3-22-2004

Effects of Two-Way Left-Turn Lane on Roadway Safety

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by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering
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College of Engineering
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Date of Approval:
March 22, 2004

Keywords: average number of crashes, distribution, prediction model, access density, posted speed, ADT, number of lanes, critical section

ACKNOWLEDGEMENTS

It is of great pride that I had a chance to work with the brilliant minds affiliated to the Department of Civil and Environmental Engineering, University of South Florida. First, I would like to thank Dr. Jian John Lu for his continued support and able guidance in my research efforts. I would also like to thank Dr. Ram Pendyala and Dr. Manjriker Gunaratne for serving on my committee and providing their valuable suggestions. And I would like to acknowledge the Florida Department of Transportation for providing funding for the research. In particular, I would like to thank Juan Pernia and Jingjing Fan for their help and suggestions throughout the research. Finally, I would like to dedicate my thesis effort to my parents Mr. Guoxiong Peng and Ms. Peifen Zhuo.

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EFFECTS OF TWO-WAY LEFT-TURN LANE ON ROADWAY SAFETY

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ABSTRACT

Two-way left-turn lane (TWLTL) is one of the common median treatments on the roadway. It is found that a number of crashes reported in Florida State are related to TWLTLs. This research focused on evaluating the effect of TWLTLs on these crashes by using the statistical crash prediction model that can estimate the expected number of crashes on TWLTLs. The crash database for analysis was extracted from the Florida Traffic Crash Database based on the TWLTL section list provided by FDOT and combined with some traffic characteristics. It consisted of totally 1688 sample sections within a three-year period from 1996 to 1998.

Based on the crash database, distribution fittings for Poisson, Negative Binomial and Lognormal regression were conducted for average number of crashes. According to the results, statistical crash predictive model was developed to estimate the average number of crashes. Negative Binomial regression was applied with four variables, ADT, access density, posted speed and number of lanes for the TWLTL sections. The regression parameters were estimated by using maximum likelihood method with statistical software. The findings of the analysis indicated that all of the variables adopted in the predictive model significantly affect the occurrence of crashes. And the average number of crashes increases with the increase of ADT, access density and number of lanes, while with the

decrease of posted speed. After that, the goodness-of-fit of developed model was performed in term of Pearson's R-square and likelihood ratio index. The results showed that the Negative Binomial regression model could explain the relationship between the variables and the crash occurrence

In the third part, an approach was developed to identify the TWLTL sections with safety concern. For an undivided roadway, the approach can be carried out to judge if the TWLTL is appropriate to be selected as the median treatment. During the process, the whole database was divided into six categories according to the posted speed and number of lanes. By adopting the selected percentile value from the distribution of average number of crashes for each category in the predictive model, the critical ADT values according to specific access density, number of lane and posted speed level for each category were calculated and tabulated. With the comparison of the actual ADT value and the critical ADT value, if the actual ADT is higher than the critical value, the TWLTL section is determined as the critical section, which means the TWLTL is not appropriate to be selected as the median treatment in this roadway section.

CHAPTER 1

INTRODUCTION

1.1 Background

A two-way left-turn lane (TWLTL) is a lane in the center of a road that is designed for left turn movements by both directions of traffic. It is commonly used as the median treatment on roadways. Figure 1.1 showed the basic concept of TWLTL. By decreasing the conflicts between through- and mid-block left-turn traffic, TWLTL is considered to solve the safety and operational problems on roadways.

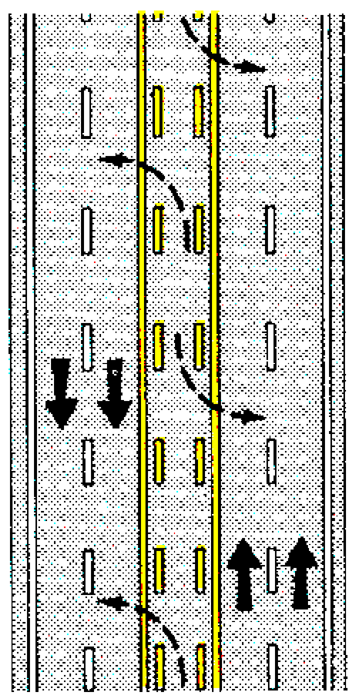

Figure 1.1 Basic Concept of Two-way Left-turn Lane

From the 1950s through the 1970s, many arterial and collector roads and streets were constructed with either two lanes or four lanes and no turn lanes or medians. Since all lanes served both through traffic and turning traffic, the accident rate caused by the conflicts between through and left-turning vehicles grew. When those roads with unmanaged development and access experience a considerable amount of turning traffic, congestion delays and crashes increase. Types of crashes most associated with turning vehicles include rear-end and left-turn collisions. Considering that TWLTLs separate left-turning traffic from through traffic, they can help solve some of these problems.

But the operation of a TWLTL also allows vehicles to make some other conflicting movements (See Figure 1.2). The conflicts involve 1) motorists trying to cross the arterial from a driveway to a driveway or street to street; 2) making a left turn off the arterial to a driveway or side street; 3) using the left-turn lane to pass stopped vehicles in the main thru lanes; 4) allowing uncontrolled U-turns across two thru lanes; 5) making a left turn from a side street or driveway onto the arterial; 6) accelerating in TWLTL to merge right; and 7) head-on accidents in the TWLTL. [7] All of these conflicts are potential traffic accidents.

These conflicts would be highlighted by the very high traffic volumes on the roadway. Previous studies have indicated that TWLTLs should generally not be used in situations where the through traffic volume is substantial. When the ADT on a street is very high, a TWLTL road may start to become ineffective. The main reason is that if a left-turning vehicle might not be able enter the TWLTL as soon as possible, it might decelerate or even stop in the inside through lane, creating delay to through traffic and a loss of capacity and efficiency. Heavy volumes on multiple through lanes may prevent a left-turning vehicle from finding a safe, acceptable gap for an extended period of time. If more left-turning vehicles queue up behind the first, its driver may feel under pressure to accept an unsafe gap. So if the number of movements made in a TWLTL becomes too large, there will be a resultant increase in accidents or near accidents.

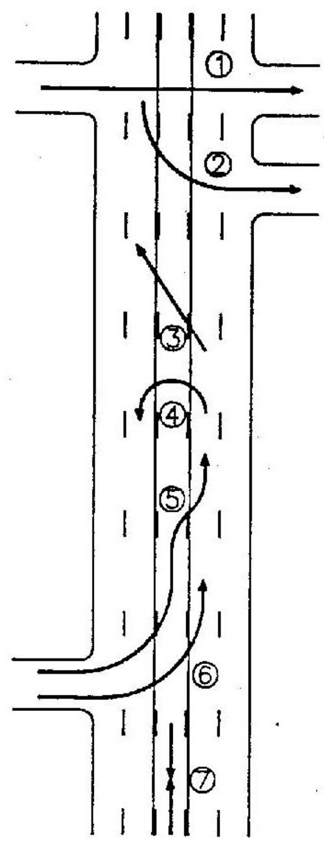

Figure 1.2 Conflicts Occurring on TWLTL Roadways

Many traffic engineering and highway designers have been concerned about whether or not TWLTLs are appropriate under certain conditions. Some of the states had some kind of guidelines for the selecting TWLTLs as the median treatment. But using data from deferent source will get deferent results. The models and procedures of the existing state of art are not applicable to all cases and locations. So this analysis was carried out by using the crash database of the state of Florida.

1.2 Research Statement

From above, it's concluded that the volume of the roadway is a very significant factor that should be taken into consideration in the decision. The book A Policy on Geometric Design of Highways and Streets, published by the American Association of State Highway and Transportation Officials (AASHTO), makes a few specific comments about the use of a TWLTL, which includes: "[TWLTL] works well where the speed on the arterial highway is relatively low and there are no heavy concentrations of left-turn traffic," and "[TWLTL] should be used only in an urban setting … where there are no more than two through lanes in each direction." In a report prepared for the Federal Highway Administration (FHWA), Azzeh et al, presented the results of a comparative analysis on the safety aspects of a raised median and TWLTL. The authors found that when driveway density was high, a raised median was safer than a TWLTL.

In this research, three factors, traffic volume, access density and post speed, were used in the analysis. And some other related factors, such as number of lanes, were also considered. And mathematical methodology was applied to develop the models to estimating accidents for roads with a TWLTL. From the model, the critical traffic volume was calculated responding to selected critical percentile value of the crash distribution. Compared with the actual road characteristics, recommendations of appropriate use of TWLTL median treatment were addressed. Detailed studies will be stated in the following chapters.

1.3 Research Purposes and Objectives

The primary purpose of this research was to analyze the factors that are influential in the safety experience of TWLTLs and develop recommendations concerning when TWLTLs may be appropriate based on these factors. The specific objectives of the study were:

1) To review the available literature and other projects in relation with the factors that were to be evaluated and analyzed;
2) To obtain the information of the related factors from the Florida Department of Transportation;
3) To conduct a detailed crash data analysis related to concerns to verify the influence of the factors on crash occurrence;
4) To develop mathematical models to identify various factors that are influential in selecting TWLTL as the median treatment;
5) To apply the approach to identify the TWLTL sections which have safety concerns;
6) To write a final report.

1.4 Outline of the Report

This report on the crash data analysis of TWLTLs consists of seven chapters. Chapter 1 provides an overview of the research project with some backgrounds in this subject area. Chapter 2 describes the brief summary of the previous studies done in selecting TWLTLs as the median treatment. Chapter 3 explains the methodology employed in achieving the previously mentioned objectives. Chapter 4 presents the data performing process, which was obtained from the FDOT Crash Database and other data resource. Analysis results and findings of the study are given in Chapter 5, it consisted of statistical analysis and prediction modeling. Chapter 6 introduced the procedure of the identification of critical TWLTL sections and advanced practical recommendation for the existed TWLTL treatment. The final chapter Chapter 7 provides the summary and conclusion of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Characteristics

Tow-way left-turn lane and raised median are two common median treatments on the roadway. Most business sector and the motoring public prefer the TWLTL to raised-median designs. In 1978, a research of TWLTLs by Ohio State University listed the general characteristics of TWLTLs.

Advantages of TWLTL over Raised Medians:

1) Removal of left-turning vehicles from through traffic while still providing maximum left-turning access;
2) Reduction of delay to left-turning vehicles;
3) Direct access to adjoining property;
4) Flexibility in roadway use, as for a detour lane, a path for emergency vehicles, refuge for disabled vehicles.

However, there are also some disadvantages of TWLTL compared with Raised Medians:

1) No refuge area for pedestrians crossing wide arterial;
2) Unsafe operation where sight distance is inadequate (such as where a TWLTL goes over a steep hill);

3) Visibility problem of painted median (on rainy nights);
4) More traffic conflict points, especially at driveways;
5) Possible misuse as a passing lane or even a travel lane;
6) Burden of instructing public in proper use. Some motorists do not know that the solid yellow line prohibits passing.

Harwood and St. John also list some characteristics and appropriate use of raised medians and TWLTLs. They found TWLTLs decrease travel time for drivers who wish to turn left and reduce deay to left-turning vehicles comparing with where median openings are not provided. They also reduce operational flexibility, such as allowing for emergency vehicle operation, lane closures, and work zones.

2.2 Existing Guideline

In the past decade, there have been many studies regarding median treatment selection. They focused on operational and safety effects of TWLTLs and other median treatment. And they addressed the situation where the median types could be appropriately used.

Parker's research, 1983, was based on a four-lane road. It presented a series of expected value tables, which indicated that in a ADT range from 10,000 to 30,000, when the driveways per mile is lower than 30 and the streets per mile is lower than 5, the number of accident per mile of TWLTL is relatively lower.

FHWA conducted a study of the accident-rate of TWLTLs and raised medians for a four-lane highway. They measured the accident rate reduction of these two median types from a previously undivided roadway. The study was carried out in three ADT levels, less than 5,000,5,000to 15,000 and more than 15,000 vehicles per day. From the comparison of the results, for all ADT ranges, TWLTLs were expected to be safer in the areas with several concentrated sources of traffic and fewer than 60 commercial low-volume driveways per mile. And for the areas with no high-volume driveways and a large number of low-volume driveways, raised medians are safer. The report also gave some comments about each median treatment. They found A TWLTL should be used when there were frequent rear-end conflicts caused by left-turning vehicles and on moderate to high volume highways that have few cross streets and many driveways.

However the book, A Policy on Geometric Design of Highways and Street, does not present a comparative analysis of medians and TWLTLs. It made a few specific comments about the use of a TWLTL, which said TWLTL works well where the speed on the arterial highway is relatively low (25 miles per hour to 45 miles per hour) and there is no large amount of the movements of left-turn traffic. And TWLTL should be used only in an urban area where there are no more than two through lanes in each direction.

2.3 Regression Model

Previous researches developed statistic models to predict the expect accident frequency for a roadway. These models have some typical independent variables, such as traffic volume, driveway density, number of arterial traffic lanes, signalized intersection density and unsignalized approach density. Finally, regression model equations were produced for the accident occurrence of different median types.

There are some studies comparing the alternative median treatments and presenting the procedures for estimating accidents for roads. Parker used data collected in Virginia to develop the equation, which is as follows:

Accidents/Mile/Year for Traversable Median (mostly TWLTL) = 5.432 Signal/Mile + 0.00173 ADT +2.157 Street/Mile + 0.0000058 Population –28.797

Squires and Parsonson got the equation with the data in Georgia. Their equation for accidents are as follows:

Accidents/Mile/Year for TWLTL = 0.0038777 ADT +22.68622 Signal/Mile – 8.85380 Approaches/Mile – 21.86862

In the existing accident prediction models, it is found that all models predict an increase in accident frequency with increasing daily traffic demand.

Bonneson and McCoy used the models to identify common trends related to median type. They used a large number of independent variables in each model. The combination of variables was established and used to calculate the accident frequency predicted by each model given a range of daily traffic demand.

CHAPTER 3

METHODOLOGY

3.1 Crash Frequency

Crash frequency was calculated in this study. Crash frequency is the actual number of reported crashes that has occurred at a certain location, which could either be a roadway section or an intersection. The number of crashes at each of the sections with TWLTLs considered in the study was obtained by using the Florida Traffic Crash Database. The primary virtues of using crash frequency are that it is simple and it makes intuitive sense. By ranking the number of reported crashes, safety analysis can identify crash-prone locations. The distribution curve of crash frequency could provide a basic concept of the TWLTLs and the results are easily understood by the general public.

The average number of crashes, which is the arithmetic mean of number of crashes, was calculated for each TWLTL section. In statistical inference, the mean is generally the most efficient estimator of the central tendency of the population characteristics being studied. The average number of crashes for section i is defined as:

$$N_i = \frac{n_i}{Y \times L}$$

Where,

N_i = average number of crashes for section i,

n_i = number of crashes at section i,

Y = the number of years when n_i crashes occurred,

L = the length of section i (mile).

3.2 Distribution Fitting

The average number of crashes was calculated for each section with the use of SPSS. Details of this procedure to obtain data will be explained in the next chapter. The estimated values are then plotted into histograms, where the independent variable (x-axis) is the average number of crashes for each section and the dependent variable (y-axis) is the number of sections. Poisson, Negative Binomial and Lognormal distribution are used to fit the frequency of crash data for higher and lower speed sections using the observed mean and variance. Subsequently, the Chi-square goodness-of-fit test was used to test the hypothesis whether the average number of crashes follows a particular probability distribution. The following presents a brief introduction to Poisson, Negative Binomial and Lognormal distribution.

The definition of Poisson distribution is: if the mean number of counts (λ) in the interval is greater than zero (λ =0), the random variable X that equals the number of counts in the interval has a Poisson distribution with parameter λ, and the probability mass function of X is

$$f(x) = \frac{e^{-\lambda}\lambda^x}{x!}. \qquad x=0,\ 1,\ 2,\ \cdots.$$

Where,

λ - observed mean value of the crash frequency

In regard to the negative binomial distribution, the probability function of X is:

$$f(x) = \begin{bmatrix} x-1 \\ r-1 \end{bmatrix} p^r (1-p)^{x-r}$$

Where,

r, p – two parameters calculated from observed mean and variance.

The mean and variance of this distribution of crash counts can be expressed in terms of parameter p and r as follows:

Mean= $E(x) = r/p$

Variance= $Var(Y) = r(1-p)/p^2$

The Log-normal distribution is the continuous probability distribution of a random variable whose logarithm follows the normal distribution. The random variable x has the range space of $R_x=\{x:0<x<\delta\}$ and y=lnx, is normally distributed with two parameters, mean μ_y and variance σ_y^2. The density function of x, say f(x), is defined as

$$f(x) = \frac{1}{x\sigma_r\sqrt{2\pi}} e^{-\frac{1}{2}\left[\frac{\ln x - \mu_r}{\sigma_r}\right]^2}$$

The mean E(x) and the variance V(x) of the log-normal distribution are

$E(x) = e^{\mu_r + \frac{1}{2}\sigma_r^2}$

$V(x) = e^{2\mu_r + \sigma_r^2}(e^{\sigma_r^2} - 1)$

3.3 Chi-Square Test

The Chi-square goodness-of fit test is used to test the hypothesis whether the average number of crashes follows a particular probability distribution. The test procedure requires a set of randomly chosen samples of size n from X, whose probability density function is unknown. These n observations are then plotted into a frequency histogram of k class interviews.

O_i represents the observed frequency in the i^{th} class interval. The expected frequency in the i^{th} class interval denoted E_i could be calculated from the hypothesized probability distribution. The test statistic is,

$$\chi^2 = SUM[(O_i - E_i)^2 / (E_i)]$$

Where,

O_i – observed frequency in the class interval i.

E_i – expected frequency in the class interval i.

It can be shown that, if the population follows the hypothesized distribution, χ_0^2 has, approximately a Chi-square distribution with k-p-1 degrees of freedom, where p represents the number of parameters of the hypothesized distribution estimated by sample statistics. This approximation improves as n increases. If the calculated value of the test statistic $\chi_0^2 > \chi_{a,k-p-1}^2$, the hypothesis that the distribution of the population is the hypothesized distribution would be rejected. a=0.05.

