CRITERIA FOR SETTING SPEED LIMITS

IN URBAN AND SUBURBAN AREAS IN FLORIDA

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Criteria for Setting Speed Limits in Urban and Suburban Areas in Florida

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16. Abstract

Current methods of setting speed limits include maximum statutory limits by road class and geometric characteristics and speed zoning practice for the roads where the legislated limit does not reflect local differences. Speed limits in speed zones are set based on 85th percentile speed, which need to be adjusted based on such factors as crash experience, roadside development, and roadway geometry. However, reflecting these factors into the posted speed limit is likely to rely on practitioner's subjective decision-making. The purpose of this study was to develop mathematical models to set speed limits using more objective approaches. This study focused on nonlimited-access arterial roads in urban and suburban areas in Florida. These roads are characterized by a great variation in geometry, roadside development, and traffic movements, and therefore, the legislated speed limit may not be appropriate. For this project, traffic, geometric, and roadside information were collected at 104 sites with low crash occurrence, 85th percentile speed near the posted speed, and uniform traffic flow. Those variables were converted into adjustment factors that were applied to an ideal speed, chosen as the maximum statutory speed corresponding to the selected facility type. Accordingly, the ideal speed was reduced to a reasonable posted speed limit based on actual conditions at the selected site. The adjustment factors developed in this study are for such variable as access density, road class, lateral clearance, lane width, and signal spacing. It was found that the model developed in this study predicted speed limits more realistic than using 85th percentile speed solely. In addition, subjectiveness in adjusting the 85th percentile speed can be diminished by using the engineering based model. Results of this study may help the FDOT and its districts to quantify the speed limits and provide more objective justifications for setting speed limits.

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ABSTRACT

Current methods of setting speed limits include maximum statutory limits by road class and geometric characteristics and speed zoning practice for the roads where the legislated limit does not reflect local differences. Speed limits in speed zones are set based on 85th percentile speed, which need to be adjusted based on such factors as crash experience, roadside development, and roadway geometry. However, reflecting these factors into the posted speed limit is likely to rely on practitioner's subjective decision-making. The purpose of this study was to develop mathematical models to set speed limits using more objective approaches. This study focused on nonlimited-access arterial roads in urban and suburban areas in Florida. These roads are characterized by a great variation in geometry, roadside development, and traffic movements, and therefore, the legislated speed limit may not be appropriate. For this project, traffic, geometric, and roadside information were collected at 104 sites with low crash occurrence, 85th percentile speed near the posted speed, and uniform traffic flow. Those variables were converted into adjustment factors that were applied to an ideal speed, chosen as the maximum statutory speed corresponding to the selected facility type. Accordingly, the ideal speed was reduced to a reasonable posted speed limit based on actual conditions at the selected site. The adjustment factors developed in this study are for such variable as access density, road class, lateral clearance, lane width, and signal spacing. It was found that the model developed in this study predicted speed limits more realistic than using 85th percentile speed solely. In addition, subjectiveness in adjusting the 85th percentile speed can be diminished by using the engineering based model. Results of this study may help the FDOT and its districts to quantify the speed limits and provide more objective justifications for setting speed limits.

Key words: Speed Limits, Posted Speed, 85th Percentile Speed, Speed Zoning, Crash Rate, Speed Variance, and Adjustment Factors

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CHAPTER 1: INTRODUCTION

1.1. Background

Setting speed limits has a long history in the United States, where the main concern in the early days was to ensure pedestrian safety. Over time, traffic has tremendously increased, vehicle and highway technologies have improved, and related fatalities have also increased dramatically. Often, speed limit practice is understood simply as a tool to control vehicle speeds and forced to lower to mitigate the risks advocated by crash statistics. According to National Highway Traffic Safety Administration (NHTSA), one third of all fatal crashes in the year 2000 were related to speeding, that is, exceeding the posted speed limit or traveling too fast for the existing conditions [1]. The main purpose of speed limit is to inform drivers of the maximum speed in which a normally prudent driver can travel safely on the roadway [2]. A properly set speed limit prompts a reasonable balance between mobility (travel time) and safety (fewer crashes and conflicts) for a certain road class or a specific highway section. The numeric value of speed limits is the major tool in deciding an appropriate enforcement level.

With a collaboration of various agencies including Federal Highway Administration (FHWA), NHTSA, and the Center for Disease Control and Prevention in conjunction with Transportation Research Board (TRB), the criteria used by states to set speed limits in all types of roadways were examined and guidelines to set appropriate speed limits were recommended [2]. According to the report, current approaches for setting speed limits in the U.S. consists of two main methods: maximum statutory speed limit and speed zoning.

Also known as the blanket speed, the legislated speed limits cover a wide area (e.g., central business district (CBD), urban or rural area) set by road class (e.g., interstate highway, arterial, or local road). In determining a legislated speed limit such factors as design speed, vehicle operating speed, crash history, and enforcement experience are taken to consideration [2]. The authorized bodies of setting the statutory limits are Federal and state agencies, and also by ordinances of local governments. The 55 MPH of National Maximum Speed Limit (NMSL) is an example of the statutory limit of the Federal level, which was initiated to reduce gas consumption during the ‘oil- shock’ in the 1970s. The NMSL had continued until 1995 because it was found that the lowered speed limit contributed to reduce crashes in highways. The NMSL was repealed in 1995, returning the authority to set speed limits to individual states.

However, since road conditions widely vary within an area, state and local governments have the authority to alter speed limits in their jurisdiction for a roadway section where the legislated limit is not appropriate. Such a section is called a ‘speed zone’ and speed limits are set based on engineering investigations. The 85th percentile speed under free-flow condition is the most decisive factor used in setting speed limits and other factors, such as crash experience, roadside development and roadway geometry, parking and pedestrian level are also taken into consideration [2].

In 1985, Parker surveyed state and local transportation officials and the four most influential factors for speed zoning procedure were identified in descending order as: 85th percentile speed, accidents and pace speed (tied for second), and type and amount of roadside development [3]. The report also stated that these four factors are measurable in quantitative units and they are utilized by a number of states as part of a procedure to adjust the speed limit.

In 1993, Institute of Transportation Engineers (ITE) Technical Committee on Speed Zoning Guidelines recommended that speed zoning be established on the basis of an engineering study and be set at the nearest 5 MPH increment to the 85th percentile speed or the upper limit of the 10 MPH pace [4]. The ITE Committee also recommended that the engineering study may consider other factors such as geometric factors, roadside development, road and shoulder surface characteristics, pedestrian and bicyclist activities, speed limits on adjoining segments, and accident experience or potential.

