
Total	10	1246.342			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-165.5238	81.2302	-2.0377	0.1112	-391.0554	60.0077
Speed	18.6628	5.3183	3.5091	0.0247	3.8967	33.4288
Speed square	-0.2377	0.0698	-3.4062	0.0271	-0.4314	-0.0439
AADT	-0.0211	0.0066	-3.2128	0.0325	-0.0394	-0.0029
AADT square	6.54E-07	2.11E-07	3.1035	0.0361	6.89E-08	1.24E-06
Access density	0.0264	0.7930	0.0333	0.9751	-2.1753	2.2280
Access density square	-0.0097	0.0125	-0.7782	0.4799	-0.0444	0.0250

1. The R square shows a good fit,

2. The F-statistic shows that all the coefficients of the model are zero,

3. None of the coefficients show significant t-statistic values.

3. Linear Regression Analysis of Four-lane Highways

- **Linear Model for Four-lane Highways: All Sections**

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.3984
R Square	0.1587
Adjusted R Square	0.1488
Standard Error	8.4340
Observations	87

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1140.44	1140.440	16.033	0.000133
Residual	85	6046.305	71.133		
Total	86	7186.745			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	4.8374	1.6617	2.9111	0.0046	1.5335
Access density	0.2264	0.0565	4.0041	0.0001	0.1140

1. The R square does not show a good fit,
2. The coefficient of access density shows a significant t-statistic value.

- Linear Model for Four-lane Highways: 0.3 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.8223
R Square	0.6761
Adjusted R Square	0.4332
Standard Error	8.8046
Observations	8

ANOVA

	df	SS	MS	F	Significance F
Regression	3	647.3744	215.7915	2.7837	0.1739
Residual	4	310.0811	77.5203		
Total	7	957.4554			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	110.3518	43.5990	2.5311	0.0646	-10.6985	231.4022
Speed	-2.6985	1.2038	-2.2417	0.0885	-6.0408	0.6437
AADT	0.0014	0.0013	1.1327	0.3206	-0.0021	0.0049
Access Density	-0.6621	0.5754	-1.1508	0.3139	-2.2597	0.9354

1. The R square shows a good fit, but the sample size is too small to obtain any definitive conclusions.

- Linear Model for Four-lane Highways: 0.6 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.4447
R Square	0.1978
Adjusted R Square	0.0473
Standard Error	10.4625
Observations	20

ANOVA

	df	SS	MS	F	Significance F
Regression	3	431.728	143.9093	1.3147	0.3042
Residual	16	1751.426	109.4641		
Total	19	2183.154			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	8.0700	22.7025	0.3555	0.7269	-40.0571	56.1972
Speed	0.1412	0.4099	0.3446	0.7349	-0.7277	1.0101
AADT	-0.0006	0.0005	-1.1187	0.2798	-0.0016	0.0005
Access Density	0.2662	0.2017	1.3198	0.2055	-0.1614	0.6939

1. The R square does not show a good fit,
2. The F-statistic shows that all the coefficients of the model are zero,
3. None of the coefficients show significant t-statistic values.

- Linear Model for Four-lane Highways: 0.9 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7425
R Square	0.5513
Adjusted R Square	0.4840
Standard Error	6.4776
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1031.109	343.7030	8.1914	0.0009
Residual	20	839.179	41.9590		
Total	23	1870.288			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	44.1753	15.2788	2.8913	0.0090	12.3043	76.0463
Speed	-0.6903	0.2207	-3.1273	0.0053	-1.1507	-0.2298
AADT	-0.0002	0.0003	-0.8300	0.4164	-0.0007	0.0003
Access Density	0.0319	0.1464	0.2176	0.8299	-0.2735	0.3373

1. The R square does not show a very good fit,
2. The F-statistic shows that at least one of the coefficients of the model is not zero,
3. None of the coefficients show significant t-statistic values.