3.4 Crash Prediction Models

3.4.1 General

Developing crash prediction models is a means of summarizing the complicated interactive effect of these crash related factors on the basis of information contained in the data, as well as engineering judgment (e.g. the selection of independent variables), and analytical assumptions about the crash process (e.g. which probability law will be relatively appropriate to apply to the crash study). This approach relates safety to site characteristics. The models use crash frequency as the dependent variable together with various site characteristics for a large number of sites over an extended period of time. The modeling approach finds a relationship between crash frequency, traffic characteristics (such as volume and speed), and road geometry (such as segment length and lane width). A crash prediction model with good quality should estimate the occurrence of crash accurately at a specific statistical confidence level; meanwhile, the model shall make good engineering sense.

Many types of statistical regression models have been used to develop crash prediction models in the past 30 years. Two general types of regression models have been considered to apply to the crash data: (1) conventional linear regression model; and (2) generalized linear model, negative binomial regression models.

3.4.2 Poisson Model and Negative Binomial Model

Conventional regression models are proved to be inappropriate to model the traffic crash data, which are non-negative, random, discrete and sporadic in nature.

As alternatives, generalized linear models were explored and adopted in recent crash studies due to their advantages over conventional linear regression models. The regression models adopted in this study are based on observed crash frequency distributions. Based on crash frequency distributions and previous studies, Poisson regression and Negative Binomial regression were chosen to estimate the model parameters. Both in the two regressions, the regression parameters were estimated by maximum likelihood method.

Generally, Poisson regressions can be used to build the relationships between crash frequencies and a set of predictor variables under assumptions that crash frequencies are Poisson distributed. However, the inability of the Poisson model to handle over-dispersed data is a major concern with regard to studying crash frequencies. This inability is caused by the major limitation of the Poisson regression model, which requires the variance of the data to be equal to the mean. The variance of most crash count data will be significantly greater than the mean, so the crash data are likely to be over-dispersed. When the mean and the variance of the data are not approximately equal, the variances of the estimated Poisson model coefficients tend to be understand and the coefficients themselves are biased. The Negative Binomial regression model is an extension of Poisson regression model. This restraint can be overcome by Negative Binomial regressions, which assume crash frequencies are negative binomial distributed.

3.4.3 Prediction Modeling Procedure

The crash modeling consists of seven major tasks: (1) to obtain and process the crash data; (2) to determine the safety measures that were adopted as dependent variables in the modeling, and find appropriate probability functions to describe the random variation of crash frequencies; (3) to select and analyze the predictor variables; (4) to determine an appropriate functional form and parameterization, $f(.,\beta)$, to describe the effects of predictor variables on expected crash frequencies; (5) to estimate the regression parameter β in $f(.,\beta)$ using appropriate statistical algorithm based on crash data and probability assumptions; (6) to assess the quality of developed models, and make sure that the models make good engineering sense in addition to fulfilling statistical goodness-of-fit criteria; and (7) to apply the developed models, and convert the modeling results to tables for use. The tasks are briefly presented in the following paragraphs.

The modeling database was created from the Florida crash database maintained by FDOT, which consists of all crashes occurred on state roadways for a certain period of time. The TWLTL sections included in the modeling database contained safety related characteristics and crash counts occurred within the influence area of those TWLTLs. The process of generating the modeling database will be presented in detail later.

Another important issue was to determine which TWLTL section characteristics should be used as predictor variables in the model. The principle to select the predictor variables was to include the factors that have distribution to the roadway safety. Totally four characteristics including ADT on the roadway, access density on the roadway, posted speed on the roadway and number of lanes on the roadway. The predictor variables used in the model were easy to obtain by FDOT traffic engineers when applying the models.

Once each variable parameters of crash predictive model were estimated, the average number of crashes can be estimated by replacing the regression parameter, β_0, β_1, β_2, …, β_q, with the estimated values, and the variables X_{i1}, X_{i2}, …, X_{iq}, with the corresponding values of the section characteristics. If a predictor variable is insignificant and was excluded from the final model, the variable would be omitted in the linear equation. However, the estimated average number of crashes will only provide a statistic of the safety measure either for an infinite number of sections with the same characteristics or a section in an infinite time period with every characteristic unchanged.

3.4.4 Evaluation of Goodness-of-fit

So far there is no commonly acceptable measure that can give an absolute assessment of goodness-of-fit for generalized linear models. Therefore, several measures are selected and calculated, and jointly will give a relatively accurate evaluation of the models. First, deviance is defined as minus twice the logarithm of the ratio of the maximum likelihood under current model and the maximum likelihood under saturated model. Thus, deviance describes lack of fit, greater deviance indicates poorer fit. Secondly, the Pearson's chi-square is asymptotic to the chi-square distribution with n-p-1 degrees of freedom for large sample sizes and exact for normally distributed error structures. Therefore, for a model, similar to deviance, the greater the Pearson's chi-square, the poorer the fit.

In traditional least square regression, the coefficient of determination, R^2, is frequently used to assess the goodness-of-fit of a model. It represents the proportion of variation in the data that is explained by the model. However, it was shown that R^2 is not an appropriate measure to assess the goodness-of-fit of crash prediction models due to their non-normal and nonlinear nature. As a variation, a measure based on the standardized residuals, Pearson's R^2, can be calculated for each model to give some indication of the goodness-of-fit.

$$R_p^2 = 1 - \frac{\sum_{i=1}^{n} \frac{(y_i - \mu_i)^2}{\mu_i}}{\sum_{i=1}^{n} \frac{(y_i - \overline{y})^2}{\overline{y}}}$$

Where,

R_p^2 -- Pearson's R-square statistic;

y_i -- observed number of crash at i^{th} section during a time period;

μ_i -- estimated average number of crashes during a time period;

$\overline{y}$ -- average crash counts at all sections of interest.

In addition, as the counterpart of R2 in nonlinear regression, a measure of overall statistical fit, the likelihood ratio index can be computed as,

$$\rho^2 = 1 - \frac{L(\beta)}{L(0)}$$

Where,

$L(\beta)$ -- Log-likelihood at convergence;

$L(0)$ -- restricted log-likelihood (all parameters are set to zero except for the intercept).

The value of 0.200 is quite satisfactory considering the variance in the data, and values tend to be generally lower than typical R^2 values.

CHAPTER 4

DATA COLLECTION

The purpose of the chapter is to describe the process of the data collection effort in this research. This chapter address the time period, the FDOT crash database, system for identify the roadway sections, the procedures for gathering relevant crash data and creating a specific crash database for the research.

4.1 Analysis Time Period

In this study, crash data of three consecutive years, from 1996 through 1998, were used for the analysis process. It is commonly believed that three years will usually provide a sufficient number of crashes for analysis while reducing the possibility of extraneous factors influencing the crash data. Changes that have occurred at the site during the analysis period can result in changes to the crash characteristics. These include changes in the surrounding land use in addition to changes at the site itself. These changes have a higher probability of occurring, as the analysis period becomes longer. A time frame of three years is the most common choice as it is a good trade-off between the desire for larger samples and the desire that conditions have not changed much within the time frame.

4.2 Setting-up of the Crash Database

This section provides the general information about the creation of the crash database for the purpose of this project. The data set creation was conducted using the Florida Traffic Crash database, which was obtained from the State Data Program of the National Highway Traffic Safety Administration established under the U.S. Department of Transportation. (NHTSA, 1998).

4.2.1 Extracting the Original Database

The crash data of a 3-year period from 1996 to 1998 was used in this study. Corresponding to each year, there is one data file consisting of all crashes occurred on state roads during that year. For each crash, several record types containing specific information related to the crash are included. Table 4.1 lists the different record types for each crash. All files, stored in ASCII format, have the same database structure. A SAS (Statistical Analysis System) program was written and used in order to change the ASCII format to SAS format. SAS program uses Structured Query Language (SQL) to gather all of crash data needed for the files.

First of all, based on the possible contribution to crash occurrence, 168 variables were selected for the original database for the research. These variables were selected from five of the twelve record types, which included the factors that were considered having effect on the safety of TWLTLs. The record types selected were record “00” (Time and Location), record “01” (Characteristics), “09” (RCI-Features-I), record “10” (RCI-Features-II), and record “11” (RCI-Point). In order to put the 168 variables in one file, these files with record type “00”, “01”, “09”, “10” and “11” were merged into one merged file for each year. As explained above, only the data of three consecutive years, from 1996 to 1998, were used for the further analysis.

Table 4.1 Description of Record Type

Record Type	Description
00	Time and location
01	Characteristics
02	Vehicle
03	Towed
04	Driver
05	Passenger
06	Pedestrian
07	Property Damage Amount
08	Reserved for future use
09	RCI-Features-I
10	RCI-Features-II
11	RCI-Point
12	RCI-Total

4.2.2 Sorting the Data Set

A statistical package software program SPSS was used to handle the large data sets.. SPSS and SAS are the two most popular statistical programs in the social sciences, but SPSS is much easier to use. With SPSS software, the data files of three years were merged into one file. Each data record consists of a number of variables. In order to make the database smaller and easier to manipulate, it is necessary to select some variables that are useful for the study. Table 4.2 addresses the description of the selected variables. As the safety-related characteristics, the variables, Average Daily Traffic (ADT), posted speed (POSTSPED), and number of lanes (NUMBLANE), were would be medaled in further analysis.

Table 4.2 Description of the Selected Variables

Variable Name	Description
DISTID	District ID
COUNTYID	County ID
SECID	Section ID
SUBSECID	Subsection ID
MILEPOST	Milepost
ADT	Average Daily Traffic
POSTSPED	Posted Speed on the roadway
NUMBLANE	Number of lanes considering both sides of the roadway
ACCNUMB	Accident number
SITELOC	Site location

Additionally, some other variables, district ID (DISTID), county ID (COUNTYID), section ID (SECID), subsection ID (SUBSECID), milepost (MILEPOST), accident number (ACCNUMB), and site location (SITELOC) were also remained. The first five variables, district ID, county ID, section ID, subsection ID, milepost were used to identify the sections related to TWLTLs, which was described next.

In FDOT database, a certain accident number corresponds to one crash record. If there are more than one vehicle involved in the crash, some characteristics variables, such as vehicle movement, may have several different values. Thus in the crash database, there can be several crash records indicating just he same accident because of different values of some variables. Therefore, in order to avoid the analysis bias of the crash counts, duplicate crashes were taken out from the data set according to the accident number.

Based on the variable of site location, it could be judged if the crashes in the section were related to TWLTLs. Some accident locations are found very close to an intersection, it is possible that the accident is not influenced by the TWLTLs but by the nearest intersection, like the conflicts caused by impropriate signal circle . The code "02" and "03" of the site location indicate "at intersection" and "influenced by intersection". So with the criteria, the records with these two codes of site location were taken out of the data set. Then the database is prepared for the further analysis.

4.2.3 Converting the Crash-based Database to Section-based Database

After the database based on crashes was all set, the next step is to convert it to section-based database. In the section-based modeling database, a record should correspond to a section. The procedure to obtain the section-based database involved the selection of three types of variables for a three-year period for each TWLTL section. Three types of variables were included in the modeling database, (1) TWLTL section ID, (2) section characteristics variables, and (3) crash counts variables.

FDOT provided a list of 3535 sections with TWLTLs in the 7 districts of Florida State. Each section was identified by roadway ID, begin milepost and end milepost. The roadway ID is an eight-digit code consisting of county number, section number, and a subsection number. The first two digits correspond to the county number; the next three numbers are the actual section number of the roadway. And the last three numbers are known as the subsection number. The breakpoints of the TWLTL on a roadway are indicated by mileposts (begin/end milepost). The mileposts are used to describe the interacting points of TWLTL on the roadway. Each crash has its own milepost of location. Those crashes, of which the mileposts were within one of the ranges of begin milepost and end milepost on the list, were grouped in one section record. The sections studied in this research were summarized based on the element, District ID, County ID, section ID subsection ID, begin milepost and end milepost of the list sent by FDOT. The list is an EXEL file that includes all the TWLTL sections found in Florida State. Table 4.3 gives the variables included in the section list. If the TWLTL section obtained from the original crash database was not found in the list, these sections were taken out considering that the median treatment was changed in the time period.

Crash data for a section in three years could be zero, one of more crashes. This possibility of having different average number of crashes also means that it could be zero, one or more crash records related to this section in the section-based database. During data manipulation, the average number of crashes of each section was easily to determine by summing up the crash counts for one TWLTL section. But one problem encountered was that if there were more than one crash in the section, inconsistency of the data among the crash records could be possible. It was important to calculate or select a value for each variable. For the number of lanes, all records had the same value. So that value would be taken for the variable in this section. For posted speed the values are different, the value that appeared most frequently for a variable was chosen to present that variable in the section. For ADT, it could be as many values as the number of crash record. Average ADT was calculated by averaging the ADT values of all the crashes in the section.

If there was zero crash or no crash in the section, the average number of crashes was recorded as “0”. While the values of all the variables were missing. The values of number of lanes and posted speed were obtained from the TWLTL section list mentioned above, which include the variables of ADT, Posted speed and number of lanes. Table 4.3 shows the variables listed in the TWLTL section list. Meanwhile, with this information, these two variables obtained during the previous procedure could be double checked to make sure the variables of the database and the spreadsheet were compatible. If there were difference between them, the values from the TWLTL section list by FDOT were used, which were more reliable.

The missing ADT were obtained from a computer disk of Florida Traffic Information prepared by FDOT. The FTI system contains the main characteristics information including ADT. The program was easy to operate. After inputting the district number and the eight-digit road ID, the road was highlighted on a map of that area. Clicking any point of the road, the ADT of that section was shown on the screen. Thus ADT of the zero crash section were obtained by using of the system. Finally, the dataset of zero crash section was combined with the previous dataset. The final database consisted of reliable information which is required for analysis.

Table 4.3 Variables Included in TWLTL Section List from FDOT

Variables
District
Roadway ID
Begin Point
End Point
Net Length (miles)
Local Name
Median Type
Median Width
Speed Limit
Left & Right Number of Lanes
Left & Right Width of Lanes
Right Number of Lanes
Right Width of Lanes
Left Number of Lanes
Left Width of Lanes

4.3 Obtaining the Access Density

As present in Chapter 2, the access density is also a significant factor that should be considered in the analysis. But this variable was unavailable in the FDOT Crash Database. Obtaining the information of access was the most time-consuming part of this research. FDOT provided a hard drive containing review software and a large amount of images reflecting the roadways in Florida State. These images were recorded by video camera and saved as "*.jpg" format files. When the road ID, begin milepost and end milepost were input, the images would keep going when click the "play" button. While reviewing the video record according to the TWLTL section list obtained above, the number of driveways along the roadway with TWLTLs was counted and recorded. The same method was applied on the opposite direction of the movement of the images. After that, the two numbers were added up as the number of the driveways in this section. Then the access density was calculated as following:

Access Density = number of driveways (in both directions)/ length of section

During the procedure, it was found some sections don't have TWLTLs, probably due to the change of the conditions of the roadways after that time period. Thus these sections were taken out of the database. Finally, 1688 sections with access density were available. Combining the data set of access density with the database extracted from the original database, the specific section-based database for this research was completed with all the information required.

4.4 Database Summary

Once the steps choosing time frames for crash analysis, identifying sections related crashes, selecting variables for the database, and gathering the missing information were completed, the database was set up to perform the statistical analysis for the further analysis. Figure 4.1 shows part of the sample database that includes all the variables for developing the crash occurrence predictive model.

Table 4.4 Sample Crash Database for Analysis

Road ID	Begin Milepost	End Milepost	Section Length	Access Density	ADT	Posted speed	Number of lanes	Average Number of Crashes
101050000	6.448	6.980	.53	3.76	11200.00	55	2	1.00
101050000	7.727	9.096	1.37	6.57	10500.00	55	2	.00
101050000	9.096	9.515	.42	14.32	16004.00	50	2	1.00
101050000	12.799	13.347	.55	3.65	16004.00	45	2	1.00
101060000	9.244	10.311	1.07	54.36	20172.73	45	4	7.00
103001000	6.101	6.267	.17	6.02	21500.00	45	2	.00
103010000	21.798	22.067	.27	3.72	4600.00	60	2	.00
103010000	28.256	28.755	.50	2.00	4100.00	60	2	.00

Table 4.4 Sample Crash Database for Analysis (Cont')

103030001	16.470	16.704	.23	4.27	42000.00	45	4	.00
103080000	35.064	35.679	.62	3.25	7800.00	45	2	.00
103080000	37.856	38.888	1.03	34.88	13200.00	45	2	4.00
103080000	38.888	39.761	.87	29.78	8240.00	45	2	2.00
104020000	2.065	2.257	.19	10.42	4900.00	60	2	.00
104020000	13.693	13.775	.08	85.37	12700.00	35	2	8.00
104020000	13.775	14.315	.54	83.33	11500.00	35	2	1.00
104040000	15.018	15.469	.45	4.43	7500.00	45	2	.00
105020000	13.180	13.402	.22	9.01	4200.00	50	2	.00
105090000	.000	.364	.36	5.49	4800.00	50	2	.00
106010000	13.221	13.831	.61	47.54	12488.89	45	2	5.00
106010000	14.992	15.231	.24	87.87	16600.00	45	4	.00
106010000	15.231	15.556	.32	43.08	17500.00	55	4	2.00
106030000	11.973	12.338	.36	5.48	6100.00	60	2	.00
107010000	7.790	8.260	.47	10.64	9950.00	45	4	1.00
107010000	8.260	8.608	.35	8.62	11950.00	45	4	2.00
107010000	8.608	8.710	.10	78.43	11500.00	40	4	3.00
107010000	8.734	9.279	.55	89.91	11940.00	35	4	3.00
107010000	9.514	9.630	.12	34.48	11800.00	35	4	.00
107010000	9.630	10.000	.37	37.84	11800.00	45	4	.00
107010000	10.000	10.071	.07	28.17	9300.00	50	4	.00
107010000	10.071	10.181	.11	27.27	9300.00	50	2	.00
107010000	12.251	12.574	.32	6.19	9300.00	60	2	.00
107010000	14.270	14.522	.25	7.94	9300.00	60	2	.00
107010000	18.228	18.470	.24	8.26	6000.00	60	2	.00
107030000	2.280	2.345	.07	61.54	20000.00	50	4	5.00
107030000	2.345	3.518	1.17	84.40	17040.00	35	4	3.00
107060000	15.922	16.716	.79	61.71	6880.00	45	2	2.00
107060000	16.716	16.944	.23	78.95	6700.00	35	2	6.00
107060000	17.008	17.486	.48	69.04	10530.00	35	2	7.00
107060000	18.397	18.498	.10	19.80	14900.00	50	2	.00
109030001	.396	.722	.33	70.55	13600.00	35	2	3.00
109030001	.722	1.058	.34	29.76	13000.00	35	2	4.00
109040000	.877	1.049	.17	23.26	10300.00	30	2	.00
109040000	3.408	3.769	.36	5.54	5600.00	55	4	.00
109080000	.936	1.194	.26	7.75	10300.00	60	2	.00
109080000	2.877	2.996	.12	50.42	10300.00	45	2	.00
109080000	2.996	3.082	.09	69.77	10300.00	35	2	.00
109110000	2.846	2.968	.12	16.39	3600.00	55	2	.00
109110000	3.292	3.572	.28	7.14	3600.00	55	2	.00
109110000	6.476	6.807	.33	6.04	3600.00	55	2	.00
109110000	10.512	10.712	.20	25.00	3600.00	45	2	.00

CHAPTER 5

RESULTS FOR STATISTICAL MODELING

5.1 Crash Data Analysis

5.1.1 Crash Distribution for Average Number of Crashes

The dependent variable adopted in the modeling process was average number of crashes, which was defined as number of crashes per mile per year in each TWLTL section. Prior to the statistical modeling, the general shape of average number of crashes was assessed in order to provide the basis for crash distribution assumptions for modeling. The number of those TWLTL sections that have the same average number of crashes were plotted as data points on the frequency distribution curve. When all the points, number of sections, on one distribution curve were cumulated, the number would always equal to the total sample sections. Figure 5.1 shows the statistical results for average crashes.