Influences of speed limits to highway safety were often argued among interest groups. The relationships between posted speed, operating speed, and crash experience have been examined nationwide. Effects of altering speed limits on operating speed or highway safety have also been widely studied. After the repeal of NMSL of 55 MPH in 1995, most state and local governments raised speed limits on the interstate system, which led the researchers to examine the effects of altering speed limits mainly on such facilities. In 1996, the Iowa Speed Limit Task Force found a significant increase in all types of crashes after speed limits increased [5].

In 1992, Parker examined the effect of raising and lowering posted speed limits on driver behavior and accidents for non-limited access rural and urban highways, concluding that altering speed limits had little effect on drivers' speed selection [6]. The study also found that unreasonably low speed limits significantly increased driver violation of speed limits. It was evident that there were changes in speeds and the number of crashes corresponding with altering speed limits in the interstate highways; however, there was little effect on nonlimited-access highways [2]. This implies that in nonlimited-access roads, drivers were not sensitive to the speed limit signs, but to the other conditions such as speeds of other vehicles, geometric characteristics, roadside clearance, and roadside developments.

In general, the approach currently used widely to set speed limits is that maximum speed limits are first legislated broadly by road class and geographic area, and in cases where the statutory limits do not fit specific roadway or traffic conditions, speed zoning practice is applied for that highway section based on engineering study.

1.2. Research Statement

It is common traffic engineering knowledge that most drivers (about 85 %) travel at a reasonably safe speed under various roadway conditions encountered. Studies have shown that a speed limit set near 85th percentile speed is the most favorable in terms of safety, driving comfort, and driver's compliance to enforcement. A number of studies have examined the impacts of altering speed limits on safety and the relationship between operating speed and posted speed on major highways. It has been shown that the magnitude of the effects is dependant on the road class.

While most of those studies focused on high-speed roadways, such as interstate highways, rural highways, and urban freeways, a few studies have been conducted on lower class roadways, such as nonlimited-access arterials and local roads in urban areas. Arguments on setting the appropriate speed limits for such roadways have continued and consensus between various interest groups is hardly reached. This results in difficulty in having a broadly granted methodology to evaluate the adequacy of current speed limit posted and to establish appropriate speed limits.

Meanwhile, the decisions based on the 85th percentile speed along with other notable factors (e.g., crash experience or public concern) are often made subjectively and somewhat arbitrarily by state and local governments. As mentioned earlier, in speed zoning practice, the 85th percentile speed is considered as the most decisive factor in speed limit and the limit needs to be periodically adjusted on the basis of such factors as crash experience, roadside development, roadway geometry, and parking and pedestrian levels [2]. However, considering those factors to adjust speed limits are mostly based on the practitioner's experiences. For some roadways in urban and suburban areas, the speed limits determined by this method may not be appropriate for safe and efficient movement of vehicles. Also, there is a need to justify the speed limits that were set on empirical basis, in order to mitigate safety concerns from local developments or residents.

Therefore, the main purpose of this study was to assess the approaches that determine speed limits of roadways in urban and suburban areas and to develop methodologies or models that can establish criteria for setting speed limits based on more objective factors and approaches. This study intended to resolve some of the concerns that FDOT and its district offices have regarding the determination of posted speed limits in urban and suburban areas. Results of the study can help FDOT and its district offices to quantify the speed limits and provide more objective justifications for setting speed limits.

1.3. Research Objectives

Information databases were searched to determine whether or not there were any past similar studies that could be reviewed as references, especially technical reports and papers related to roadway speed limit determinations. Existing models and methodologies used by other states and countries to establish posted speed limits were surveyed. Afterward, development of the model to be used for setting speed limits in this study was based on statistical analyses of data of operating speeds and other important factors such as geometric characteristics, land use, area development, crash history, environmental impact, vehicle composition and traffic progressive performance on different types of facilities. Statistical tests were also used to identify the important factors that have significant impacts on speed limits.

Following is an introduction to the building of the mathematical model in this project. This research started from the method of the speed zoning practice, which is to set a speed limit based on the 85th percentile speed and adjust the speed limit taking into consideration such factors related to traffic, geometric, and roadside developments conditions. The format of the preliminary model would be expressed as:

$$\textit{Speed limit} = 85^{th}\ \textit{percentile speed} - f(\textit{traffic}) - f(\textit{geometric}) - f(\textit{roadside}) \quad \text{(Eq. 1.1)}$$

where f(condition) is a function of the condition with regard to the speed limit. To quantify the conditions, the equation was transformed to:

$$\textit{Speed limit} = 85^{th}\ \textit{percentile speed} \times f_{adj}(\textit{traffic}) \times f_{adj}(\textit{geometric}) \times f_{adj}(\textit{roadside}) \quad \text{(Eq. 1.2)}$$

The f_{adj}(condition i) is a factor to adjust speed limit for the effect of condition i, which was defined as an adjustment factor in this study. The f_{adj} is alternatively called as an adjustment module because an f_{adj} will be expressed as an equation that is independently modifiable element in the speed limit model shown in Equation 1.2. In short, the adjustment module is an equation to generate the adjustment factor for a variable in a specific roadway.

However, it is probable that the observed 85^{th} percentile speeds were already influenced by the posted speed limit and the level of enforcement. Thus, instead of using the 85^{th} percentile speed, the maximum statutory speed was considered and the model format is expressed as:

$$\textit{Speed limit} = \textit{Max. statutory speed} \times f_{adj}(\textit{traffic}) \times f_{adj}(\textit{geometric}) \times f_{adj}(\textit{roadside}) \quad \text{(Eq. 1.3)}$$

The equation shown in Equation 1.3 indicates that speed limits will be the maximum allowable limit of 60 MPH in arterial roads in Florida. The speed limits are then adjusted by actual traffic, geometric and roadside development conditions. The effect of a variable on the 85^{th} percentile speed was defined as the variable's sensitivity, which was used to build the adjustment module. Each adjustment factor should be in the range between 0.0 and 1.0.

This study focused on nonlimited-access arterials in Florida state roadway system in urban and suburban areas. These roadways are characterized by a great variation in roadside conditions and frequent vehicle conflicts. In comparison to the other classes of roads, there are less fatal crashes but the number of injury crashes is nearly doubled [2]. Speed zoning, which should be based on engineering study, would be more suitable since the statutory speed limit would not be widely applicable in these types of roads.