- Linear Model for Four-lane Highways: 1.2 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6846
R Square	0.4686
Adjusted R Square	0.3624
Standard Error	6.0547
Observations	19

ANOVA

	df	SS	MS	F	Significance F
Regression	3	484.984	161.6613	4.4098	0.0206
Residual	15	549.892	36.6595		
Total	18	1034.876			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	45.3003	11.6861	3.8764	0.0015	20.3918	70.2087
Speed	-0.6265	0.1861	-3.3663	0.0042	-1.0231	-0.2298
AADT	-0.0002	0.0004	-0.6006	0.5571	-0.0011	0.0006
Access Density	-0.1118	0.0941	-1.1884	0.2531	-0.3123	0.0887

1. The R square does not show a good fit,
2. The F-statistic shows that at least one of the coefficients of the model is not zero,
3. None of the coefficients show significant t-statistic values.

- Linear Model for Four-lane Highways: above 1.5 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7899
R Square	0.6239
Adjusted R Square	0.5213
Standard Error	4.3556
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	3	346.201	115.4004	6.0829	0.0107
Residual	11	208.685	18.9714		
Total	14	554.886			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	13.0964	15.8531	0.8261	0.4263	-21.7961	47.9889
Speed	-0.1792	0.2080	-0.8612	0.4075	-0.6371	0.2787
AADT	-0.0001	0.0004	-0.2491	0.8078	-0.0010	0.0008
Access Density	0.2683	0.1241	2.1612	0.0536	-0.0049	0.5415

1. The R square shows a good fit,
2. The F-statistic shows that at least one of the coefficients of the model is not zero,
3. None of the coefficients show significant t-statistic values.

4. Nonlinear Regression Analysis of Four-lane Highways

- Nonlinear Model for Four-lane Highways: 0.3 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.8469
R Square	0.7172
Adjusted R Square	-0.9795
Standard Error	16.4545
Observations	8

ANOVA

	df	SS	MS	F	Significance F
Regression	6	686.7046	114.4508	0.4227	0.8250
Residual	1	270.7509	270.7509		
Total	7	957.4554			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	393.9541	1.66E+09	2.38E-07	1	-2.1E+10	2.1E+10
Speed	-14.0693	67266527	-2.1E-07	1	-8.5E+08	8.55E+08
Speed square	0.1466	801965.4	1.83E-07	1	-1E+07	10189893
AADT	-0.0071	31041.09	-2.3E-07	1	-394413	394412.7
AADT square	0.0000	0.8097	2.61E-07	1	-10.2882	10.28817
Access density	0.3731	3.166221	0.117837	0.925327	-39.8574	40.60357
Access density square	-0.0160	0.043205	-0.36977	0.774522	-0.56494	0.532989

1. The R square shows a good fit, but the sample size is too small to obtain any definitive conclusions.

- Nonlinear Model for Four-lane Highways: 0.6 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6127
R Square	0.3754
Adjusted R Square	0.0871
Standard Error	10.2416
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	819.585	136.5974	1.3023	0.3226
Residual	13	1363.569	104.8899		
Total	19	2183.154			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-43.9996	78.7575	-0.5587	0.5859	-214.1449	126.1457
Speed	-1.2420	3.8845	-0.3197	0.7542	-9.6340	7.1499
Speed square	0.0116	0.0453	0.2569	0.8013	-0.0861	0.1094
AADT	0.0101	0.0058	1.7307	0.1071	-0.0025	0.0227
AADT square	-2.6E-07	1.45E-07	-1.8210	0.0917	-5.8E-07	4.92E-08
Access density	-0.7258	0.8398	-0.8643	0.4031	-2.5401	1.0885
Access density square	0.0133	0.0133	0.9972	0.3369	-0.0155	0.0420

1. The R square does not show a good fit,
2. The F-statistic shows that all the coefficients of the model are zero,
3. None of the coefficients show significant t-statistic values.