In the figure, it is clearly that a large number of TWLTL sections had no or low crash experience. And the distribution seems to follow the Poisson distribution.

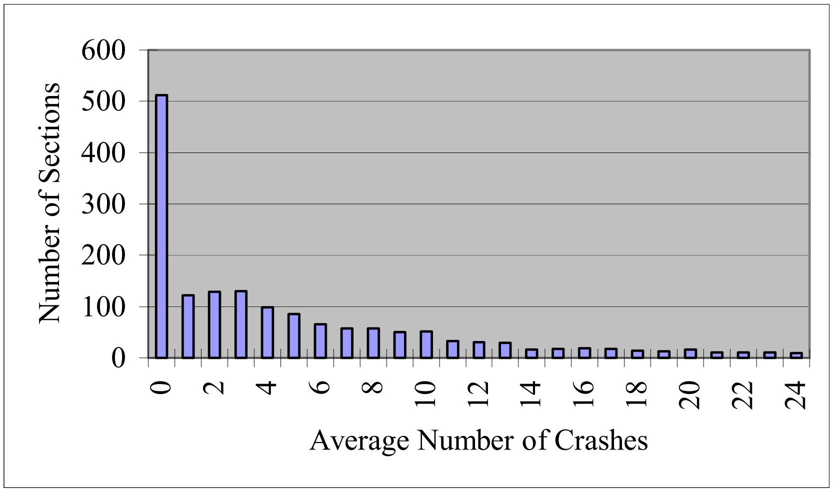

Figure 5.1 Average Number of Crashes

5.1.2 Distribution Fitting for Average Number of Crashes

Based on the frequency distribution and cumulative probability for average number of crashes, the mean and variance were calculated for the distribution fitting. Table 5.1 shows the procedure to get the mean and variance for number of crashes per mile per year. The mean or expected value of the discrete random variable X, denoted as E(x), and the variance of x, denoted as V(x), are calculated as

$$E(x) = \sum_{x} x \times f(x)$$

$$V(x) = \sum_{x} (x - E(x))^2 \times f(x)$$

Where,

$f(x)$ = the probability of each random variable x.

Table 5.1 Mean and Variance of Average Number of Crashes

x	Frequency	F(x)	Cumulative Percent	Xf(x)	(x-E(x))2
0	512	16.0	16.0	0.00	3.69
1	122	3.8	19.8	0.04	0.55
2	129	4.0	23.8	0.08	0.32
3	130	4.1	27.9	0.12	0.13
4	98	3.1	30.9	0.12	0.02
5	86	2.7	33.6	0.13	0.00

Table 5.1 Mean and Variance of Average Number of Crashes (Cont')

6	66	2.1	35.7	0.12	0.03
7	57	1.8	37.4	0.12	0.09
8	57	1.8	39.2	0.14	0.18
9	50	1.6	40.8	0.14	0.27
10	51	1.6	42.4	0.16	0.43
11	33	1.0	43.4	0.11	0.39
12	30	0.9	44.3	0.11	0.48
13	29	0.9	45.2	0.12	0.61
14	16	0.5	45.7	0.07	0.42
15	17	0.5	46.3	0.08	0.55
16	19	0.6	46.8	0.09	0.74
17	18	0.6	47.4	0.10	0.83
18	14	0.4	47.8	0.08	0.76
19	13	0.4	48.3	0.08	0.82
20	16	0.5	48.8	0.10	1.15
21	10	0.3	49.1	0.07	0.82
22	10	0.3	49.4	0.07	0.92
23	11	0.3	49.7	0.08	1.14
24	9	0.3	50.0	0.07	1.03
			E(x)=2.40		V(x)=16.39

Using the observed mean and variance, the Poisson, Negative Binomial, and Lognormal distribution models were reviewed and tested to determine which one best fit the crash distribution. Table 5.2 through 5.4 demonstrates that the Chi-square test for Poisson distribution, Negative Binomial distribution, and lognormal distribution fitted for average number of crashes in the TWLTL sections.

Table 5.2 Chi-square Test for Poisson Distribution Fitted

for Average Number of Crashes

x	f(i)	f(x)-poission	f(I)-f(x)	(f(I)-f(x))^2	(f(I)-f(x))^2/f(x)
0	31.9	0.09072	0.22868	0.05230	0.576468
1	7.6	0.21772	-0.14162	0.02006	0.092113
2	8.0	0.26127	-0.18079	0.03269	0.125107
3	8.1	0.20901	-0.12792	0.01636	0.078284
4	6.1	0.12541	-0.06427	0.00413	0.032941
5	5.4	0.06020	-0.00655	0.00004	0.000712

Table 5.2 Chi-square Test for Poisson Distribution Fitted

for Average Number of Crashes (Cont')

6	4.1	0.02408	0.01709	0.00029	0.012136
7	3.6	0.00826	0.02730	0.00075	0.090297
8	3.6	0.00248	0.03308	0.00109	0.441889
9	3.1	0.00066	0.03053	0.00093	1.411409
10	3.2	0.00016	0.03166	0.00100	6.322554
11	2.1	0.00003	0.02055	0.00042	12.21348
12	1.9	0.00001	0.01871	0.00035	50.60148
13	1.8	0.00000	0.01809	0.00033	256.2764
14	1.0	0.00000	0.00998	0.00010	455.105
15	1.1	0.00000	0.01061	0.00011	3211.188
16	1.2	0.00000	0.01185	0.00014	26741.53
17	1.1	0.00000	0.01123	0.00013	170005.1
18	0.9	0.00000	0.00873	0.00008	771319.7
19	0.8	0.00000	0.00811	0.00007	5265110
20	1.0	0.00000	0.00998	0.00010	66462926
21	0.6	0.00000	0.00624	0.00004	2.27E+08
22	0.6	0.00000	0.00624	0.00004	2.08E+09
23	0.7	0.00000	0.00686	0.00005	2.41E+10
24	0.6	0.00000	0.00561	0.00003	1.62E+11
					Chi^2=1.88E+11

Table 5.3 Chi-square Test for Negative Binomial Distribution Fitted

for Average Number of Crashes

x	f(i)	f(x)-NegBinom	f(i)-f(x)	(f(i)-f(x))^2	(f(i)-f(x))^2/f(x)
0	31.9	0.15	0.1730	0.029919	0.2043
1	7.6	0.12	-0.0489	0.002389	0.0191
2	8.0	0.11	-0.0262	0.000687	0.0064
3	8.1	0.09	-0.0100	9.93E-05	0.0011
4	6.1	0.08	-0.0166	0.000275	0.0035
5	5.4	0.07	-0.0127	0.000161	0.0024
6	4.1	0.06	-0.0155	0.000239	0.0042
7	3.6	0.05	-0.0128	0.000163	0.0034
8	3.6	0.04	-0.0057	3.25E-05	0.0008
9	3.1	0.04	-0.0040	1.62E-05	0.0005
10	3.2	0.03	0.0018	3.07E-06	0.0001
11	2.1	0.03	-0.0051	2.57E-05	0.0010
12	1.9	0.02	-0.0032	1.02E-05	0.0005

Table 5.3 Chi-square Test for Negative Binomial Distribution Fitted

for Average Number of Crashes (Cont')

13	1.8	0.02	-0.0006	3.65E-07	0.0000
14	1.0	0.02	-0.0060	3.57E-05	0.0022
15	1.1	0.01	-0.0030	9.1E-06	0.0007
16	1.2	0.01	0.0002	5.12E-08	0.0000
17	1.1	0.01	0.0013	1.7E-06	0.0002
18	0.9	0.01	0.0003	6.9E-08	0.0000
19	0.8	0.01	0.0009	7.73E-07	0.0001
20	1.0	0.01	0.0038	1.45E-05	0.0024
21	0.6	0.01	0.0010	9.41E-07	0.0002
22	0.6	0.00	0.0017	3.03E-06	0.0007
23	0.7	0.00	0.0030	9.14E-06	0.0024
24	0.6	0.00	0.0023	5.47E-06	0.0017
					Chi^2=0.2578

Table 5.4 Chi-square Test for Lognormal Distribution Fitted

for Average Number of Crashes

x	f(i)	f(x)-Log	f(i)-f(x)	(f(i)-f(x))^2	(f(i)-f(x))^2/f(x)
0	31.9	0	0.319401	0.102017	*
1	7.6	0.338126	-0.26202	0.068654	0.203042
2	8.0	0.156943	-0.07647	0.005847	0.037258
3	8.1	0.084905	-0.00381	1.45E-05	0.000171
4	6.1	0.05099	0.010145	0.000103	0.002019
5	5.4	0.032911	0.020739	0.00043	0.013068
6	4.1	0.02239	0.018782	0.000353	0.015756
7	3.6	0.015859	0.0197	0.000388	0.024471
8	3.6	0.011596	0.023962	0.000574	0.049515
9	3.1	0.008702	0.022489	0.000506	0.058121
10	3.2	0.006673	0.025143	0.000632	0.094739
11	2.1	0.005211	0.015376	0.000236	0.045373
12	1.9	0.004133	0.014582	0.000213	0.051447
13	1.8	0.003323	0.014768	0.000218	0.065627
14	1.0	0.002704	0.007277	5.3E-05	0.019584
15	1.1	0.002224	0.008381	7.02E-05	0.031591
16	1.2	0.001846	0.010007	0.0001	0.054246
17	1.1	0.001545	0.009684	9.38E-05	0.060675
18	0.9	0.001304	0.00743	5.52E-05	0.04234
19	0.8	0.001108	0.007002	4.9E-05	0.044267

Table 5.4 Chi-square Test for Lognormal Distribution Fitted

for Average Number of Crashes (Cont')

20	1.0	0.000947	0.009034	8.16E-05	0.08619
21	0.6	0.000814	0.005424	2.94E-05	0.036126
22	0.6	0.000704	0.005534	3.06E-05	0.0435
23	0.7	0.000612	0.00625	3.91E-05	0.063859
24	0.6	0.000534	0.00508	2.58E-05	0.048334
					Chi^2=1.191321

The Chi-square calculation value obtained from the distribution fitted for the crashes was calculated with:

$$\chi_0^2 = \sum_{i=1}^{k} (f(i) - f(x))^2 / f(x)$$

The value estimated of χ_0^2 is 1.88^{11}, which is much bigger than the Chi-square test value obtained from the Negative Binomial distribution fitting, 0.2578, and the value from the Log-normal distribution fitting, 1.1913. Between the Chi-square test value of Negative Binomial distribution and Log-normal distribution, the one obtained from Negative Binomial is bigger. And the Chi-square from the Negative Binomial distribution fitting χ_0^2=0.2578. This value is smaller than the Chi-square table value, which indicates that the hypothesis that the distribution of the average number of crashes is hypothesized Negative Binomial distribution will not be rejected. It could be concluded that the Negative Binomial distribution is better to fit the distribution of average number of crashes for TWLTL sections from the Chi-square test comparison. Figure 5.2 through 5.4 present the graphs of frequency distributions, which illustrate the respective distribution fitting of the average number of crashes. Therefore, the Negative Binomial distribution was selected as the fitted distribution to fit the average number of crashes.

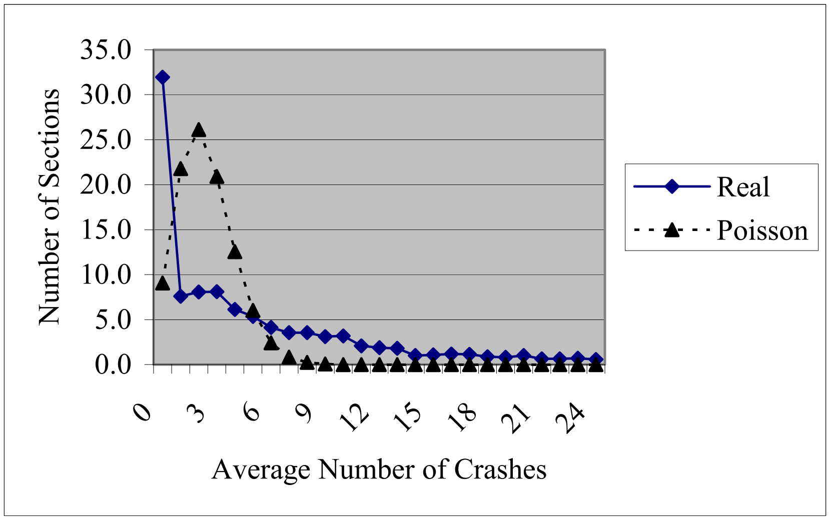

Figure 5.2 Poisson Distribution of Average Number of Crashes

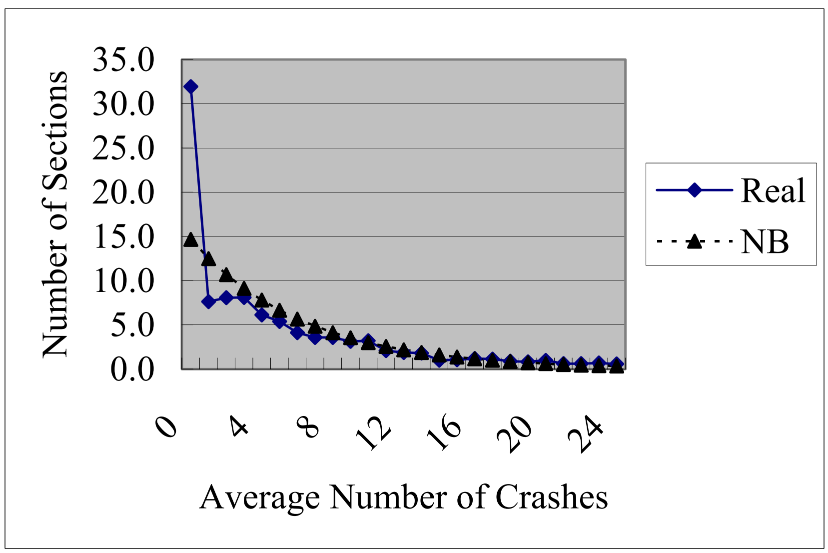

Figure 5.3 Negative Binomial Distribution of Average Number of Crashes

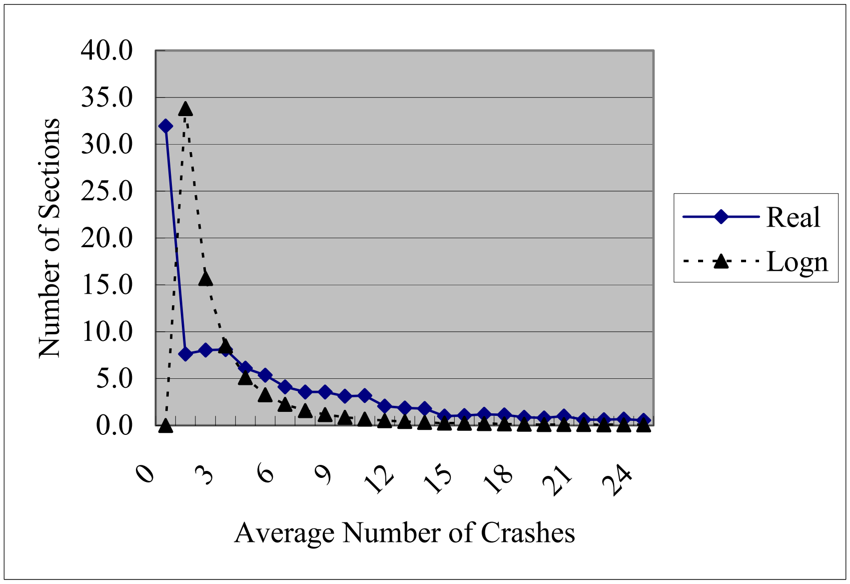

Figure 5.4 Lognormal Distribution of Average Number of Crashes

5.2 Crash Predictive Model

5.2.1 Predictor Variables

After the modeling database was built, all the variables were available for the development of the model. Table 5.5 through 5.8 show the summary descriptive statistics for these independent variables

Table 5.5 Descriptive Statistics for the Variable ADT

Statistics	ADT
Mean	20110
Standard Deviation	11534
Minim	1800
Maxim	78722

Table 5.6 Descriptive Statistics for the Variable Access Density

Statistics	Access Density
Mean	32.86
Standard Deviation	25.26
Minim	0.5
Maxim	149

Table 5.7 Descriptive Statistics for the Number of Lanes

Number of Lanes	Frequency	Percentage
2	722	42.8
4	833	49.3
6	133	7.9

Table 5.8 Descriptive Statistics for the Posted Speed

Posted Speed	Frequency	Percentage
25	18	1.1
30	124	7.3
35	410	24.3
40	296	17.5
45	583	34.5
50	77	4.6
55	141	8.4
60	39	2.4

It was found for the variables, ADT and access density, the maxim values were much higher than the median values. The higher values may be a result of particular reasons under abnormal traffic conditions. In the modeling process, these sections were taken out from the data set. And since all the ADT values are so big that the evaluated parameter for this variable may be much small than other parameter, the weight of ADT is determined as 1/10000 vph.