To build the model, data were obtained from FDOT and additional field observations including the posted speed limit, 85^{th} percentile speed, geometric characteristics, roadside conditions, etc. In the project, study sites were selected where fewer crashes were experienced and drivers' compliance to the speed limit was higher (smaller differences between the 85^{th} percentile speed and the posted speed). In total, 89 roadways were selected for data collection for modeling, and an additional four roadways were reserved to validate the model performance.

Then, existing posted speed limits on these roadways selected for the project were assessed to check the adequacy of these speed limits. The assessment was based on the comparison of real traffic speed and posted speed limits. The field data and the results from the assessment were combined to develop the model. The factors that contributed to the determination of the 85^{th} percentile speed were considered as the variables for the models. Statistical models were developed and the selection of final model was based on model assessment during the modeling process. After the model was developed, the independent sample was used to validate the accuracy and applicability of the model. Revision to the model was made to ensure the quality of the final model. Lastly, recommendations were presented to aid future investigations.

1.4. Outline of the Report

This report consists of 6 chapters. Chapter 1 provides a comprehensive introduction to this report. Chapter 2 focuses on a review of literature addressing such topics as posted speed, speed-related crashes, speed limit regulations and policies. The approach and methodology used to construct a mathematical speed limit setting model is presented in Chapter 3. Chapter 4 explains the field observation methods and describes the collected information. Chapter 5 examines the field data and constructs the speed limit model. Additionally, the final model selected was statistically examined. Lastly, Chapter 6 provides the conclusions and recommendations.

CHAPTER 2: LITERATURE REVIEW

This chapter introduces the literature on speed, speed limit, crashes related to speed and speed limit, and legislations with regard to the speed limit. Prominent sources for literature were Transportation Research Information System (TRIS), National Technical Information Service (NTIS), U.S. Department of Transportation Intelligent Transportation System (U.S DOT ITS), Institute of Transportation Engineers (ITE), Institute for Scientific Information (ISI) Web of Knowledge, Engineering Index by State University System of Florida, California Partners for Advanced Transit and Highways (PATH).

This chapter starts from a review of documents and technical papers on safety statistics and concerns associated with vehicle speed. In addition to a review on the relationship between operating speed and posted speed limit, issues on the effects of altering speed limits on operating speed and safety are presented. Attention was primarily focused on identifying whether or not there were any past similar studies in the U.S. and other countries. Especially those studies related to roadway speed limit determinations, existing models and methodologies used by other states and countries to establish posted speed limits were surveyed. Then, Florida's current methodology used in setting speed limit is presented followed by the Florida legislations related speed limit. The factors influence vehicle's speed and posted speed was collected from the references and presented in the last section.

2.1. Vehicle Operating Speeds, Speed Limit and Safety

Most drivers select speed at a tradeoff between travel time and safety, at which they can both govern and feel comfortable [2]. Speed has been regarded as one of the major factors in the traffic safety issue. The NHTSA estimates that in year 2000 approximately 30 percent of fatal crashes in the U.S. and 25 percent in Florida were speeding-related [1]. It is often believed that higher speeds may increase the odds of a vehicle becoming involved in a crash. Many researchers have investigated the relationship between speed and safety. In 1998, Coffman and Stuster reviewed the literature on safety related to speed and speed management. The authors summarized that: (a) crash rates are lowest if travel speeds are near to the average speed of traffic and increase for vehicles that travel much faster or slower than the average speed, (b) crash rates increase with increased speed-variance on all type of roadways, and (c) when a crash occurs, it's injury level depends on the change in speed of the vehicle at the moment of impact [7].

Until 1995, the posted speed limit on interstate highways was 55 MPH, which was the MNSL. Drivers ignored the speed limit to a greater extent. This was because the speed limit was considered too low for the type of roadway provided [2]. In 1988, Garber and Gradiraju found that higher travel speeds were relevant to higher design speeds, irrespective of the posted speed limits [8]. The authors also stated that minimum variance could be maintained when the posted speed limit was less than 10 MPH below the design speed of the roadway. It was evident that unrealistically low speed limits aimed to reduce traffic speeds are ineffective and make it difficult to set an appropriate enforcement level. In situations where variance in traffic speeds is smaller when a higher speed limit is imposed, the number of crashes decreased [9]. Thus, speed limits designed to reduce the fatality rate should concentrate on reducing the variance in vehicular speeds.

There have been a number of studies on the effects of altering speed limit but the results are conflicting. Some of those reported that altering speed limits has little effect on drivers' speed selection and number of crashes, while others found both vehicle speeds increase and crashes increase after speed limit increases. Spitz (1984) performed a research that covered 10 California cities, and found no change in travel speed even when speed limit was changed [10]. In 1987, Ullman and Dudek studied roadways in the urban fringe area and confirmed Spitz's results [11]. Parker (1992) studied non-freeways at 100 sites in 22 states [6]. He examined the effect of raising and lowering posted speed limits on driver behavior and crashes for nonlimited-access rural and urban highways. Speed and crash data were collected before and after speed limits were changed. The before-after data were compared with the corresponding data from other states that did not alter speed limits. The results indicated that lowering or raising speed limits has little effect on motorist's speed selection.

Lowering speed limits below the 50^{th} percentile speed does not reduce crashes as well, but does significantly increase drivers' violation of the speed limits. In conclusion, their findings again confirmed that the majority of drivers (about 85 percent) travel at reasonably safe speeds for the various roadway conditions they encounter, regardless of speed limit signs.

However, studies in the U.S. and other countries have shown that raised speed limit induces an increase in speeds on interstate highways. After the repeal of the NMSL of 55 MPH in 1995, each state became responsible to set speed limits in its jurisdiction. Some states raised their speed limit immediately after the Act was in effect, while other states waited to evaluate or observe the effects of speed limit change on speed and safety [2]. Studies performed on that occasion indicated that vehicle speeds increased when speed limit was increased. The Iowa State Safety Task Force examined rural expressways and freeways where speed limits were raised from 55 MPH to 65 MPH in 1996 [5]. They found that 85^{th} percentile speeds increased by 7.8 mph (on an average) and fatal crashes increased by 28%. Overall, the crashes increased by 23%. The drivers' compliance to speed limits improved when the number of speeding tickets was reduced.