- Nonlinear Model for Four-lane Highways: 0.9 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7744
R Square	0.5998
Adjusted R Square	0.4585
Standard Error	6.6357
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	1121.734	186.9556	4.2458	0.0086
Residual	17	748.555	44.0326		
Total	23	1870.288			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	27.5699	80.3511	0.3431	0.7357	-141.9563	197.0962
Speed	-0.6205	3.8592	-0.1608	0.8742	-8.7626	7.5217
Speed square	-0.0024	0.0426	-0.0557	0.9562	-0.0922	0.0874
AADT	0.0017	0.0015	1.1084	0.2831	-0.0015	0.0049
AADT square	-4E-08	3.43E-08	-1.1793	0.2545	-1.1E-07	3.19E-08
Access density	-0.0933	0.4228	-0.2207	0.8280	-0.9854	0.7988
Access density square	0.0003	0.0078	0.0417	0.9672	-0.0161	0.0168

1. The R square does not show a very good fit,
2. The F-statistic shows that at least one of the coefficients of the model is not zero,
3. None of the coefficients show significant t-statistic values.

- Nonlinear Model for Four-lane Highways: 1.2 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.8362
R Square	0.6992
Adjusted R Square	0.5488
Standard Error	5.0930
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	723.618	120.6029	4.6496	0.0114
Residual	12	311.258	25.9382		
Total	18	1034.876			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-39.2109	36.9646	-1.0608	0.3097	-119.7499	41.3281
Speed	2.5544	2.0755	1.2308	0.2420	-1.9676	7.0765
Speed square	-0.0357	0.0251	-1.4222	0.1804	-0.0904	0.0190
AADT	0.0010	0.0041	0.2470	0.8091	-0.0080	0.0100
AADT square	-3.5E-08	1.13E-07	-0.3105	0.7615	-2.8E-07	2.11E-07
Access density	0.3454	0.2775	1.2447	0.2370	-0.2592	0.9500
Access density square	-0.0069	0.0039	-1.7757	0.1011	-0.0154	0.0016

1. The R square shows a good fit,
2. The F-statistic shows that at least one of the coefficients of the model is not zero,
3. None of the coefficients show significant t-statistic values.

- Nonlinear Model for Four-lane Highways: above 1.5 miles

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.8331
R Square	0.6940
Adjusted R Square	0.4646
Standard Error	4.6066
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	6	385.117	64.1862	3.0246	0.0753
Residual	8	169.770	21.2212		
Total	14	554.886			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	30.1358	92.2667	0.3266	0.7523	-182.6316	242.9033
Speed	2.7293	3.1562	0.8647	0.4124	-4.5489	10.0074
Speed square	-0.0341	0.0377	-0.9040	0.3924	-0.1210	0.0528
AADT	-0.0093	0.0091	-1.0276	0.3342	-0.0303	0.0116
AADT square	2.73E-07	2.58E-07	1.0598	0.3202	-3.2E-07	8.67E-07
Access density	0.3160	0.6507	0.4857	0.6402	-1.1844	1.8165
Access density square	-0.0020	0.0082	-0.2460	0.8119	-0.0209	0.0169

1. The R square shows a good fit,
2. The F-statistic shows that all the coefficients of the model are zero,
3. None of the coefficients show significant t-statistic values.

APPENDIX C

SAMPLE DATABASE OF ROAD SECTIONS

- Two-lane Highway Database

Lanes	Length (mile)	Speed Limit (mph)	Shoulder	Median	AADT	Access Density (#/mile)	Accident Rate (#/MVM 1:10)
2	0.3	35	N	N	11700	50.00	15.61
2	0.3	35	Y	N	11700	0.00	0.00
2	0.3	45	Y	N	18000	0.00	0.00
2	0.3	45	Y	N	18000	3.33	0.00
2	0.3	25	N	N	18000	46.67	0.00
2	0.3	25	N	N	18000	13.33	0.00
2	0.6	30	N	N	27000	43.33	8.46
2	0.6	30	N	N	27000	21.67	3.38
2	0.6	35	N	N	18000	23.33	7.61
2	0.6	45	Y	N	18000	5.00	10.15
2	0.6	45	Y	N	18000	40.00	7.61
2	0.6	30	N	N	16000	21.67	19.98
2	0.6	45	Y	N	13000	5.00	3.51
2	0.6	30	Y	N	16000	5.00	37.10
2	0.6	45	Y	N	13000	28.33	7.02
2	0.6	35	Y	N	11700	35.00	19.51
2	0.6	45	Y	N	11700	8.33	23.42
2	0.6	45	Y	N	11700	10.00	7.81
2	0.6	50	Y	N	20500	15.00	2.23
2	0.6	50	Y	N	20500	20.00	22.27
2	0.6	35	Y	N	16000	20.00	2.85
2	0.6	35	Y	N	15000	13.33	12.18
2	0.6	35	Y	N	8000	36.67	28.54
2	0.6	35	N	N	20000	40.00	11.42
2	0.6	50	Y	N	16000	23.33	2.85
2	0.6	50	Y	N	15000	35.00	15.22
2	0.6	35	Y	N	8000	50.00	57.08
2	0.6	45	Y	N	18000	35.00	25.37
2	0.6	35	N	N	10000	23.33	27.40
2	0.6	50	Y	N	20000	15.00	4.57
2	0.6	45	Y	N	18000	16.67	0.00
2	0.6	45	Y	N	18000	0.00	7.61