Based on the distribution, posted speed has two levels, less than 45 mph and equal to or greater than 45 mph. And the variable of posted speed was transformed from continuous to discrete value because the results of models will be tabulated for application so that traffic engineers could easily apply the level of posted speed (lower and higher) to the model. And the values used in the model were 0 and 1. Thus the data set was divided to two categories by the posted speed of 45 mph. Also, the number of lanes has three common values, 2, 4 and 6. The two posted speed categories could be divided into six groups with 2 lanes, 4 lanes, and 6 lanes considering both sides of the road. Thus the sample sections could be divided into six categories. The categories are described as below.

Table 5.9 Description of Categories for Analysis

Category	Description
1	Higher speed & Two-way 2-lane Sections
2	Higher speed & Two-way 4-lane Sections
3	Higher speed & Two-way 6-lane Sections
4	Lower speed & Two-way 2-lane Sections
5	Lower speed & Two-way 4-lane Sections
6	Lower speed & Two-way 6-lane Sections

5.2.2 Models for the Average Number of Crashes

The effect of TWLTLs on roadway accident frequency could be studied with statistics models. The following section presents summary of modeling process. Previous research has shown that conventional linear regression is not appropriate for estimating the relationships among the accident frequency and roadway characteristics. Poisson or negative binomial regression is a more proper analysis approach. The regression-based test for over dispersion can determine the selection between Negative Binomial regression model and Poisson regression model. The over dispersion parameter α is statistically significant (α=6.72), indicating the appropriateness of the Negative Binomial regression model rather than Poisson regression model to estimate model coefficients. The Negative Binomial regression model is an extension of Poisson regression model and can overcome the limitation of Poisson regression, which does not require the variance of dependent variable to be equal to its mean.

Therefore, Negative Binomial regression model was adopted to develop the predictive model of the crash occurrence of the TWLTLs. The parameters estimations were carried out with LIMDEP software package. The results of the negative binomial regression are presented in Table 5.9. The explanations of the contents of Table 5.10 are listed on Table 5.11.

Table 5.10 Estimated Parameters of the Negative Binomial Model

Variable	Coefficient Estimate	Standard Error	Relative Effect	Chi-Square	Pr>Chisq
Constant	0.0082	0.1045		0.0343	0.8532
Access Density	0.0193	0.0013	1.0082	39.7870	<0.0001
Average ADT	0.5253	0.0389	1.6910	182.3541	<0.0001
Posted Speed	-0.3039	0.0633	0.7379	23.0491	<0.0001
Number of Lanes	0.1124	0.0348	1.1190	10.4622	0.0012

Table 5.11 Explanations of Contents of the Results

Column	Explanation
Coefficient Estimate	Estimated parameters.
Standard Error	Estimated standard deviation associated with each parameter.
Relative Effect	Exponent of the estimated parameter of the variable.
Chi-square	Chi-square test statistic for testing that the parameter is 0. This was computed as the square of the ratio of the parameter estimate divided by its standard error.
Pr>Chi-Sq	The probability of obtaining a Chi-square statistic greater than that observed given that the true parameter is 0

From the table, it was found the significance of the variables was all under 0.05. That demonstrated the variables adopted in the model, ADT, access density, posted speed and number of lanes are significant at 5% confidence level. While the estimated constant is 0.0193, with p-value equal to 0.8593, which means that the effect of constant is extremely insignificant. The Negative Binomial regression was run again after the constant was removed from the regression equation. The results showed that removing constant from the model had very few effects on other variables.

Among the four variables, ADT, Access Density and number of lanes had a positive effect on the safety of TWLTLs. These findings suggested that the increase of their values increase the likelihood of accident. For example, Figure 5.5 shows the intuitional relationship between the dependent and independents for the category of higher speed and two-way 4-lane sections. For ADT, it's the common sense that the higher traffic volume the more accidents occurred. And the higher access density also leads to potential accidents. If there is a business area along the roadway with TWLTL, it results in a great number of left-turn movements by motorist, which could cause the probability of accident occurrence. For the same reason, the more lanes in one direction on the roadway, the more chance for the motorists to change lane in order to make left-turn, which is associated with rear-end accidents.

On the other hand, the sign of the parameters of posted speed was negative. It was also demonstrated that the relative effect for posted speed is 0.74, which means that sections with posted speed more than or equal to 45 mph would have 26% fewer average crashes than similar sections with posted speed less than 45 mph. Even though, this result may not be as expected. The common engineering knowledge is that high speed more likely results in severe crashes. However, drivers tend to travel at speeds in which they feel comfortable given the prevailing conditions. Therefore, this finding could be because lower posted speed more likely promotes speed differential that is generally more closely associated with crashes.

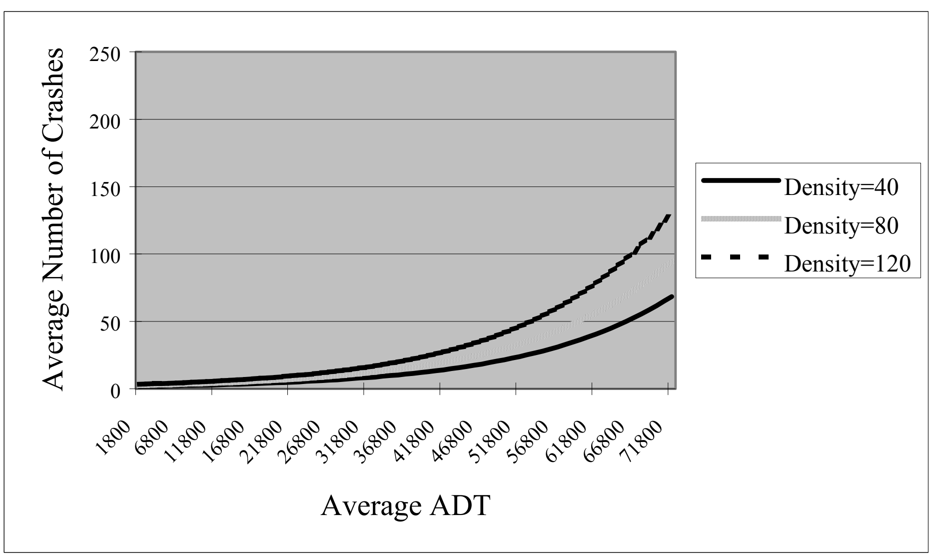

Figure 5.5 The Model Curve of Higher Speed and Two-way 4-lane Sections

5.2.3 Goodness-of fit of Model

The following step is to assess the goodness-of-fit of the model. Four statistics, including deviance, Pearson's Chi-square, and likelihood ratio index, were adopted. The deviance is defined as minus twice the logarithm of the ratio of the maximum likelihood under current model and the maximum likelihood under saturated model. Thus, deviance describes lack of fit, greater deviance indicates poorer fit. Secondly, in traditional least square regression, the coefficient of determination, R^2, is frequently used to assess the goodness-of-fit of a model. It represents the proportion of variation in the data that is explained by the model. However, it was shown that R^2 is not an appropriate measure to assess the goodness-of-fit of models due to their non-normal and nonlinear nature. As a variation, a measure based on the standardized residuals, Pearson's χ^2, can be calculated to give some indication of the goodness-of-fit. The Pearson's χ^2 is asymptotic to the χ^2 distribution with n-p-1 degrees of freedom for large sample sizes and exact for normally distributed error structures. Therefore, for a model similar to deviance, the greater the Pearson's χ^2, the poorer the fit. However, this statistic is not well defined in terms of minimum sample size when applied to non-normal distributions. Therefore, it should not be used as an absolute measure of model significance. In addition, as the counterpart of R^2 in nonlinear regression, a measure of overall statistical fit, the likelihood ratio index can be computed. Table 5.12 presents the four statistics for the Negative Binomial model of the average crashes.

Table 5.12 Criteria for Assessing the Goodness-of-Fit

Item	Value
Number of Observations	1688
Number of Variables in Model	4
Number of Parameters in Model	4
Degree of Freedom	1684
Log-likelihood Function	-4513.050
Restricted Log likelihood	-8273.891
Deviance	2323.92
Deviance/DOF	1.38
Pearson Chi-square	2237.23
Pearson Chi-square/DOF	1.33
Pearson R-square	31.81%
Likelihood Ratio Index	45.45%

Both the mean deviance and Pearson's Chi-square ratio are over one, and the Pearson's R-square and the likelihood are around 30% and 40%. The statistics indicate that the developed model has satisfactory capability in fitting the data and explaining the variation of the data.

CHAPTER 6

APPLICATION OF STATISTICS MODEL

ADT is known as the most significant factor contributing to crash occurrence on the TWLTL sections and most traffic engineers will first consider it in their roadway design. In this chapter, an approach to identify the "unsafe" TWLTL sections regarding the traffic volume was explored. The approach employed distribution fitting results and critical value, like the 85^{th} percentile value to obtain the critical value of average crash frequency. Then by using the predictive model developed above, the critical value of ADT could be evaluated for a TWLTL section with specific traffic characteristics, posted speed, access density and number of lanes. Thus, with the comparison of the actual ADT value and the critical ADT value, the critical TWLTL section could be determined.

6.1 Distribution Fitting

The method used for average number of crashes distribution fitting was also applied for each category. The categories were described in Table 5.9. If all the distribution were not rejected by the Chi-square test (χ_0^2), the distribution with smaller Chi-square calculation value was selected as the fitted distribution. If the Chi-square value of the three distributions were close, the Chi-square value with big difference from the critical Chi-square value, was selected. Table 6.1 exhibits the Chi-squar tests for fitting Poisson, Negative Binomial and Lognormal distributions for each category. Three of them were fitted to Negative Binomial Distribution, the rest of them was fitted to Lognormal distribution.

Table 6.1 Chi-square Test for Poisson, Negative Binomial and Lognormal Distribution Fitting

Category	Poisson		Negative Binomial		Lognormal		Distribution Selected
	Chi-square Calculation χ_0^2	Chi-square Table Value $\chi_{a,k-p-1}^2$	Chi-square Calculation χ_0^2	Chi-square Table Value $\chi_{a,k-p-1}^2$	Chi-square Calculation χ_0^2	Chi-square Table Value $\chi_{a,k-p-1}^2$	
1	21623860.35	26.2962	0.98	24.9958	0.26	24.9958	NB
2	10010.42	33.9244	0.88	32.6705	0.27	33.9244	NB
3	2421.98	41.3372	3.35	40.1133	0.58	40.1133	Lognormal
4	7385.36	26.2962	0.20	24.9958	0.36	24.9958	NB
5	593.15	36.4151	7.71	35.1752	0.23	35.1752	Lognormal
6	279.78	35.1752	1.89	33.9244	0.80	33.9244	Lognormal

6.2 The 85th Percentile Value of Crashes

Based on the distribution, the 85th percentile values of each crash distribution were obtained. The 85th percentile is the point where 85 percent of the crashes in a section will occur either at or below this measurement. This value is often used in engineering analysis because the data in the top 15 percent, considered the top portion of the population, is not targeted in design. The application of the two values is described in further section. Table 6.2 presents the 85th percentile values for average number of crashes for each category, respectively. And Table 6.3 presents the 85th percentile values after the linear regression for the previous values.

Table 6.2 85th Percentile Value for Average Crashes Distribution for Each Category

Number of lanes	Higher Speed	Lower Speed
2	8.85	6.84
4	14.00	10.91
6	19.20	14.98

Table 6.3 85th Percentile Value for Average Crashes Distribution for Each Category after Linear Regression

Number of lanes	Higher Speed	Lower Speed
2	8.11	6.72
4	15.5	11.16
6	18.46	14.86

6.3 Estimation of the Critical Value

After obtaining the 85th percentile value, the respective critical ADT values for each category were evaluated by using the predictive model. To calculate the ADT value, the other characteristics were given for the equation. Figure 6.1 and 6.2 show the example procedure of the evaluation of ADT. Table 6.4 presented the results of the evaluations according to some given conditions.

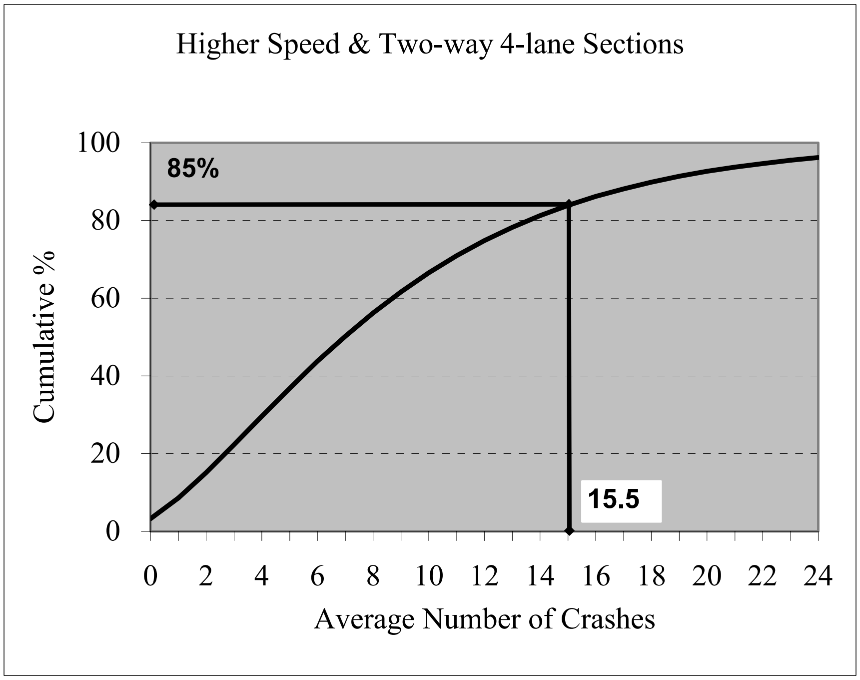

Figure 6.1 The 85% Percentile Value of the Average Crashes for Higher Speed and Two-way 4-lane Sections

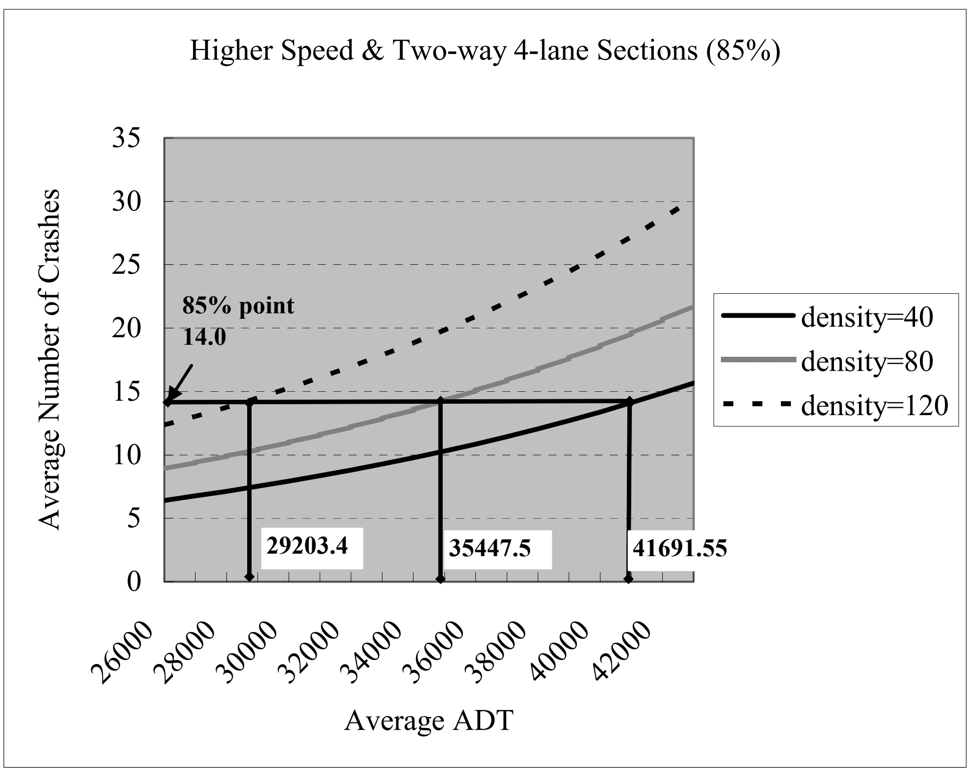

Figure 6.2 Evaluation of ADT According to 85th Percentile Value

Table 6.4 Results of Evaluation of ADT

Percentile			85%
High Speed	2-lane	40 accesses per mile	36505.2
		80 accesses per mile	30261.2
		120 accesses per mile	24017.0
	4-lane	40 accesses per mile	40956.7
		80 accesses per mile	34712.7
		120 accesses per mile	28468.6
	6-lane	40 accesses per mile	42690.0
		80 accesses per mile	36446.0
		120 accesses per mile	30202.0
Low Speed	2-lane	40 accesses per mile	25712.7
		80 accesses per mile	19469.6
		120 accesses per mile	13224.6
	4-lane	40 accesses per mile	30321.3
		80 accesses per mile	24077.3
		120 accesses per mile	17833.2
	6-lane	40 accesses per mile	32077.2
		80 accesses per mile	25833.2
		120 accesses per mile	19589.1

"*" means the ADT in this situation was not available from the figure.