In general, when speed limits are raised, research showed that freeways and interstate highways have negative effects, whereas low speed, nonlimited-access highways have little effects. In 1998, Coleman and Morford argued that due to the concurrent lack of some information such as full vehicle miles traveled (VMT), it is not known how increased travel on higher speed roadways, shift in travel, and other traffic safety factors (e.g., changes in alcohol involvement, belt use) or various economic factors (e.g., fuel consumption, roadway maintenance, travel time) may have contributed to the increase in interstate fatalities and economic costs [12].

The other speed limit study by Lave in 1992 has an approach to evaluate system-wide consequences other than the local effect of raising speed limit [13]. The findings revealed that states that raised their speed limits had the highway fatality rate increased by 3.5

percent, compared to the states that maintained the existing speed limit. However, taken as a whole, the overall statewide fatality rates fell by 3.4% to 5.1% in the states that raised the speed limits to 65 MPH. That would be because: (a) drivers may have switched to safer roadways, or (b) enforcement deployment strategies have changed. Table 2.1 summarizes the studies on the effects of raising or lowering speed limits.

TABLE 2.1: Effects of Altering Speed Limits (Source: [7])

Reference	Country	Change		Results
		Before	After	
Nilsson (1990)	Sweden	110 km/h (68 mi/h)	90 km/h (56 mi/h)	Speeds declined by 14 km/h Fatal crashes declined by 21%
Engel (1990)	Denmark	60 km/h (37 mi/h)	50 km/h (31 mi/h)	Fatal crashes declined by 24% Injury crashes declined by 9%
Peltola (1991)	UK	100 km/h (62 mi/h)	80 km/h (50 mi/h)	Speeds declined by 4 km/h Crashes declined by 14%
Sliogeris (1992)	Australia	110 km/h (68 mi/h)	100 km/h (62 mi/h)	Injury crashes declined by 19%
Finch et al. (1994)	Switzerland	130 km/h (81 mi/h)	120 km/h (75 mi/h)	Speeds declined by 5 km/h Fatal crashes declined by 12%
Scharping (1994)	Germany	60 km/h (37 mi/h)	50 km/h (31 mi/h)	Crashes declined by 20%
Newstead and Mullan (1996)	Australia	5-20 km/h decreases (3-12 mi/h decreases)		No significant change (4% increase relative to sites not changed)
Parker (1997)	USA 22 states	5-20 mi/h decreases (8-32 km/h decreases)		No significant changes

(a) Speed Limit Decreases

TABLE 2.1: (Continued)

Reference	Country	Change		Results
		Before	After	
NHTSA (1989)	USA	55 mi/h (89 km/h)	65 mi/h (105 km/h)	Fatal crashes increased by 21%
McKnight, Kleinand Tippetts (1990),	USA	55 mi/h (89 km/h)	65 mi/h (105 km/h)	Fatal crashes increased by 22% Speeding increased by 48%
Garber and Graham (1990)	USA (40 states)	55 mi/h (89 km/h)	65 mi/h (105 km/h)	Fatalities increased by 15% Decrease or no effect in12 states
Streff and Schultz (1991)	USA (Michigan)	55 mi/h 89 km/h)	65 mi/h (105 km/h)	Fatal and injury crashes increased significantly on rural freeways
Pant, Adhami and Niehaus (1992)	USA (Ohio)	55 mi/h (89 km/h)	65 mi/h (105 km/h)	Injury and property damage crashes increased but not fatal crashes
Sliogeris (1992)	Australia	100 km/h (62 mi/h)	110 km/h (68 mi/h	Injury crashes increased by 25%
Lave and Elias (1994)	USA (40 states)	55 mi/h (89 km/h)	65 mi/h (105 km/h)	Statewide fatality rates decreased 3-5% (Significant in 14 of 40 states)
Iowa Safety Task Force (1996)	USA (Iowa)	55 mi/h (89 km/h)	65 mi/h (105 km/h)	Fatal crashes increased by 36%
Parker (1992)	USA (Michigan)	Various		No significant changes
Newstead and Mullan (1996)	Australia (Victoria)	5-20 km/h increases (3-12 mi/h increases)		Crashes increased by 8% 35% decline in zones raised from 60-80
Parker (1997)	USA 22 states	5-15 mi/h (8-24 km/h)		No significant changes

(b) Speed Limit Increases

2.2. Current Studies and Practices of Setting Speed Limits

Professionals have agreed that the 85th percentile speed should be the basis for setting speed limits on most highway types. Other factors that have also been taken into consideration to set speed limits include legislative statutes, accident experience, roadside development, parking/pedestrian activity, traffic volume and vehicle mix, design speed, public attitude, safe speed for curves, visibility restrictions, road surface characteristics and width, shoulder type and width, number of intersections, existing traffic control devices, test run experiments, and upper limit of 10-MPH pace [2].

A study in Kentucky stated that the 85^{th} percentile speed should be used as the basis to establish speed limits, assuming that drivers have an understanding of a reasonable speed and operate their vehicles at a speed they consider appropriate for the roadway geometric and environment, regardless of speed limit [14]. The author also recommended setting differential speed limits for cars and trucks and using advisory speed signs as a supplemental traffic control device.

Another study by Harwood in Australia in 1995 examined the general speed in local streets in suburban areas (substantially built-up areas) [15]. He argued that a general speed might be suitable for some of the roadways to which it applies. There may be many sections that the speed limit is too high or too low. If all speed limits were set based on 85^{th} percentile speed, it would result in driver's confusion because there would be numerous signs on roadways. This would require tremendous human and financial resources. Also, it is doubtful if setting limits based on the 85^{th} percentile speed would be appropriate in residential area roadways, on which the primary function is distributing traffic. He concluded that a 50 km/h (31.1 MPH) speed limit applied on a local street in the study would provide high level of compliance, whereas, 40 km/h (24.9 MPH) results in a low compliance level.

In 1995, Fitzpatrick et al. recommends that speed limits on all roadways should be set by an engineering based speed study [16]. The authors recommended that the 85^{th} percentile speed in conjunction with legal minimum and maximum speeds should establish the boundaries of the speed limits. The 85th percentile speed is considered as the appropriate posted speed limit even for those sections of roadway that have an inferred design speed less than the 85th percentile speed. If a section of roadway has a posted speed limit in excess of the roadway's inferred design speed and a safety concern exists at the location, then appropriate warning or informational signs should be installed. New or reconstructed roadways should be designed to accommodate operating speeds consistent with the roadway's highest anticipated posted speed limit based on the roadway's initial or ultimate function.