Table (Continued)

Lanes	Length (mile)	Speed Limit (mph)	Shoulder	Median	AADT	Access Density (#/mile)	Accident Rate (#/MVM 1:10)
2	0.6	30	N	N	21000	31.67	4.35
2	0.6	30	N	N	21000	40.00	0.00
2	0.6	45	N	N	27000	11.67	6.76
2	0.6	45	N	N	27000	10.00	16.91
2	0.6	35	N	N	18000	48.33	7.61
2	0.6	35	N	N	18000	30.00	20.29
2	0.6	35	N	N	18000	36.67	15.22
2	0.7	35	Y	N	21000	22.86	1.86
2	0.7	35	Y	N	21000	18.57	7.46
2	0.8	30	N	N	14000	45.00	9.78
2	0.8	30	N	N	14000	36.25	12.23
2	0.9	50	Y	N	14000	13.33	4.35
2	0.9	50	Y	N	14000	3.33	0.00
2	0.9	40	Y	N	27000	24.44	10.15
2	0.9	30	Y	N	13200	40.00	4.61
2	0.9	40	Y	N	27000	23.33	12.40
2	0.9	30	Y	N	13600	65.56	6.72
2	0.9	35	N	N	10000	47.78	24.35
2	0.9	35	N	N	18000	43.33	8.46
2	0.9	35	N	N	10000	56.67	36.53
2	0.9	35	N	N	10000	50.00	24.35
2	0.9	35	N	N	18000	43.33	6.76
2	0.9	35	N	N	18000	14.44	8.46
2	0.9	50	Y	N	22000	18.89	9.69
2	0.9	50	Y	N	22000	4.44	5.53
2	0.9	35	Y	N	18000	51.11	8.46
2	0.9	30	Y	N	16000	30.00	32.34
2	0.9	45	Y	N	16000	26.67	5.71
2	0.9	50	Y	N	20000	32.22	12.18
2	0.9	50	Y	N	20000	25.56	4.57
2	0.9	30	N	N	16000	34.44	11.42
2	0.9	45	Y	N	16000	35.56	3.81
2	0.9	50	Y	N	20500	3.33	2.97
2	0.9	50	Y	N	20500	11.11	8.91
2	0.9	35	Y	N	15000	16.67	14.21
2	0.9	30	N	N	8000	17.78	41.86
2	0.9	45	Y	N	18000	24.44	1.69
2	0.9	45	Y	N	18000	18.89	13.53

Table (Continued)