The results presented a general range of traffic volume within which the TWLTL could be used on the roadway. The conditions for each category were similar, including the posted speed level, number of lanes and access density of the roadway. According to the statistics analysis of the access density, three levels were selected to give a basic concept of the traffic volume. The three levels were 40 accesses per mile, 80 accesses per mile and 120 accesses per mile.

6.4 Identification of the Critical Sections

To identify the critical TWLTL sections that present safety concerns, the next step is to compare the actual ADT to the critical ADT value listed in the table. If the actual ADT value of the section is higher than the estimated critical ADT value, the TWLTL section is identified as critical.

To apply this method, the first issue is to select a percentile value of average number of crashes. For example, if the 85th percentile value is selected, this means that 85% of the TWLTL sections of a group with similar characteristics have an average number of crashes equal to or lower than the 85th percentile value of average number of crashes obtained from crash distribution. Those TWLTL sections that were identified as critical were exhibited in tables. Table 6.5 shows the critical sections in District 7 in Florida State. It is a reference for traffic engineers to further study of improving the roadways which is using TWLTLs as the median treatment.

Table 6.5 TWLTL Sections Identified as Critical for District 7

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Higher Speed	2	*						
	4	710130000	4.5	4.796	44	41,036	45	15.77
		715120000	5.65	5.723	27	53,500	50	9.13
	6	710030000	1.554	1.697	112	43,125	45	9.32
		710030000	1.798	2.166	76	43,040	45	22.64
		710030000	2.36	3.014	73	42,771	45	17.84
		710130000	8.827	8.926	61	49,375	45	13.47
		710130000	9.596	9.789	78	64,984	45	55.27
		710160000	0.265	0.646	63	74,224	45	25.37
		710160000	0.899	1.24	62	78,722	45	17.6
		710160000	1.24	1.939	44	77,500	45	0
		715040000	4.693	4.843	13	50,833	45	6.67
		715040000	4.947	5.541	71	52,850	45	16.84
		715040000	5.841	5.911	43	52,167	45	14.29
Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Lower Speed	2	715020000	0	1.073	79	21,692	30	4.04
		715020000	3.67	4.952	83	25,167	40	1.56
		715020000	7.571	9.23	33	28,174	40	4.62
	4	715007000	3.544	3.798	83	28,100	40	6.56
		715040000	0.803	1.034	82	25,700	35	14.43
		715090000	1.254	2.227	99	24,709	35	3.77
		715090000	2.227	2.338	117	29,667	40	9.01
	6	702000000	14.203	14.545	99	26,450	40	9.75
		710030000	0.052	0.449	86	41,568	40	36.94
		710030000	0.545	0.9	79	41,688	40	30.05

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 Summary

This research was conducted to evaluate the safety impact of TWLTLs on the roadway crashes. This paper consists of three major parts (1) setting up a database for analysis, (2) establishing statistical model to explain the relationship between traffic characteristics and accident occurrence, and (3) developing the criteria to determine the improvement of TWLTL treatment.

First, the database was built by use of SPSS and SAS package. There were some issues for the data collection (1) selecting useful variables for data analysis, (2) taking out the crashes which are not related to TWLTL, (3) aggregating the crashes occurring in a certain TWLTL section in order to transfer the crash-based database into section-based database, (4) obtaining the missing data for the variables from the data source by FDOT, (5) discarding some section samples whose value of the variables indicated abnormal traffic situation. Finally, a three-year crash history database including totally 1688 TWLTL sections and four major variables all over Florida State was used in this research.

For the modeling part, distribution fitting analysis for the Poisson, negative binomial and lognormal distribution were first performed for the crash data. The results of comparing the Chi-square of each distribution helped to decide which distribution model the crash data set best fit. Based on this statistics result, crash prediction model was developed to estimate the average number of crashes by four variables, ADT, posted speed, access density and number of lanes. Negative binomial regression model was applied since the crash data showed over-dispersion. The regression parameters were estimated by using the maximum likelihood method with LIMDEP program. The goodness-of-fit for the developed models were evaluated with Pearson's R-square and likelihood ratio index.

After that, an approach for the appropriate use of TWLTLs was carried out by using the model developed above. First, based on the distribution of the four variables, the whole database was divided into six categories according to the posted speed level and number of lanes. For each category, the selected percentile values of the average number of crash were obtained from the distribution fitting curve. With the employment of these critical values and some specific characteristics into the predictive model, the traffic volume on the TWLTLs was calculated, called critical ADT value. Thus, a list of critical ADT value responding to different posted speed level, different number of lanes, different access density and average number of crashes according to selected percentile value. If the actual ADT value is higher than the critical value, the TWLTL section was regarded as a critical section which needs improvement for the median treatment.

7.2 Conclusions

The distribution fitting test for the average number of crashes showed it follows a negative binomial regression distribution. The predictive model indicates the relationship between the independents, ADT, posted speed, access density and number of lanes, and the dependents, average number of crashes. From the results, the predictor variables are all significant at 5% confidence level, which means they do affect the occurrence of accidents in TWLTL sections. With the growth of traffic volume, number of lane, and access density, the number of crashes grows up, which can be understood by common traffic engineer sense. The three variables could increase the movements of left-turn which cause the accidents frequently on the roadway. The model also indicated posted speed has a negative effect on the frequency of crash. This is because of the difference speed generated by the motorist to drive comfortably, which is the main cause of the accidents.

To apply the predictive model, the TWLTL sections were divided into six categories, high posted speed and two-way 2-lane sections, high posted speed and two-way 4-lane sections, high posted speed and two-way 6-lane sections, low posted speed and two-way 2-lane sections, low posted speed and two-way 4-lane sections, and low posted speed and two-way 6-lane sections. For each category, with the use of the predictor model, ADT value can be calculated corresponding to specific access density.

In order to control the crash frequency at a certain level, the value of the roadway characteristics should be controlled. Though the average daily traffic volume is random and discrete, there must be a range of ADT within which the roadway is appropriate to install TWLTs as the treatment, which means the crash frequency should under a distribution percentile level. The critical ADT values for different percentile value of average number of crashes are tabulated in Appendix C. Once the critical percentile is determined, according to the posted speed value, number of lanes and access density, the critical ADT value can be obtained from the table. Then the critical TWLTL sections can be identified based on the critical ADT value. The TWLTL sections identified as critical in seven districts of Florida State are tabulated in Appendix D, which presents the need of improving the existing TWLTL sections. While for a future roadway the median type of which is not determined yet, once the percentile considered critical for roadway safety is decided, the respective critical ADT value can be obtained from the table. If the actual traffic volume is higher than the critical ADT value, this section is regarded not appropriate to use TWLTL as the median treatment. This approach is easy for traffic engineering to get the basic concept of the safety effect of TWLTLs on roadway and consider in highway design.

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APPENDICES

Appendix A. Distribution Fitting for Six Categories

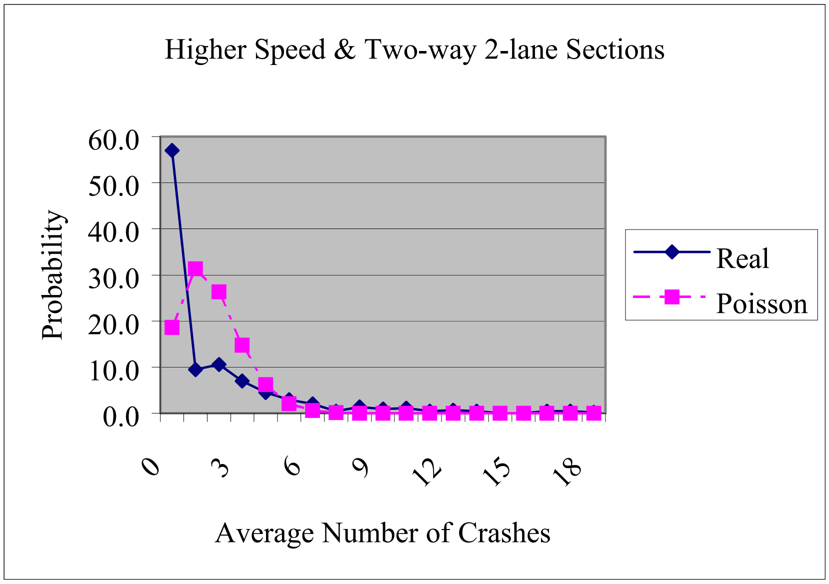


Figure A.1 Poisson Distribution Fitting
for Higher Speed and Two-way 2-lane Sections

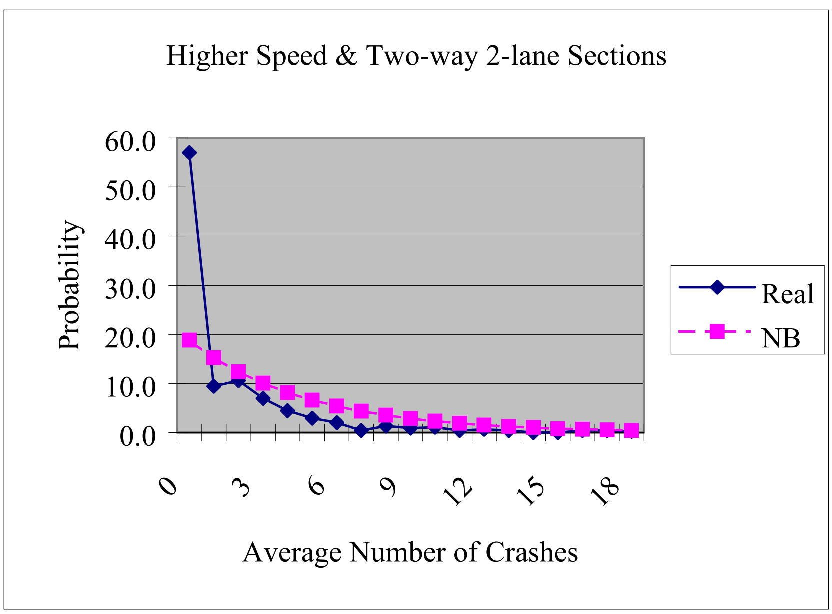
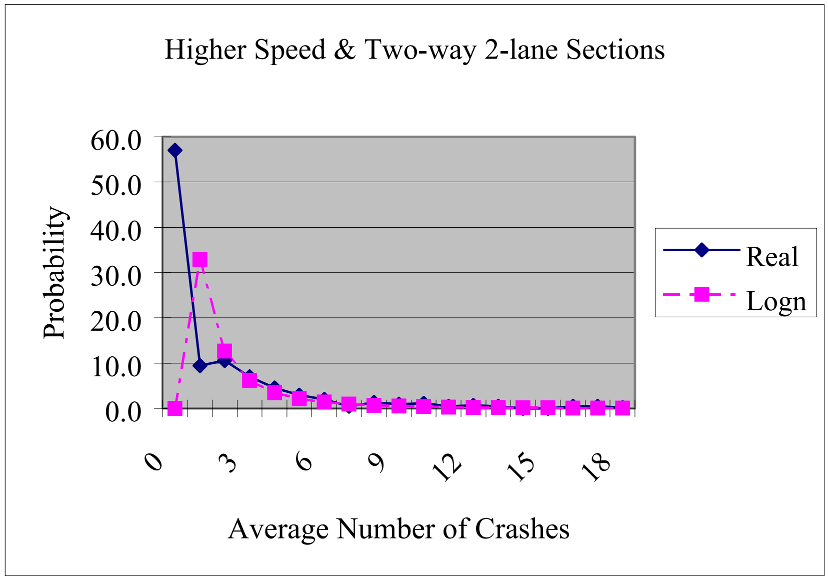


Figure A.2 Negative Binomial Distribution Fitting
for Higher Speed and Two-way 2-lane Sections

Appendix A (Continued)



FigureA.3 Lognormal Distribution Fitting
for Higher Speed and Two-way 2-lane Sections

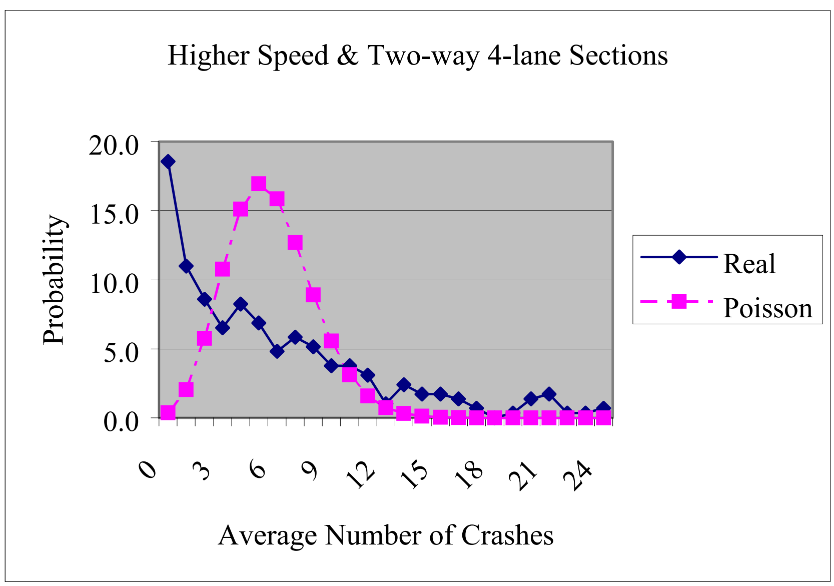


Figure A.4 Poisson Distribution Fitting
for Higher Speed and Two-way 4-lane Sections

Appendix A (Continued)

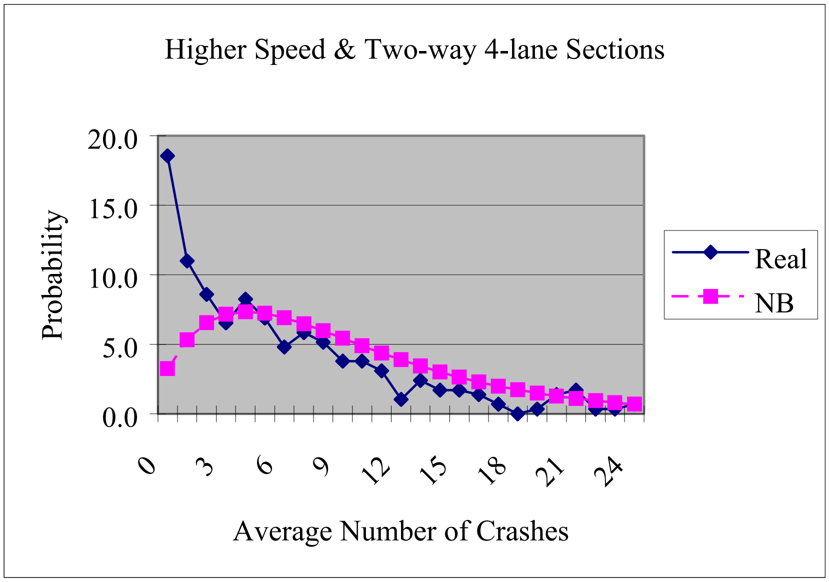


Figure A.5 Negative Binomial Distribution Fitting
for Higher Speed and Two-way 4-lane Sections

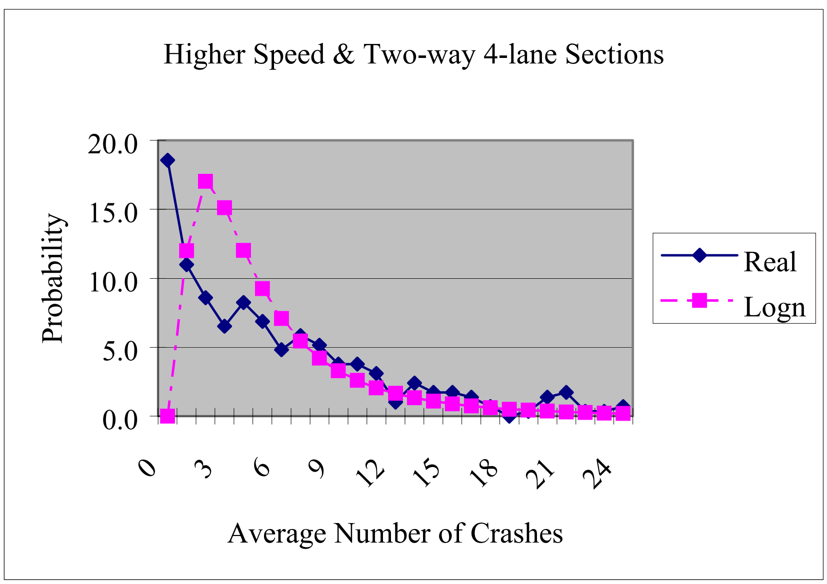


Figure A.6 Lognormal Distribution Fitting
for Higher Speed and Two-way 4-lane Sections

Appendix A (Continued)

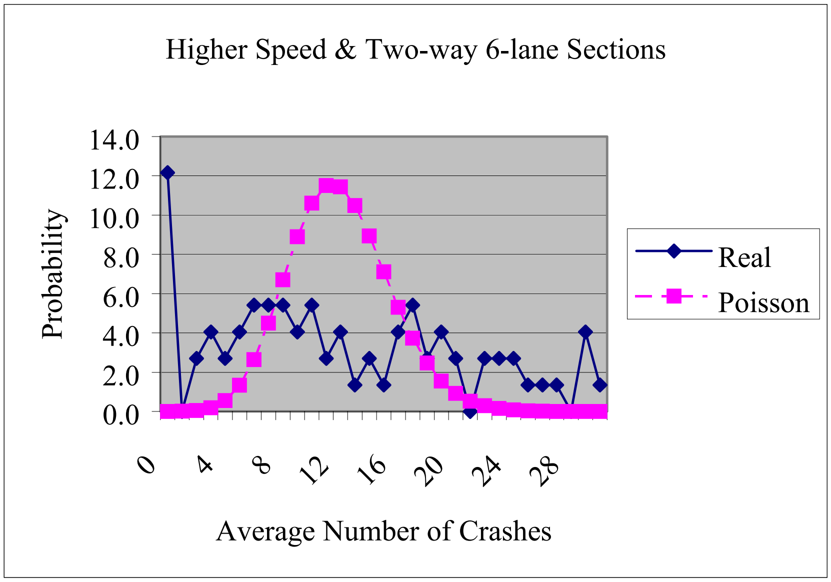


Figure A.7 Poisson Distribution Fitting
for Higher Speed and Two-way 6-lane Sections