In 2002, Fitzpatric surveyed 128 speed zones and found that 23-52% of the 85th percentile speeds were equal to the posted speed limit in urban and suburban collectors and local streets and 72% were equal to the posted speed limit on rural roads [17]. The author concluded that the 85th percentile speed is used only as a starting point; the posted speed limits are mostly set below the 85th percentile value by as much as 8-12 mph.

In conjunction with the National Highway System (NHS) Designation Act of 1995, NHTSA, FHWA, and the Center for Disease Control and Prevention have contracted with the Transportation Research Board (TRB) to examine the criteria used by states to establish speed limits as well as to recommend improvements to the current methodology. A multidisciplinary panel of experts (TRB Committee for Guidance on Setting and Enforcing Speed Limits) has been formed to review criteria for setting speed limits. By efforts of TRB and the supporting agencies, Special Report 254, Managing Speed was published in 1998. The main objective was to review the current practice for setting and enforcing speed limits on all types of roadways. The report classified the methods for setting speed limits into 4 groups [2].

(a) A statutory speed limit is a general speed limit established by the legislature. Also known as the blanket speed, the legislated speed limits cover a wide area (e.g., CBD, urban or rural area) set by road class (e.g., interstate highway, arterial, or local road). In determining a legislated speed limit, such factors as design speed, vehicle operating speed, crash history, and enforcement experience are taken to consideration. The authorized bodies of setting the statutory limits are Federal and state agencies, and also by ordinances of local governments. The 55 MPH of National Maximum Speed Limit (NMSL) is an example of the statutory limit of the Federal level, which was initiated in 1973 to reduce gas consumption [2]. The NMSL had continued until 1995 because it was found that the lowered speed limit contributed to reduced crashes on highways. The NMSL was repealed in 1995, returning the authority to set speed limits to individual states.

(b) Optimum speed limits are set based on cost-benefit approach. It encounters an optimum level from a societal perspective. This approach has not been applied due to the difficulty to quantify the scio-economic variables.

(c) Engineering study method sets speed limits based on the 85th percentile speed and adjusted based on crash experience, roadside development, geometry, and maximum statutory speed. A speed zone is a section of street or highway where statutory speed is not appropriate and the speed limit is set based on the engineering study. The purpose of speed zoning is to establish a speed limit that is reasonable and safe for a given section of roadway [18]. The ITE Technical Council Committee 4M-25 recommended that speed zoning be established on the basis of an engineering study and be set at the nearest 5 MPH increment to the 85th percentile speed or the upper limit of the 10 MPH pace [4]. Speed zoning should not be considered where 85th percentile speed is within ± 3MPH of the statutory speed limit. The existing speed limit within a speed zone should not be changed if the 85th percentile speed is within ± 3MPH of the posted speed limit, and in no case should the speed limit be set below the median speed of the 10 MPH pace. Setting speed limit solely by the 85th percentile speed may be compatible with higher classes of roadways where the major function is to serve through traffic movement. In lower classes of roadways or roadways in developed areas, using other factors along with the 85th percentile speeds would be reasonable to set appropriate speed limits to encounter the variances in geometry, traffic and roadside developments.

(d) The last method is an expert system based approach, which is a computer program that imitates an expert's thought process to solve complex problems in a given field [2]. Australia Roadway Research Board (ARRB) developed computerized road safety applications as known as XLIMITS series. The applications incorporate complex decision making processes that road authorities use to calculate speed limits [19]. Here they take into account existing speed limit, operating speed, land use, accessibility, roadway characteristics, accident history, and other relevant factors.

Conclusively, the TRB Special Report 254 stated that the approach widely used to set speed limit in the U.S. is sound, i.e. speed limits are legislated by broad road class and geometric area with exceptions (speed zoning) in order to reflect local differences for the roads where statutory limits do not fit [2]. Also, guidelines for each class of roadways in setting legislated speed limit and speed zoning are presented as the committees' suggestion.

2.3. Speed Limit Law in Florida

2.3.1. Florida Statutory Speed Limit

This chapter summarizes Florida State Statutes related to speed limits, referenced by the Florida Statute and additional summary of states' speed laws provided by the NHTSA [20]. As a basic speed rule, the statute states that no person shall drive a vehicle at a speed greater than is reasonable and prudent under the conditions and having regard to the actual and potential hazards existing (316.183(1)&(4)).

A statutory speed limit on limited-access highway is set as 70 MPH (316.187 (2)(a)) with an annotation that other provisions of law establish the maximum speed limit of 65 MPH on any other highway, which has 4 lanes that are divided by a median strip and which are located outside urban areas with populations more than 5,000 (316.187(2)(b)). In all locations unless specified, 55 MPH is established (316.183(2)). Likewise, 30 MPH is in business and residence districts (316.183(2) & 316.189(2)(a)) with an annotation that after an investigation, local authorities may establish a maximum speed limit of 20 MPH or 25 MPH in residence districts (316.183).

As supplementary directions for the posted (maximum) speed limits, the statutes include following statements. After engineering and traffic investigations, the state or local governments (within their jurisdictions) may increase or decrease the statutory speed limit on a highway. However, the state cannot establish a speed limit greater than 70 MPH and local jurisdictions cannot establish a maximum speed limit greater than 60 MPH (316.187(2)(e) & 316.189(1)&(2)(b)).

In addition, under separate statutory authority, the State Department of Transportation or a local government may reduce the speed limits otherwise proscribed by law on any highway (or part thereof) or bridge. Such action must be based on the needs to avoid damage to such highway or bridge due to either its design or to weather related conditions (316.555). Under such authority, it may be possible to provide different speeds for different types of vehicles.

Posted minimum speed limits is also stated, that is, no person shall drive a motor vehicle at such a slow speed as to impede or block the normal and reasonable movement of traffic, (316.183(5)). The minimum speed limit is established mainly on interstate and defense highways with at least 4 lanes, which is 40 MPH (316.183(2)). Speed limits for school buses and vehicles passing through a work zone and school zone are also stated in the statutes. Appendix A provides full text of the section of Statutes related to speed limit.

2.3.2. Speed Zoning in Florida

A guidebook, Speed Zoning for Highways, Roads and Street in Florida by Florida Department of Transportation (FDOT) explains the procedures and practices for performing engineering and traffic investigations related to speed zoning in Florida [21]. The FDOT uses the 85^{th} percentile methods of determining appropriate and safe posted speed limits in conjunction with the maximum statute based speeds. By measuring the speed of hundreds of vehicles at various points along the roadway, traffic engineers are able to use data to determine a reasonable and safe maximum speed to post for all vehicles to travel.