Lanes	Length (mile)	Speed Limit (mph)	Shoulder	Median	AADT	Access Density (#/mile)	Accident Rate (#/MVM 1:10)
2	0.9	30	N	N	13000	30.00	25.76
2	0.9	35	N	N	10000	35.56	12.18
2	0.9	50	Y	N	15000	11.11	18.26
2	0.9	30	N	N	8000	23.33	49.47
2	0.9	35	N	N	20000	41.11	9.13
2	0.9	30	N	N	12000	43.33	48.20
2	0.9	35	N	N	10000	40.00	33.49
2	0.9	35	N	N	10000	30.00	51.75
2	0.9	35	N	N	10000	36.67	24.35
2	0.9	35	N	N	10000	54.44	12.18
2	0.9	35	Y	N	14000	45.56	4.35
2	1.1	30	N	N	12000	22.73	4.15
2	1.1	45	Y	N	20000	28.18	9.96
2	1.1	45	Y	N	13500	13.64	1.84
2	1.1	50	Y	N	14000	6.36	3.56
2	1.1	30	N	N	12000	28.18	18.68
2	1.1	45	Y	N	20000	31.82	6.23
2	1.1	45	Y	N	13500	29.09	9.22
2	1.1	50	Y	N	14000	9.09	5.34
2	1.2	25	N	N	12000	45.00	0.00
2	1.2	50	Y	N	14000	29.17	29.35
2	1.2	25	N	N	12000	20.00	0.00
2	1.2	50	Y	N	14000	21.67	14.68
2	1.2	45	Y	N	11700	8.33	9.76
2	1.2	50	Y	N	22000	13.33	4.15
2	1.2	40	Y	N	21000	30.83	40.23
2	1.2	50	Y	N	20500	14.17	12.25
2	1.2	50	Y	N	20000	22.50	5.71
2	1.2	50	Y	N	22000	5.83	8.30
2	1.2	50	Y	N	21000	28.33	38.05
2	1.2	40	N	N	16000	26.67	9.99
2	1.2	35	N	N	20000	36.67	10.27
2	1.2	40	N	N	16000	20.00	8.56
2	1.2	35	Y	N	18000	47.50	10.15
2	1.5	25	Y	N	22000	7.33	6.64
2	1.5	25	Y	N	22000	18.67	0.83
2	1.5	35	Y	N	15000	49.33	4.87
2	1.5	35	N	N	18000	42.67	11.16

Table (Continued)

Lanes	Length (mile)	Speed Limit (mph)	Shoulder	Median	AADT	Access Density (#/mile)	Accident Rate (#/MVM 1:10)
2	1.7	40	Y	N	18000	31.18	28.65
2	1.7	40	Y	N	18000	34.71	25.07
2	1.8	50	Y	N	14000	6.11	6.52
2	1.8	50	Y	N	14000	18.89	6.52
2	1.8	50	Y	N	20500	11.11	8.91
2	1.8	35	N	N	10000	43.33	35.01
2	2.7	35	Y	N	14000	34.81	9.42

- Four-lane Highway Database

Lanes	Length (mile)	Speed Limit (mph)	Shoulder	Median	AADT	Access Density (#/mile)	Accident Rate (#/MVM 1:10)
4	0.3	45	Y	N	11700	6.67	0.00
4	0.3	50	Y	N	20000	3.33	0.00
4	0.3	45	Y	N	11700	0.00	7.81
4	0.3	50	Y	N	20000	6.67	0.00
4	0.3	35	Y	N	15000	26.67	30.44
4	0.3	35	Y	N	15000	20.00	12.18
4	0.3	40	N	N	27000	50.00	3.38
4	0.3	40	N	N	27000	33.33	23.68
4	0.5	40	Y	N	22000	38.00	7.47
4	0.5	40	Y	N	22000	32.00	2.49
4	0.6	30	Y	N	22000	45.00	12.45
4	0.6	35	Y	Y	18000	48.33	5.07
4	0.6	35	Y	Y	18000	41.67	12.68
4	0.6	45	Y	N	13500	1.67	10.15
4	0.6	55	Y	Y	25000	10.00	7.31
4	0.6	45	Y	N	13500	16.67	0.00
4	0.6	55	Y	Y	25000	10.00	3.65
4	0.6	35	N	N	20000	16.67	11.42
4	0.6	35	N	N	27000	28.33	3.38
4	0.6	30	Y	N	27000	51.67	1.69
4	0.6	35	Y	N	19000	30.00	16.82
4	0.6	35	Y	N	19000	30.00	19.23
4	0.6	30	N	N	13200	41.67	13.84

Table (Continued)