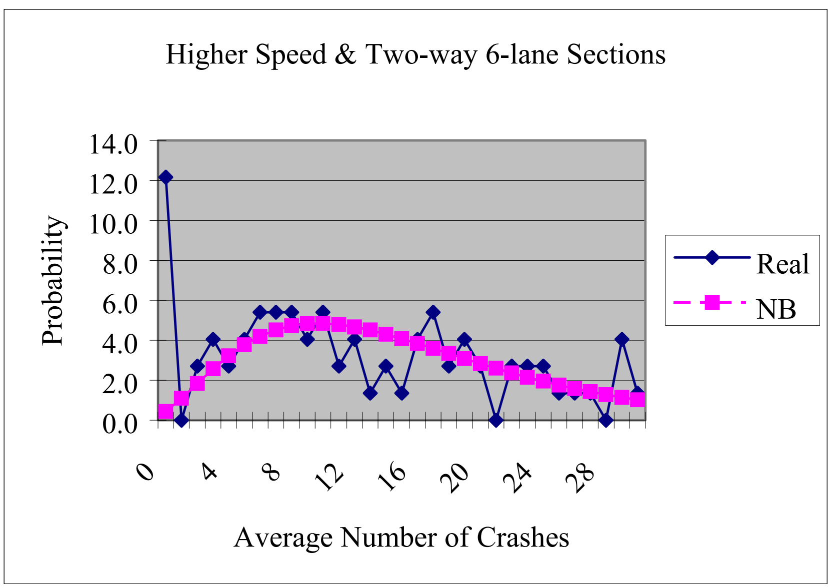


Figure A.8 Negative Binomial Distribution Fitting
for Higher Speed and Two-way 6-lane Sections

Appendix A (Continued)

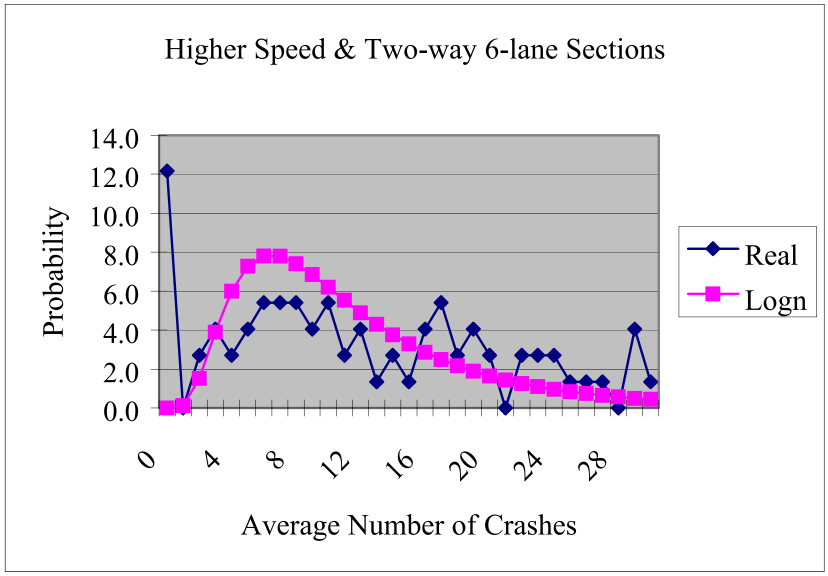


Figure A.9 Lognormal Distribution Fitting
for Higher Speed and Two-way 6-lane Sections

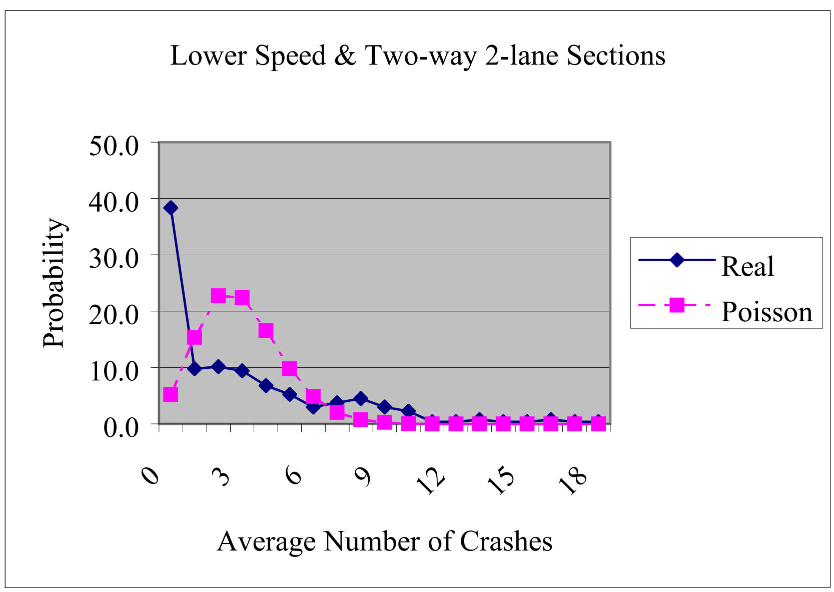


Figure A.10 Poisson Distribution Fitting
for Lower Speed and Two-way 2-lane Sections

Appendix A (Continued)

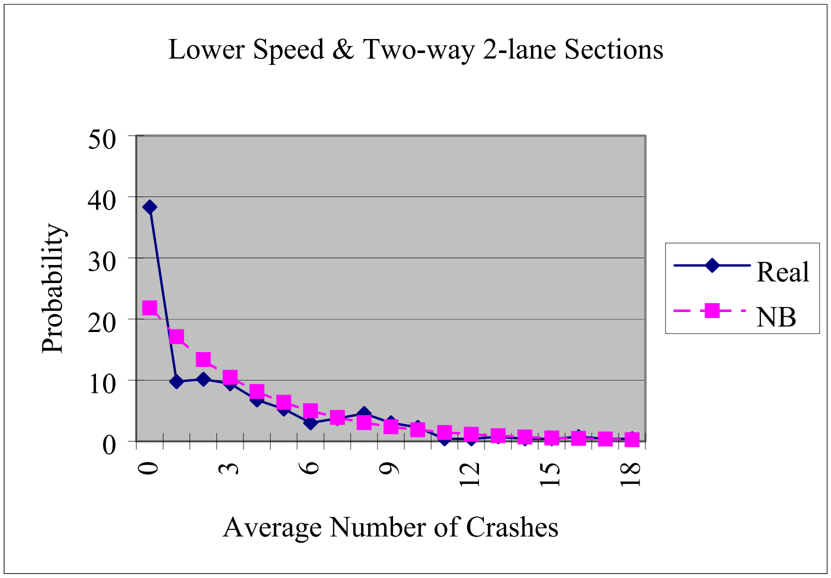


Figure A.11 Negative Binomial Distribution Fitting
for Lower Speed and Two-way 2-lane Sections

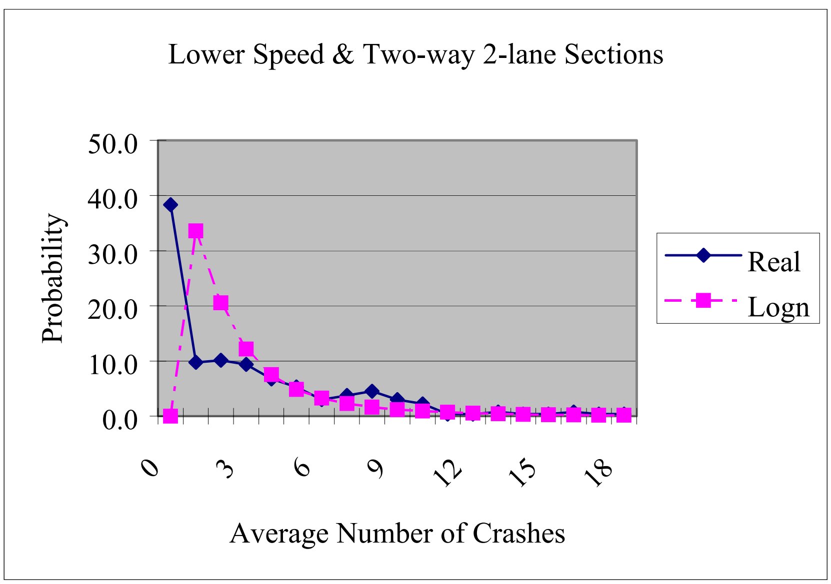


Figure A.12 Lognormal Distribution Fitting
for Lower Speed and Two-way 2-lane Sections

Appendix A (Continued)

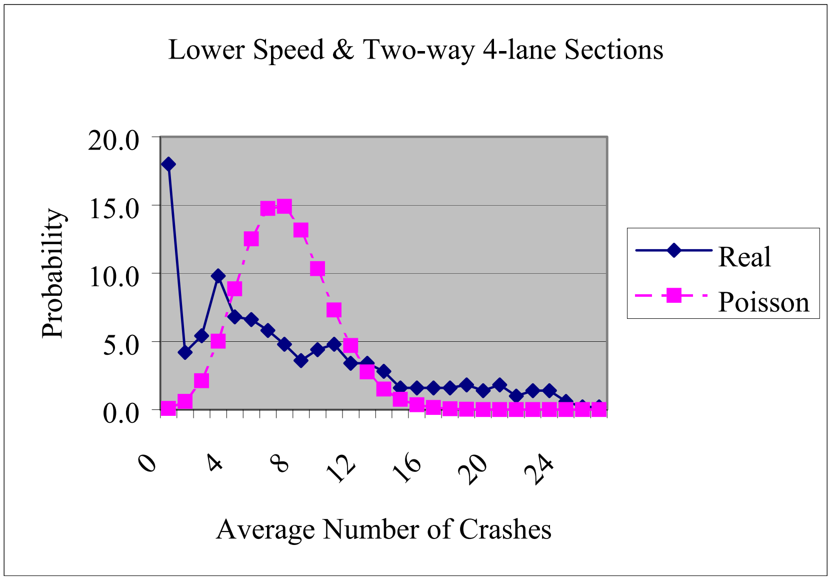


Figure A.13 Poisson Distribution Fitting
for Lower Speed and Two-way 4-lane Sections

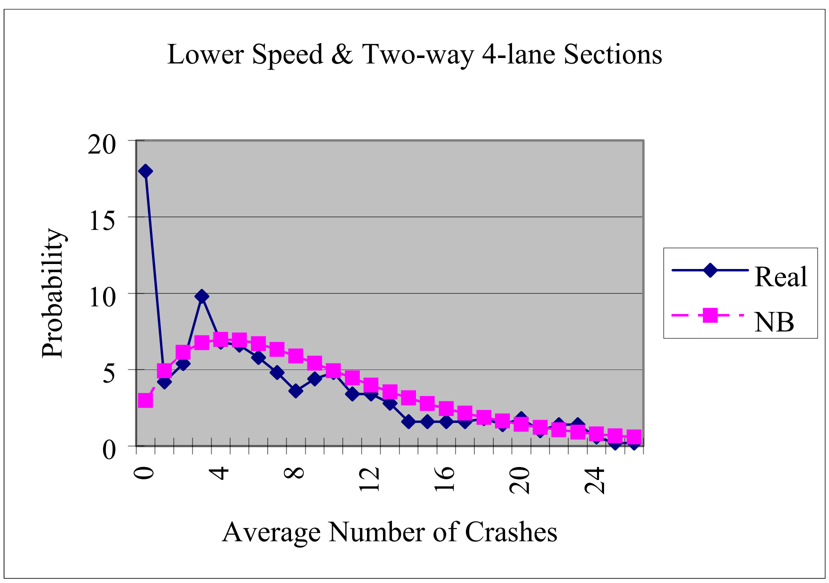


Figure A.14 Negative Binomial Distribution Fitting
for Lower Speed and Two-way 4-lane Sections

Appendix A (Continued)

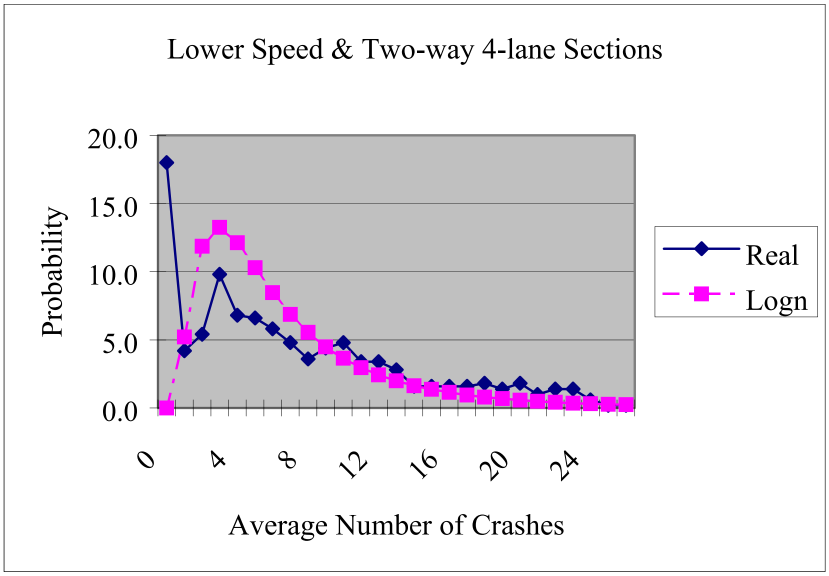


Figure A.15 Lognormal Distribution Fitting
for Lower Speed and Two-way 4-lane Sections

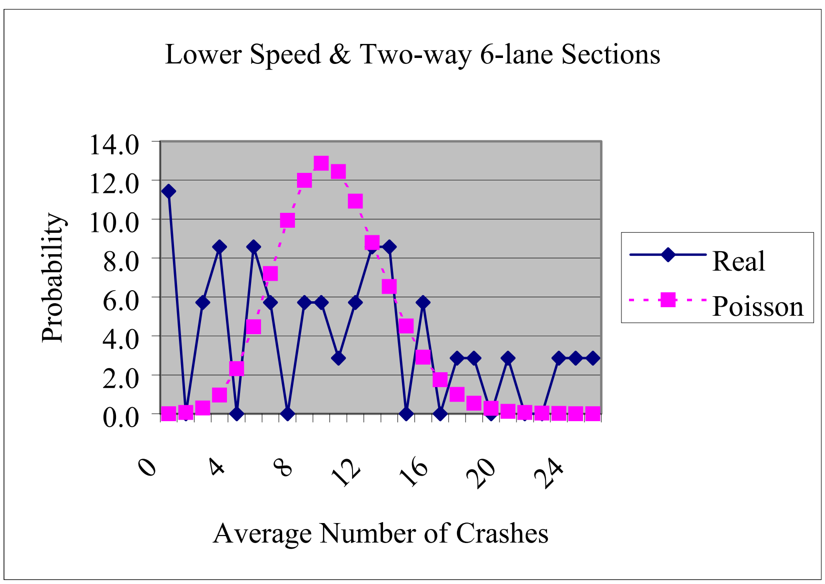


Figure A.16 Poisson Distribution Fitting
for Lower Speed and Two-way 6-lane Sections

Appendix A (Continued)

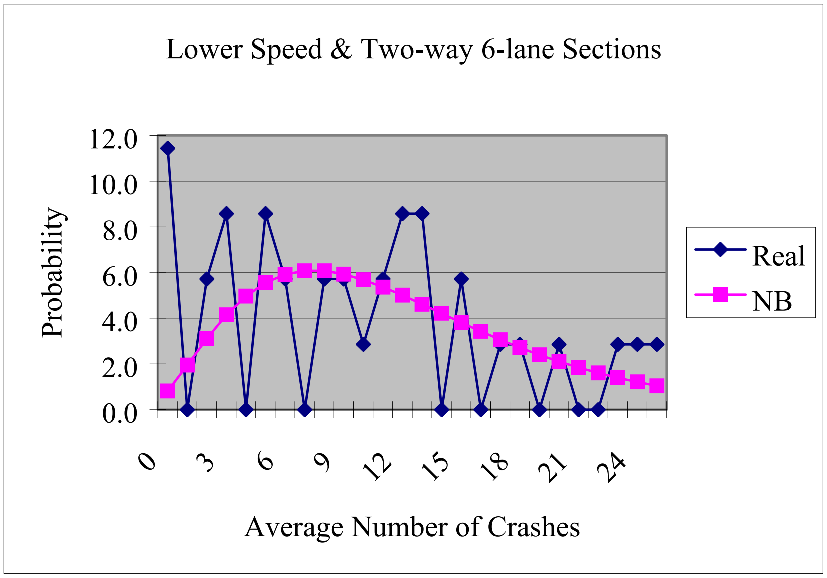


Figure A.17 Negative Binomial Distribution Fitting
for Lower Speed and Two-way 6-lane Sections