The document recommends the measurement of prevailing speed of free-flowing traffic during good weather and roadway conditions. The parameters of the vehicle speeds are by means of 85^{th} percentile speed, upper limit of 10 mph pace, or average test run speed. It also states that the less variation in vehicular speed at a particular location, the safer the conditions will be, and realistic speed limits will reduce the variance (dispersion) of speed even though the average, mean, or 85^{th} percentile speed may not change appreciably. Conclusively, setting a speed limit in speed zone should be based on understanding of the purpose and function of speed zoning in the interest of safety and traffic operation facing various situations.

The point of view on speed limits by FDOT traffic engineers is presented on their website (http://www11.myflorida.com/trafficoperations/speedlim.htm, 2003). It states that:

"The primary purpose is to provide improved safety by reducing the probability and severity of crashes. A speed limit sign notifies drivers of the maximum speed that is considered acceptably safe for favorable weather and visibility. It is intended to establish the standard in which normally cautious drivers can react safely to driving problems encountered on the roadway. Properly set speed limits provide more uniform flow of traffic and appropriately balance risk and travel time, which results in the efficient use of the highway's capacity and less crashes."

The website also describes how speed limits are established; "…about 85 percent of all drivers travel at reasonably safe speeds for the various roadway conditions they encounter, regardless of speed limit signs. This leaves 15 percent of drivers who must be reminded of the maximum speed limit. This reminder must be coupled with meaningful enforcement. Based on this knowledge, a traffic engineering study is conducted to establish speed limits on the state highway. The Department uses the 85^{th} percentile method of determining appropriate and safe posted speed limits in conjunction with the maximum statute based speeds. This method is based on extensive nationally accepted studies and observations. By measuring the speed of hundreds of vehicles at various points along the roadway, traffic engineers are able to use data to determine a reasonable and safe maximum speed to post for all vehicles to travel." In general, the procedure of speed zoning in Florida is almost identical to the speed zoning method widely used in the U.S.

2.4. Factors that Affects Operating Speed and Speed Limit

Drivers choose speed from a conscious and subconscious decision-making process. Researchers have examined and identified factors that influence vehicle speeds. Mostly, the focuses were on roadway geometry, traffic, and roadside development. Human factors and socio-economic factors are often ignored because it is difficult to quantify them. Listed below are the factors that can influence a driver's speed selection. These factors are categorized by the relevancy. Some of these factors may be considered for setting speed limits. The factors that can possibly be used in speed limit model were marked with * in the list.

(a) Human factors: driver age, driver skill, personality of driver, emotional and/or physical condition of driver, familiarity of driver with roadway*, influence of alcohol and/or other drugs, number of passengers, type of passengers,

(b) Trip-oriented factors: time of day, purpose of trip, urgency of trip, length of trip,

(c) Vehicular factors: type of vehicle, condition of vehicle, vehicle weight,

(d) Environmental conditions: weather condition, ambient light*, visibility*,

(e) Geometric conditions: number of lanes*, lane width*, median type*, roadside clearance*, roadway alignment* (vertical and horizontal curvature),

(f) Traffic conditions: traffic volume, percentage of heavy vehicles*, speed of other vehicles, pedestrians especially children*, presence and location of cyclists*, vehicle parking*,

(g) Topographical factors: land use*, road functional classification*, signal spacing*, frequency of assesses such as driveways and median openings*, roadside development*,

(h) Traffic control devices: traffic signs*, signals*, pavement markings*,

(i) Pavement factors: pavement type and condition*, pavement roughness*, pavement wetness*, pavement surface condition (snow, ice, mud, or sand),

(j) Enforcement factors: presence of enforcement personnel or officially marked vehicles, and

(k) Others: the interval since witnessing an accident or results of an accident, recent traffic violation and point accrued.

A study was performed on four-lane suburban arterials to identify the factors that affect vehicular speed and to determine the range of the influence [22]. Using multivariate linear regression, the authors found that posted speed limit was the most significant factor for both curves and straight sections. They also performed analyses without using posted speed limit and found that only lane width was a significant variable for the straight sections, whereas existence of median and roadside development were significant factors for the curve sections.

Stokes et al. performed a similar study to quantify the effects of roadway characteristics and adjacent development patterns on 85th percentile speed in rural and urban highways [23]. The research was reported in 1999 concluding that the multivariate linear regression approaches were not satisfactory in terms of their ability to predict the 85th percentile speed in both types of areas. They also performed analyses using artificial neural network (ANN) to predict highway speeds. They found that the ANN model had better performance than the regression model and significant factors in the process were: (a) shoulder width, shoulder type, ADT, and percentage of no-passing zone in rural areas, and (b) parking type, lane type, and area density type in urban areas.

CHAPTER 3: METHODOLOGY DESCRIPTION

3.1. Concepts

This research started from the method of the speed zoning practice, which is to set a speed limit based on the 85th percentile speed and adjust the speed limit by taking into consideration additional factors related to traffic, geometric, and roadside development conditions. Assuming that conditions are independent to each other, the speed limit in speed zoning can be formulated as:

$$Speed\ limit = 85^{th}\ percentile\ speed - f(traffic) - f(geometric) - f(roadside) \quad \text{(Eq. 3.1)}$$

where f(condition) is a function of the condition with regard to the speed limit. To quantify the conditions, the equation can be transformed to:

$$Speed\ limit = 85^{th}\ percentile\ speed \times f_{adj}(traffic) \times f_{adj}(geometric) \times f_{adj}(roadside) \quad \text{(Eq. 3.2)}$$

The f_{adj}(condition i) is a factor to adjust speed limit for the effect of condition i, which was defined as an adjustment factor in this study. However, it is probable that the observed 85th percentile speeds are already influenced by the posted speed limit and the level of enforcement. Thus, there was a need to discuss alternative approaches to replace the 85th percentile speed, which was to find an ideal speed to which adjustment factors are applied to account for prevailing conditions. From an operational perspective, design speed would best explain the maximum value of a roadway section, while the maximum statutory speed limit would fit on the legal basis. Since the design speed of roads may not be readily available, the maximum statutory speed limit was considered as the maximum speed limit value utilized in the model. Hence, instead of using 85th percentile speed, the preliminary model is rewritten as:

$$Speed\ limit = Max.Statutory\ Speed \times f_{adj}(traffic) \times f_{adj}(geometric) \times f_{adj}(roadside) \quad \text{(Eq. 3.3)}$$