Lanes	Length (mile)	Speed Limit (mph)	Shoulder	Median	AADT	Access Density (#/mile)	Accident Rate (#/MVM 1:10)
4	0.6	35	N	N	27000	11.67	0.00
4	0.6	30	Y	N	27000	16.67	3.38
4	0.6	30	Y	N	13600	36.67	3.36
4	0.6	35	Y	Y	18000	48.33	48.20
4	0.6	35	N	Y	18000	46.67	15.22
4	0.6	35	Y	Y	18000	35.00	32.98
4	0.9	55	Y	Y	20000	7.78	0.00
4	0.9	55	Y	Y	15000	1.11	4.06
4	0.9	50	Y	Y	14000	13.33	2.17
4	0.9	55	Y	Y	20000	10.00	3.04
4	0.9	55	Y	Y	15000	6.67	2.03
4	0.9	50	Y	Y	14000	0.00	2.17
4	0.9	30	Y	N	37000	20.00	11.52
4	0.9	35	Y	N	19000	47.78	19.23
4	0.9	35	Y	N	16000	15.56	36.15
4	0.9	35	Y	N	16000	31.11	3.81
4	0.9	30	Y	N	37000	7.78	13.99
4	0.9	45	Y	N	19000	14.44	8.01
4	0.9	35	Y	N	19000	25.56	17.62
4	0.9	35	Y	N	19000	17.78	14.42
4	0.9	35	N	Y	18000	45.56	16.91
4	0.9	55	Y	Y	25000	2.22	2.44
4	0.9	55	Y	Y	25000	4.44	3.65
4	0.9	40	N	N	20500	18.89	14.85
4	0.9	40	N	N	22000	33.33	24.91
4	0.9	55	Y	Y	12000	11.11	5.07
4	0.9	55	Y	Y	20000	3.33	4.57
4	0.9	55	Y	Y	12000	6.67	0.00
4	0.9	55	Y	Y	20000	20.00	3.04
4	0.9	35	Y	N	19000	34.44	12.82
4	1	40	Y	N	17500	34.00	20.35
4	1	40	Y	N	17500	42.00	14.09
4	1.1	50	Y	N	14000	12.73	8.90
4	1.1	50	Y	N	14000	8.18	10.67
4	1.2	55	Y	Y	25000	11.67	1.83
4	1.2	55	Y	Y	20000	3.33	2.28
4	1.2	55	Y	Y	25000	18.33	0.91
4	1.2	55	Y	Y	20000	14.17	3.42

Table (Continued)

Lanes	Length (mile)	Speed Limit (mph)	Shoulder	Median	AADT	Access Density (#/mile)	Accident Rate (#/MVM 1:10)
4	1.2	45	N	N	20000	27.50	11.42
4	1.2	45	Y	N	19000	1.67	4.81
4	1.2	35	Y	N	19000	22.50	19.23
4	1.2	30	Y	N	13200	48.33	15.57
4	1.2	30	Y	N	22000	45.00	5.19
4	1.2	45	N	N	20000	33.33	20.55
4	1.2	45	Y	N	19000	20.83	18.02
4	1.2	35	Y	N	19000	46.67	13.22
4	1.2	30	Y	N	13600	24.17	20.15
4	1.3	50	Y	Y	14000	68.46	0.00
4	1.3	50	Y	Y	14000	33.85	0.00
4	1.5	55	Y	Y	20000	7.33	1.83
4	1.5	55	Y	Y	20000	5.33	1.83
4	1.5	35	Y	N	19000	32.67	11.54
4	1.5	35	N	N	15000	20.67	7.31
4	1.6	35	Y	Y	18000	28.13	13.32
4	1.6	35	Y	Y	18000	36.25	11.42
4	1.7	40	N	N	14000	57.06	19.57
4	1.7	40	N	N	14000	39.41	21.87
4	1.8	40	N	N	20500	22.22	11.88
4	1.8	30	Y	N	22000	38.33	20.06
4	1.8	35	Y	N	16000	27.78	19.03
4	2	50	N	N	14000	19.00	8.81
4	2	50	N	N	14000	25.00	8.81
4	2.1	35	Y	N	15000	38.57	7.83
4	2.4	30	N	N	22000	48.33	16.09

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