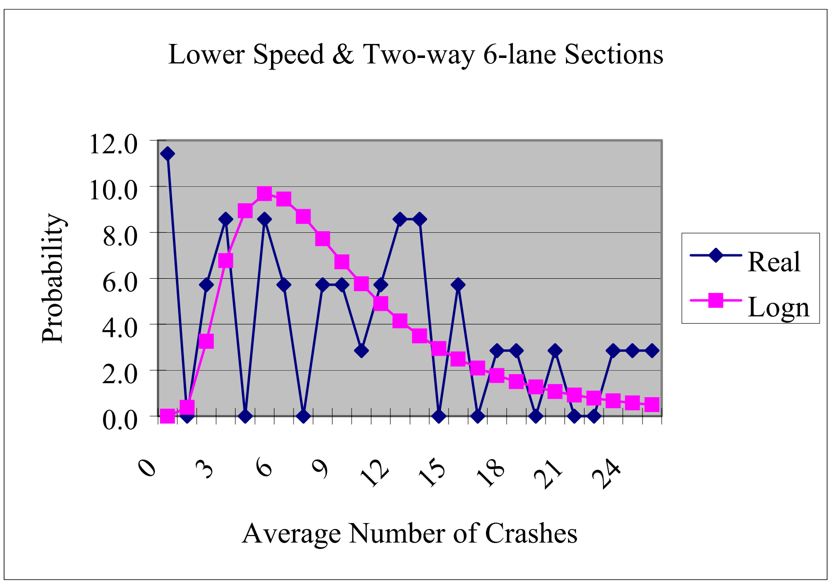


Figure A.18 Lognormal Distribution Fitting
for Lower Speed and Two-way 6-lane Sections

Appendix B. Critical ADT Value Corresponding to the 85th Percentile Value of Average Number of Crashes for Six Categories

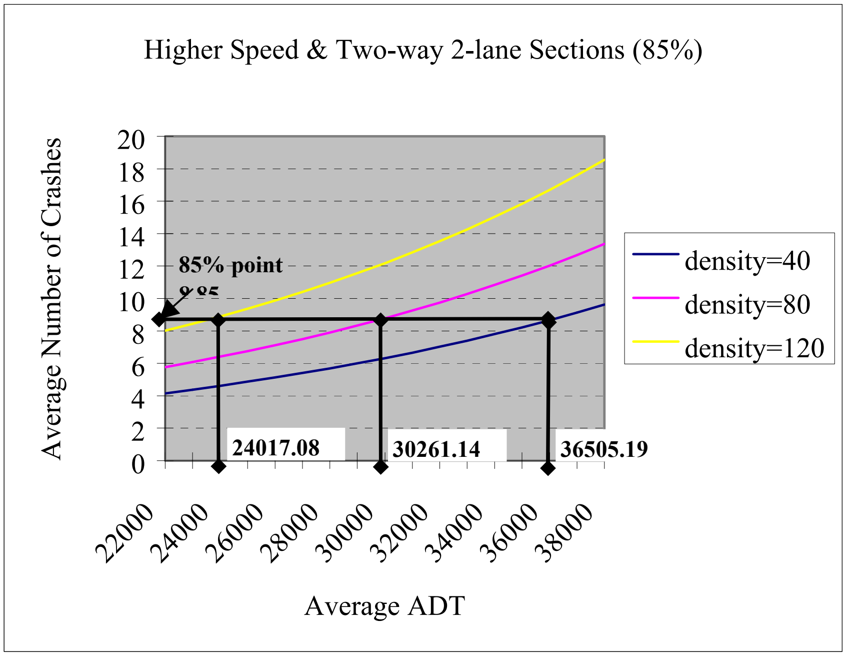


Figure B.1 Critical ADT Value for Higher Speed and Two-way 2-lane Sections

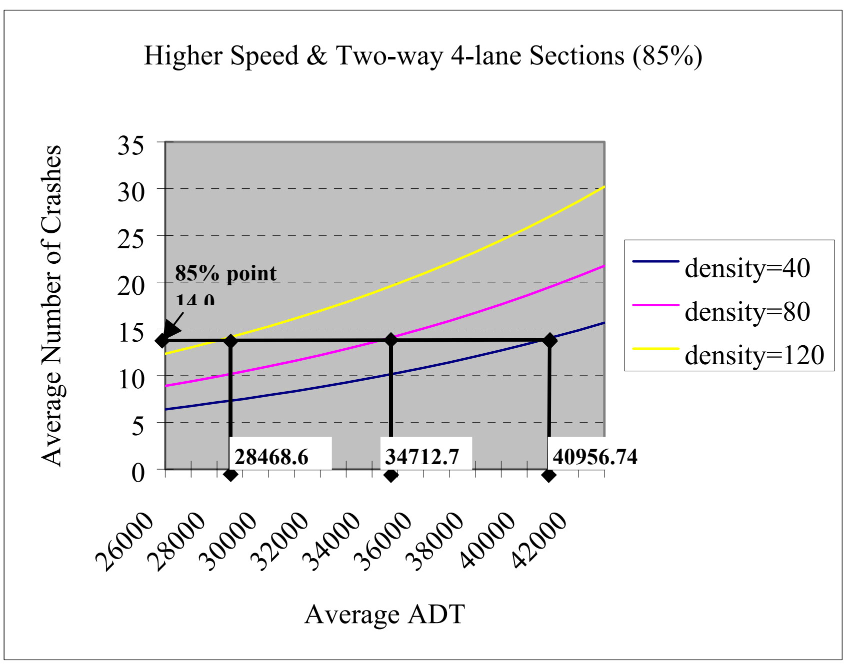


Figure B.2 Critical ADT Value for Higher Speed and Two-way 4-lane Sections

Appendix B (Continued)

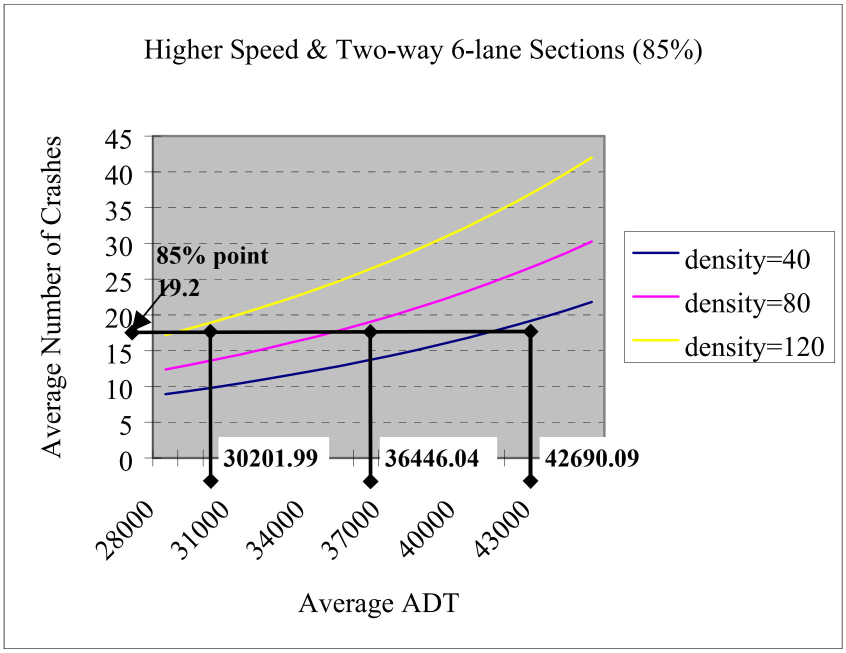


Figure B.3 Critical ADT Value for Higher Speed and Two-way 6-lane Sections

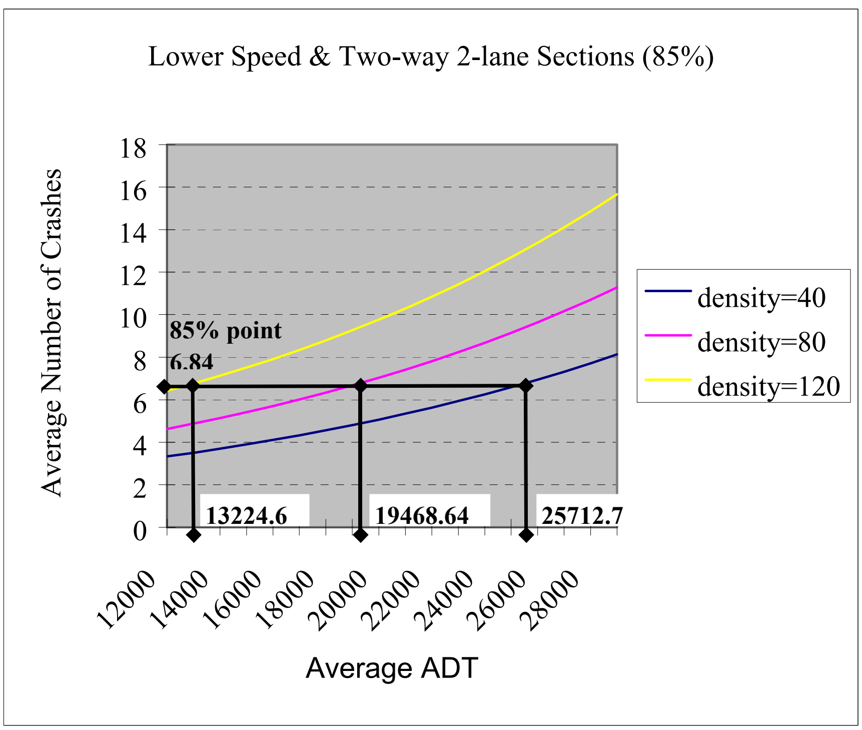


Figure B.4 Critical ADT Value for Lower Speed and Two-way 2-lane Sections

Appendix B (Continued)

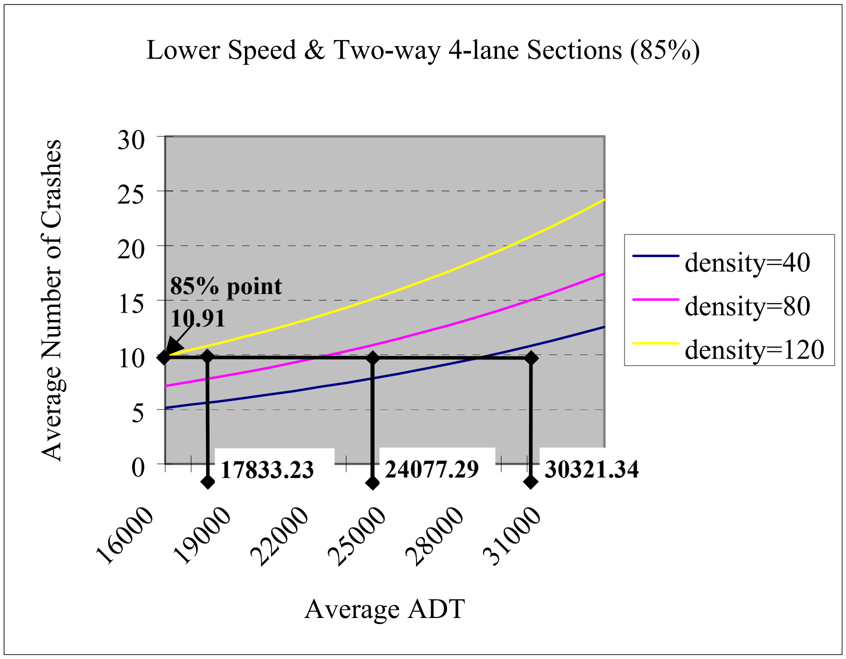


Figure B.5 Critical ADT Value for Lower Speed and Two-way 4-lane Sections

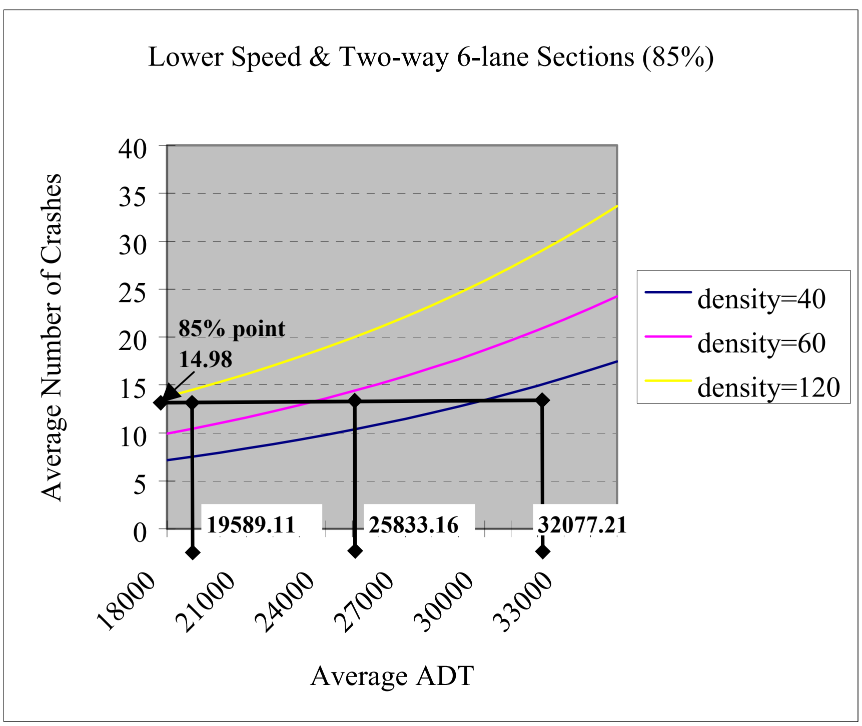


Figure B.6 Critical ADT Value for Lower Speed and Two-way 6-lane Sections

Appendix C. Critical ADT Value Corresponding to Selected Percentile Value for Six Categories

Table C.1 Critical ADT Value for Higher Speed and Two-way 2-lane Sections

	50%	75%	80%	85%	90%	95%
Access Density	2.14	6.33	7.44	8.85	10.95	14.01
10	14163.446	34808.685	37884.463	41188.225	45241.566	49932.826
20	12602.433	33247.672	36323.45	39627.212	43680.553	48371.813
30	11041.421	31686.66	34762.438	38066.199	42119.54	46810.801
40	9480.4079	30125.647	33201.425	36505.187	40558.528	45249.788
50	7919.3952	28564.634	31640.412	34944.174	38997.515	43688.775
60	6358.3824	27003.621	30079.399	33383.161	37436.502	42127.762
70	4797.3697	25442.609	28518.387	31822.148	35875.489	40566.75
80	3236.3569	23881.596	26957.374	30261.136	34314.477	39005.737
90	1675.3442	22320.583	25396.361	28700.123	32753.464	37444.724
100	114.33141	20759.57	23835.348	27139.11	31192.451	35883.711
110	-1446.6813	19198.558	22274.336	25578.097	29631.438	34322.699
120	-3007.6941	17637.545	20713.323	24017.085	28070.426	32761.686
130	-4568.7069	16076.532	19152.31	22456.072	26509.413	31200.673
140	-6129.7196	14515.519	17591.297	20895.059	24948.4	29639.66

Appendix C (Continued)

Table C.2 Critical ADT Value for Higher Speed and Two-way 4-lane Sections

	50%	75%	80%	85%	90%	95%
Access Density	6.18	10.75	12.18	14	16.29	21.15
10	30072.687	40611.189	42988.678	45639.774	48523.728	53494.002
20	28511.675	39050.176	41427.665	44078.761	46962.715	51932.989
30	26950.662	37489.163	39866.653	42517.749	45401.702	50371.976
40	25389.649	35928.151	38305.64	40956.736	43840.69	48810.963
50	23828.636	34367.138	36744.627	39395.723	42279.677	47249.951
60	22267.624	32806.125	35183.614	37834.71	40718.664	45688.938
70	20706.611	31245.112	33622.602	36273.697	39157.651	44127.925
80	19145.598	29684.1	32061.589	34712.685	37596.639	42566.912
90	17584.585	28123.087	30500.576	33151.672	36035.626	41005.9
100	16023.573	26562.074	28939.563	31590.659	34474.613	39444.887
110	14462.56	25001.061	27378.551	30029.646	32913.6	37883.874
120	12901.547	23440.049	25817.538	28468.634	31352.588	36322.861
130	11340.534	21879.036	24256.525	26907.621	29791.575	34761.849
140	9779.5216	20318.023	22695.512	25346.608	28230.562	33200.836

Appendix C (Continued)

Table C.3 Critical ADT Value for Higher Speed and Two-way 6-lane Sections

	50%	75%	80%	85%	90%	95%
Access Density	9.62	15.16	16.92	19.2	21.63	28.29
10	34217.481	42875.697	44966.616	47373.125	49641.752	54751.73
20	32656.468	41314.685	43405.604	45812.113	48080.739	53190.717
30	31095.455	39753.672	41844.591	44251.1	46519.727	51629.705
40	29534.443	38192.659	40283.578	42690.087	44958.714	50068.692
50	27973.43	36631.646	38722.565	41129.074	43397.701	48507.679
60	26412.417	35070.634	37161.553	39568.062	41836.688	46946.666
70	24851.404	33509.621	35600.54	38007.049	40275.676	45385.654
80	23290.391	31948.608	34039.527	36446.036	38714.663	43824.641
90	21729.379	30387.595	32478.514	34885.023	37153.65	42263.628
100	20168.366	28826.583	30917.502	33324.011	35592.637	40702.615
110	18607.353	27265.57	29356.489	31762.998	34031.625	39141.603
120	17046.34	25704.557	27795.476	30201.985	32470.612	37580.59
130	15485.328	24143.544	26234.463	28640.972	30909.599	36019.577
140	13924.315	22582.532	24673.45	27079.96	29348.586	34458.564

Appendix C (Continued)

Table C.4 Critical ADT Value for Lower Speed and Two-way 2-lane Sections

	50%	75%	80%	85%	90%	95%
Access Density	1.88	4.7	5.64	6.84	8.58	11.62
10	5809.476	23252.665	26723.474	30395.731	34710.335	40484.062
20	4248.4633	21691.653	25162.461	28834.718	33149.323	38923.049
30	2687.4505	20130.64	23601.448	27273.705	31588.31	37362.036
40	1126.4378	18569.627	22040.435	25712.692	30027.297	35801.023
50	-434.57497	17008.614	20479.423	24151.68	28466.284	34240.01
60	-1995.5877	15447.602	18918.41	22590.667	26905.272	32678.998
70	-3556.6005	13886.589	17357.397	21029.654	25344.259	31117.985
80	-5117.6132	12325.576	15796.384	19468.641	23783.246	29556.972
90	-6678.626	10764.563	14235.372	17907.629	22222.233	27995.959
100	-8239.6387	9203.5505	12674.359	16346.616	20661.221	26434.947
110	-9800.6515	7642.5378	11113.346	14785.603	19100.208	24873.934
120	-11361.664	6081.525	9552.3332	13224.59	17539.195	23312.921
130	-12922.677	4520.5123	7991.3205	11663.578	15978.182	21751.908
140	-14483.69	2959.4995	6430.3077	10102.565	14417.169	20190.896