The equation shown in Equation 3.3 indicates that speed limits will be the maximum allowable limit of 60 MPH in arterial roads in Florida. The speed limits are then adjusted by actual traffic, geometric and roadside development conditions. Equation 3.3 can be simplified as:

$$PSL = MSSL \times f_1 \times f_2 \times f_3 \times \Lambda \times f_i \qquad \text{(Eq. 3.4)}$$

where,

PSL : proposed speed limit (MPH) at prevailing condition,

MSSL : maximum statutory speed limit (MPH), 60 MPH for nonlimited-access highways in Florida, and

f_1, f_2, …, f_i: factors to adjust for the effects of road geometry, traffic, and drivers

The f_i is alternatively called an adjustment factor module because an f_i will be expressed as an equation that is independently modifiable element in the speed limit model shown in Equation 3.4. In short, the adjustment factor module (f_i) is a function to compute the adjustment factor (f_{ij}) for a variable (i) in a specific roadway (j). The adjustment factors are non-scale parameters and should be in the range between 0.0 and 1.0. An adjustment factor equal to 1.0 indicates the ideal condition for the variable, which does not contribute to the decrease of the 60 MPH of the maximum value. In contrast, an adjustment factor of 0.0 theoretically means the worst case where the traffic should not move (speed limit is equal to 0.0). Accordingly, proper establishment of adjustment factor modules would determine the quality of the speed limit model proposed in this study.

The effect of a variable on the 85th percentile speed was defined as the variable's sensitivity, which was used to build the adjustment module. The adjustment modules were estimated based on the data collected in the field. The sites selected for the field observations were where the speed limits were expected to be appropriately set. This study defined the 'appropriate speed limits' as such roadways where following three conditions were satisfied:

(a) Lesser crash experience: lower crash rate,

(b) Uniform traffic flow: smaller variation in vehicular speeds, and

(c) Drivers' compliance to speed limit: smaller difference between 85th percentile speed and posted speed.

In fact, vehicles' speeds are generally affected by the level of enforcement, which is different depending on the location and time. Posted speed limit could affect the vehicles' speeds, too. This project assumed that the effects of enforcement on drivers' speeds are the same irrespective of the location and time. The influence of posted speed limit on the 85th percentile speed, if existed, was also assumed as uniform.

3.2. Development of Adjustment Factor Modules

In designing the adjustment factor modules, it was initially assumed the relationship between a quantified variable (v_i) and the corresponding adjustment factor (f_i) was linear. Figure 3.1 illustrates the abstract of an f_i, that ranges between 0.000 and 1.000 on Y-axis, although the actual lowest f_i would be somewhere between 0.000 and 1.000. Also, the variable on X-axis was 'standardized' to have range between 0 and 1. A standardized variable was characterized by the notation sv_i. Consequently, an adjustment factor can be obtained by using the following equation, the adjustment module:

$$f_i = 1 - sv_i \quad \text{(Eq. 3.5)}$$

A variable can be either continuous or categorical. Depending on the variable, alternative forms were used for the f_i - sv_i relationship as illustrated in Figure 3.2. The alternative form (a) in Figure 3.2 was utilized for a categorical variable that had binary choices, which was to take one of two possible values (e.g., existence of curb in roadside). The alternative form (b) was utilized for a categorical variable that could take more than two choices (e.g., high, mid or low level of roadside development). If the variable is not ordinal but has more than 2 choices (e.g., land use of residential, business, or industrial), it was transformed to dummy variables and alternative form (a) was used.

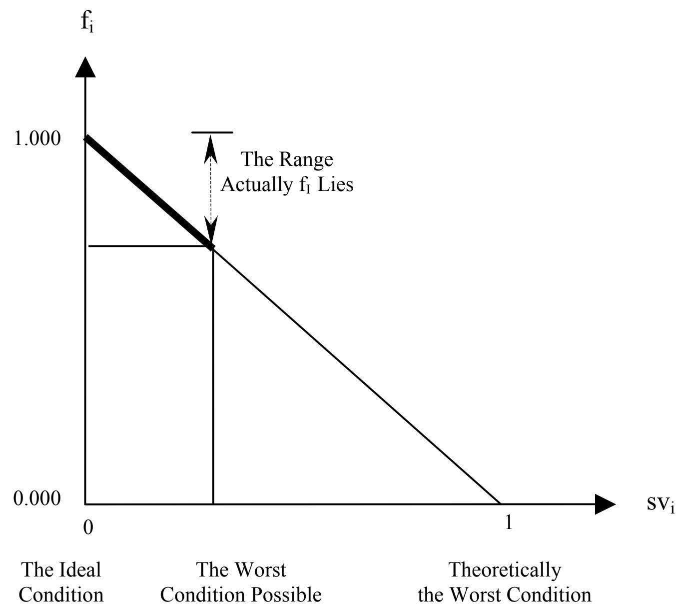


FIGURE 3.1: Framework of Adjustment Factor Module Design

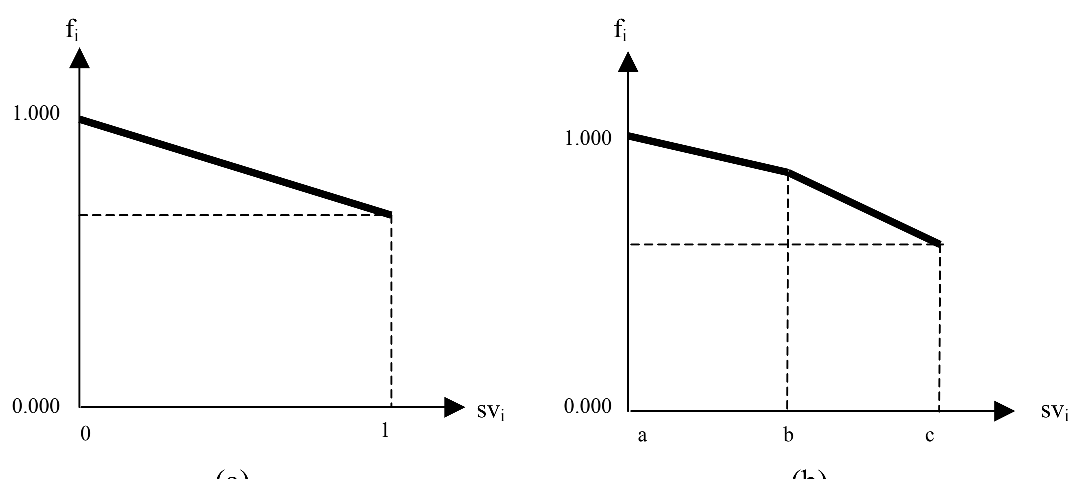


FIGURE 3.2: Alternative Forms of Adjustment Factor Module

3.3. Variable Standardization

To convert the value of a variable into a factor between 0 and 1, each variable was regressed against 85th percentile speed using the SPSS curve estimation function. The main purpose of curve estimation was to test if a variable is a statistically significant determinant of 85th percentile speed and, if so, to obtain linear relationship between the 85th percentile speeds. In this process, variables with a significance level greater than 0.05 were omitted for further investigation. To obtain higher goodness-of-fit, some variables were tested by treating them both as continuous and categorical variables and some variables were combined with the other similar variables. The slope from the best fitting linear relationship was then used for the standardization.