Appendix C (Continued)

Table C.5 Critical ADT Value for Lower Speed and Two-way 4-lane Sections

	50%	75%	80%	85%	90%	95%
Access Density	4.65	8.21	9.38	10.91	13.16	17.22
10	18769.603	29591.718	32127.922	35004.375	38573.804	43692.585
20	17208.59	28030.705	30566.91	33443.362	37012.791	42131.572
30	15647.577	26469.692	29005.897	31882.349	35451.779	40570.56
40	14086.564	24908.679	27444.884	30321.336	33890.766	39009.547
50	12525.551	23347.667	25883.871	28760.324	32329.753	37448.534
60	10964.539	21786.654	24322.859	27199.311	30768.74	35887.521
70	9403.526	20225.641	22761.846	25638.298	29207.728	34326.509
80	7842.5132	18664.628	21200.833	24077.285	27646.715	32765.496
90	6281.5005	17103.616	19639.82	22516.273	26085.702	31204.483
100	4720.4877	15542.603	18078.808	20955.26	24524.689	29643.47
110	3159.475	13981.59	16517.795	19394.247	22963.676	28082.458
120	1598.4622	12420.577	14956.782	17833.234	21402.664	26521.445
130	37.44945	10859.565	13395.769	16272.222	19841.651	24960.432
140	-1523.5633	9298.5518	11834.757	14711.209	18280.638	23399.419

Appendix C (Continued)

Table C.6 Critical ADT Value for Lower Speed and Two-way 6-lane Sections

	50%	75%	80%	85%	90%	95%
Access Density	7.42	11.72	13.12	14.98	17.74	22.82
10	23386.238	32088.269	34236.394	36760.251	39979.478	44773.222
20	21825.225	30527.257	32675.381	35199.238	38418.465	43212.209
30	20264.212	28966.244	31114.369	33638.225	36857.452	41651.196
40	18703.199	27405.231	29553.356	32077.213	35296.44	40090.184
50	17142.187	25844.218	27992.343	30516.2	33735.427	38529.171
60	15581.174	24283.205	26431.33	28955.187	32174.414	36968.158
70	14020.161	22722.193	24870.318	27394.174	30613.401	35407.145
80	12459.148	21161.18	23309.305	25833.162	29052.389	33846.133
90	10898.135	19600.167	21748.292	24272.149	27491.376	32285.12
100	9337.1227	18039.154	20187.279	22711.136	25930.363	30724.107
110	7776.11	16478.142	18626.267	21150.123	24369.35	29163.094
120	6215.0972	14917.129	17065.254	19589.111	22808.338	27602.082
130	4654.0845	13356.116	15504.241	18028.098	21247.325	26041.069
140	3093.0717	11795.103	13943.228	16467.085	19686.312	24480.056

Appendix D Identified Critical TWLTL Sections in Florida

Table D.1 Critical TWLTL Sections for District 1 in Florida

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Higher Speed	2	*						
	4	*						
	6	113010000	0	0.133	38	44,500	50	0
		113010000	2.137	2.383	61	43,900	45	33.88
		113010000	3.005	4.215	67	43,364	45	33.33
		113010000	2.383	3.005	84	43,063	45	17.15
		113010000	4.215	5.085	71	42,376	45	35.63
		117020000	15.14	16.37	56	50,477	45	17.34
Lower Speed	2	112040000	5.658	5.898	58	24,167	40	4.17
	4	113010000	5.369	5.455	116	29,688	40	31.01
		113150000	6.586	8.171	76	37,977	40	9.25
		113150000	8.171	8.305	37	36,500	40	19.9
		116030000	27.773	27.886	53	32,500	40	0
		116250000	25.749	27.348	91	36,398	40	12.3
		116250000	27.348	27.499	112	26,500	30	8.83
		116250000	27.499	28.647	85	25,293	30	8.13
		116300000	0.598	0.672	81	28,000	40	13.51
		116300000	0.672	0.758	81	30,500	35	15.5
		117020000	18.689	19.003	57	34,625	40	12.74
		117120000	0.13	0.557	73	32,732	35	21.86
		117120000	0.557	1.148	64	36,652	35	12.97
		191070000	9.628	9.842	84	29,063	35	12.46
	6	112010000	21.045	23.375	84	43,259	40	16.6
		112010000	23.375	23.459	36	44,429	40	27.78
		117020000	16.37	16.983	68	51,592	40	41.33
		117020000	16.983	17.31	34	52,196	35	23.45
		117040000	0.65	0.988	74	35,000	40	1.97

Appendix D (Continued)

Table D.2 Critical TWLTL Sections for District 2 in Florida

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Higher Speed	2	*						
	4	272230000	0.978	1.21	34	47,000	45	10.06
		272230000	1.21	1.36	53	48,833	45	13.33
	6	272100000	6.472	7.575	59	58,210	45	43.82
		272230000	0.444	0.978	58	44,422	45	19.98
Lower Speed	2	226070000	18.538	18.711	46	27,600	35	9.63
		229010000	6.338	6.58	99	26,643	35	9.64
		272110000	0.241	0.576	69	34,000	40	17.91
		272110000	0.576	1.592	78	28,625	35	5.25
	4	226010000	13.623	14.623	64	36,175	30	26.67
		226010000	14.623	15.331	62	34,319	35	22.13
		226010000	15.348	15.808	72	37,451	35	29.71
		226070000	19.416	20.017	75	29,892	30	33.28
		228010000	7.545	8.068	69	27,357	30	17.85
		272014000	1.124	1.736	49	43,441	35	21.24
		272014000	2.31	4.148	68	39,176	40	28.29
		272014000	4.325	4.595	11	35,500	40	0
		272014000	4.716	5.06	32	33,000	40	0
		272014000	5.06	5.29	48	33,000	35	0
		272014000	5.29	5.431	64	33,000	35	0
		272014000	5.431	5.493	97	27,833	35	16.13
		272014000	5.563	5.955	38	33,000	35	0
		272015000	1.084	2.116	27	35,052	40	15.5
		272015000	2.116	2.3	33	38,077	40	23.55
		272015000	2.3	2.373	27	36,500	40	9.13
		272028000	1.42	1.912	4	36,500	35	0
		272100000	3.199	3.282	84	41,233	40	60.24
		272100000	3.282	5.565	56	40,118	40	18.54
		272150000	2.14	2.996	35	31,991	35	21.81
		272170000	4.838	5.845	55	35,735	35	22.51
		272190000	0.498	3.198	50	31,266	40	15.06
		272190000	13.7	14.771	74	28,255	35	9.65
		272291000	2.902	3.244	79	28,417	35	11.7

Appendix D (Continued)

Table D.2 Critical TWLTL Sections for District 2 in Florida (Contd.)

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Lower Speed	6	229010000	8.111	9.076	71	40,345	35	14.51
		272014000	1.736	1.946	105	50,960	40	39.68
		272014000	1.946	2.253	26	48,000	40	0
		272018000	5.998	6.804	61	35,412	35	35.15

Appendix D (Continued)

Table D.3 Critical TWLTL Sections for District 3 in Florida

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Higher Speed	2	*						
	4	346020000	0.748	1.149	2	53,328	45	30.76
	6	346010000	16.178	16.682	4	53,422	45	23.81
Lower Speed	2	355100000	1.415	1.6	146	17,300	40	0
		348004000	8.239	8.789	38	35,507	40	41.21
		348012000	3.57	3.808	21	36,429	35	9.8
		348012000	4.08	4.443	25	36,943	35	32.14
		348012000	4.583	4.682	10	40,833	35	80.81
		348070000	4.2	4.47	52	31,500	35	0
		348070000	4.47	6.029	42	40,500	35	0
		348070000	6.597	6.88	32	53,500	35	0
		355005000	0.748	1.25	44	31,400	40	6.64
		355040000	11.553	11.839	21	36,250	25	4.66
		355090000	1.6	2.78	45	33,601	40	33.62
		357030000	10.905	11.151	61	33,000	35	8.13
		357030000	12.241	12.475	17	43,689	35	29.91
		357040000	12.377	12.977	17	44,500	35	0
		348020000	10.489	10.98	55	35,759	40	18.33
		348020000	10.98	11.194	61	34,891	35	35.83
		355060000	7.68	8.543	25	42,319	30	43.65
	6	357040000	0.659	2.22	46	45,301	30	14.52
		357040000	2.22	3.421	54	45,467	40	12.49
		357040000	3.421	4.661	31	43,500	40	2.15
		357040000	12.977	13.933	37	38,800	35	3.49

Appendix D (Continued)

Table D.4 Critical TWLTL Sections for District 4 in Florida

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Higher Speed	2	*						
	4	486100000	8.397	8.5	10	56,125	45	51.78
		486100000	4.2	5.09	44	41,265	45	19.1
	6	486016000	5.012	5.214	59	44,000	45	8.25
Lower Speed	2	*						
	4	486010000	0.825	2.463	63	27,467	35	6.92
		486010000	2.719	5.948	65	32,560	35	11.15
		486100000	0	0.693	45	43,875	40	11.54
		486100000	0.965	2.569	40	41,996	40	28.89
		486100000	2.569	4.2	49	41,948	40	25.75
		486100000	8.5	10.028	2	46,674	40	20.07
		486210000	3.153	3.325	64	28,500	40	3.88
		488010000	4.794	5.614	67	28,364	35	8.94
		488010000	5.614	5.809	77	28,000	35	1.71
		489090000	13.849	14.576	25	41,292	35	5.5
		493040000	0	0.391	82	27,909	35	9.38
		493120000	20.33	20.401	56	29,500	35	0
		493200000	8.228	9.127	73	27,545	35	14.83
		494010000	10.25	11.777	51	39,936	40	10.26
		494010000	11.777	12.23	42	36,705	40	16.19
		494010000	12.23	12.731	68	35,267	40	9.98
		494010000	12.731	13.496	47	31,786	30	6.1
		494010000	13.496	13.957	61	28,750	35	10.12
		494120000	7.853	9.286	42	35,967	40	3.49
	6	486040000	14.173	15.384	49	36,155	35	7.98
		486100000	10.215	10.317	10	49,944	40	29.41
		486200000	3.51	3.635	8	53,582	40	5.33

Appendix D (Continued)

Table D.5 Critical TWLTL Sections for District 5 in Florida

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Higher Speed	2	*						
	4	575010000	2.032	2.3	7	51,500	55	0
		575050000	0.232	0.491	12	46,500	55	0
		575050000	5.44	5.8	53	39,600	45	4.63
		575060000	5.34	5.85	43	48,583	45	19.61
		575060000	5.85	6.786	41	48,409	45	23.5
		577120000	4.228	4.45	18	54,950	45	15.02
		577120000	4.45	4.825	16	53,450	45	8.89
		577120000	4.825	4.987	37	54,891	45	47.33
	6	511040000	4.83	5.285	37	44,688	45	11.72
		570100000	10.144	10.586	38	47,209	45	20.36
		575003000	4.995	7.078	56	56,037	45	30.4
		575003000	7.078	7.197	67	51,594	45	44.82
		575003000	7.638	7.825	48	45,091	50	39.22
		575010000	5.967	6.745	45	47,453	45	40.7
		575010000	7.252	7.578	43	44,273	45	11.25
		575010000	7.578	8.024	72	44,000	45	15.7
		575010000	8.271	8.564	78	44,353	45	19.34
		575010000	8.792	10.045	71	45,560	45	22.08
		575010000	10.045	11.065	62	50,398	45	28.76
		577010000	0.963	1.385	45	62,000	45	15.8
		592030000	0.29	0.51	64	43,000	45	9.09
		592030000	0.51	0.625	43	45,000	45	2.9
		592090000	12.759	12.867	28	60,838	45	46.3
		592090000	12.867	13.37	64	60,906	45	18.56
		592090000	13.37	13.774	52	59,952	45	18.98

Appendix D (Continued)

Table D.5 Critical TWLTL Sections for District 5 in Florida (Contd.)

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
	2	*						
Lower Speed	4	511040000	2.32	2.715	84	30,333	35	5.06
		511040000	4.015	4.095	62	28,500	35	16.67
		536010000	14.711	14.823	116	28,000	40	2.98
		536010000	14.823	15.226	94	29,222	40	7.44
		536080000	0.47	0.81	79	27,400	35	9.8
		570140000	1.057	1.457	62	29,750	40	20
		575006000	0.138	0.929	71	33,833	35	6.32
		575006000	0.929	1.034	114	31,333	35	19.05
		575010000	12.347	12.902	41	31,385	35	23.42
		575030000	4.881	5.977	63	34,581	35	11.25
		575040000	11.855	12.283	35	34,332	35	22.59
		575040000	12.283	12.525	58	30,000	35	2.75
		575050000	15.44	15.789	63	33,000	40	0
		575060000	0	1.88	43	49,227	40	26.95
		575060000	1.88	2.18	63	45,444	40	20
		575060000	2.18	2.653	59	46,776	40	20.44
		575060000	19.653	20.309	82	46,000	35	0
		575060000	20.309	20.804	56	48,000	35	0
		575260000	3	3.08	88	26,000	40	0
		579030000	3.228	4.277	66	30,290	40	9.85
		579030000	4.302	5.515	72	27,444	40	2.47
		579040000	7.52	8.2	66	30,219	40	7.84
		579040000	8.2	8.265	62	31,000	40	10.26
		592010000	11.726	12.229	111	25,967	40	9.94

Appendix D (Continued)

Table D.5 Critical TWLTL Sections for District 5 in Florida (Contd.)

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Lower Speed	6	511040000	4.622	4.83	106	45,000	35	12.82
		536001000	24.07	24.959	79	29,563	35	12
		536003000	0	0.673	67	36,050	35	4.95
		570010000	16.24	17.168	71	36,938	40	5.75
		570020000	0	0.413	68	41,643	40	5.65
		570020000	0.413	0.83	62	40,500	40	3.2
		570020000	2.721	3.865	69	47,250	40	11.07
		570020000	3.96	4.22	85	46,250	35	5.13
		570020000	4.22	4.511	103	37,938	40	9.16
		575250000	5.898	6.016	34	40,000	40	11.3
		592030000	0	0.29	76	42,875	40	9.2
		592090000	13.774	14.07	71	60,982	40	12.39
		592090000	14.07	14.95	74	49,337	40	29.55
		592090000	14.95	15.386	55	48,935	40	23.7

Appendix D (Continued)

Table D.6 Critical TWLTL Sections for District 6 in Florida

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Higher Speed	2	*						
	4	*						
	6	*						
Lower Speed	2	*						
	4	687001000	7.646	7.874	57	37,143	40	10.23
		687008000	7.896	10.117	66	27,787	40	11.26
		687030000	11.722	11.857	15	35,214	30	17.28
		687030000	12.89	13.835	33	36,225	30	17.99
		687030000	15.574	16.14	34	33,375	35	14.13
		687030000	16.14	16.5	47	39,688	35	7.41
		687030000	18.057	19.261	41	31,256	35	24.92
		687044000	7.978	8.466	59	37,720	35	17.08
		687053000	1.663	6.029	57	36,269	40	15.04
		687062000	4.57	5.064	51	35,522	40	15.52
		687072000	3.864	5.161	57	29,377	40	18.76
		687090000	10.412	10.512	20	42,125	40	40
		687090000	10.512	12.263	27	40,305	40	21.51
		687090000	12.263	13.493	17	39,628	40	20.05
		687120000	10.245	13.159	59	39,591	35	21.96
		687120000	13.387	14.385	43	33,525	35	27.05
		687140000	5.649	5.71	82	29,500	40	60.11
		687281000	0	2.617	21	35,924	40	4.2
		687281000	5.837	6.663	25	36,281	35	6.46
		687281000	6.663	8.185	45	35,966	40	9.64
	6	687030000	11.419	11.722	20	38,571	30	7.7
		687281000	5.645	5.822	23	40,000	35	13.18

Appendix D (Continued)

Table D.7 Critical TWLTL Sections for District 7 in Florida

Posted Speed Level	Number of Lanes	Road ID	Begin Milepost	End Milepost	Access Density	ADT	Posted Speed	Avg Crashes
Higher Speed	2	*						
	4	710130000	3.806	3.874	132	29,325	45	98.04
		710130000	4.5	4.796	44	41,036	45	15.77
		715120000	5.65	5.723	27	53,500	50	9.13
	6	710030000	1.554	1.697	112	43,125	45	9.32
		710030000	1.798	2.166	76	43,040	45	22.64
		710030000	2.36	3.014	73	42,771	45	17.84
		710130000	8.827	8.926	61	49,375	45	13.47
		710130000	9.596	9.789	78	64,984	45	55.27
		710160000	0.265	0.646	63	74,224	45	25.37
		710160000	0.899	1.24	62	78,722	45	17.6
		710160000	1.24	1.939	44	77,500	45	0
		715040000	4.693	4.843	13	50,833	45	6.67
		715040000	4.947	5.541	71	52,850	45	16.84
		715040000	5.841	5.911	43	52,167	45	14.29
Lower Speed	2	715020000	0	1.073	79	21,692	30	4.04
		715020000	3.67	4.952	83	25,167	40	1.56
		715020000	7.571	9.23	33	28,174	40	4.62
	4	715007000	3.544	3.798	83	28,100	40	6.56
		715040000	0.803	1.034	82	25,700	35	14.43
		715090000	1.254	2.227	99	24,709	35	3.77
		715090000	2.227	2.338	117	29,667	40	9.01
	6	702000000	14.203	14.545	99	26,450	40	9.75
		710030000	0.052	0.449	86	41,568	40	36.94
		710030000	0.545	0.9	79	41,688	40	30.05
		710030000	1.064	1.441	61	42,921	40	55.7