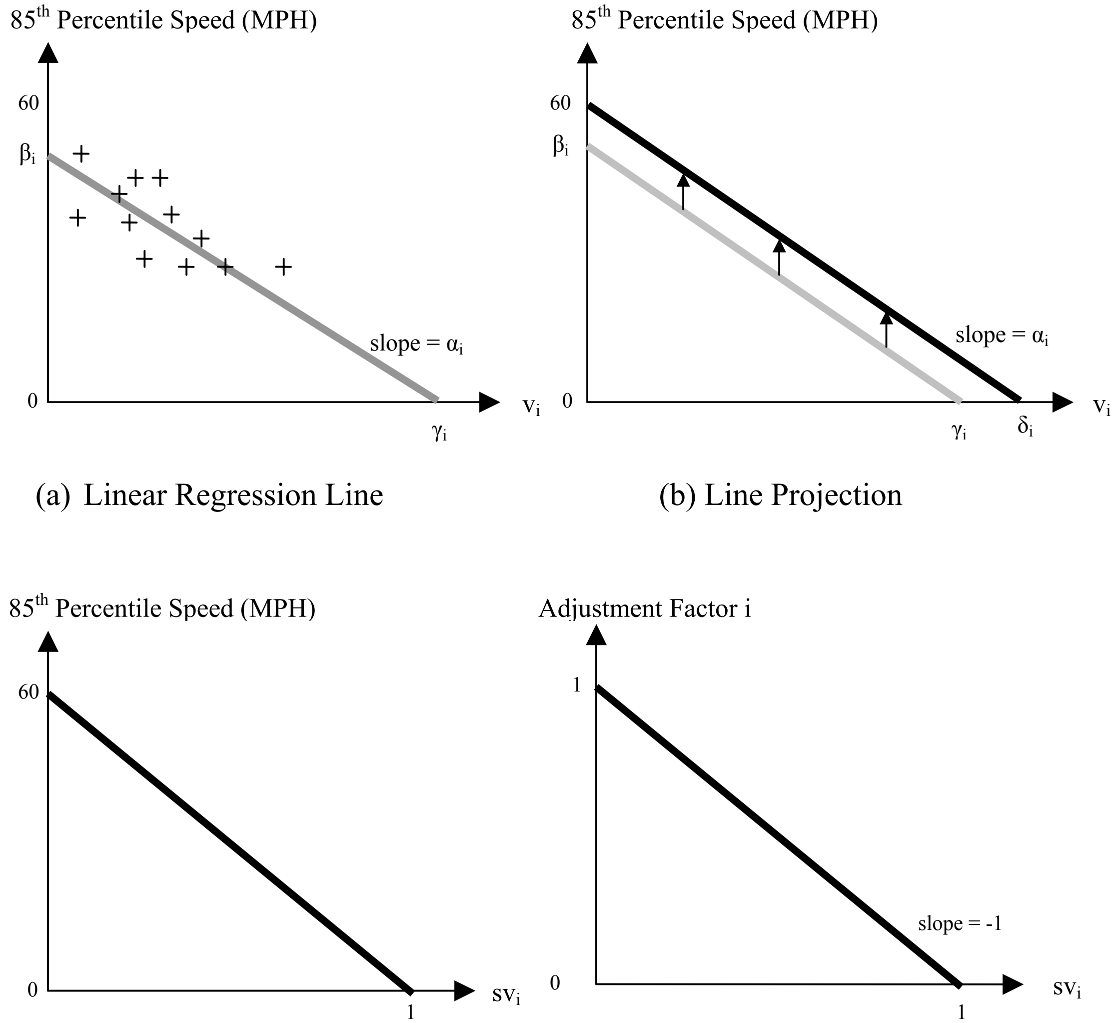
If the slope from the linear regression estimation is α_i and its intercept is β_i (Figure 3.3 (a)), the relationship obtained between 85th percentile speed and a variable i (v_i) could be expressed as:

$$85^{th}\ percentile\ speed = \beta_i + (\alpha_i \times v_i) \qquad \text{(Eq. 3.6)}$$

The slope α can be considered as the sensitivity of the 85th percentile speed against v_i. The regression line was moved vertically upward to having the intercept 60 MPH (Figure 3.3 (b)). Let the intercept of the transferred line with X-axis be called δ_i. The δ_i and zero can be interpreted as the two extreme conditions that a variable i can have; the ideal condition and the worst condition. Finally, the values of 60 MPH in Y-axis and δ_i in X-axis were converted proportionally into the range 0 and 1 (Figure 3.3 (c) and (d)). The following two equations give the values of δ_i (Eq. 3.7) and the standardized variable (sv_i) (Eq. 3.8).

$$\delta_i = 60 / \alpha_i \qquad \text{(Eq. 3.7)}$$

$$sv_i = v_i / \delta_i \qquad \text{(Eq. 3.8)}$$



(a) Linear Regression Line

(b) Line Projection

(c) Standardized Variable i (X-axis)

(d) Standardized Y-axis

FIGURE 3.3: Standardization Procedure

Substituting the Equations 3.7 and 3.8 into Equation 3.5, the adjustment factor of variable i in a study site j is computed as:

$$f_{ij} = 1 - (v_{ij} \times \alpha_i) / 60 \qquad \text{(Eq. 3.9)}$$

The method is also applicable in the case of a categorical variable regardless of whether it is ordinal or nominal.

3.4. Weighting Factors

The purpose of employing weighting factors was to assign appropriate levels of importance to each variable in the model shown in Equation 3.4. The model with the weighting factors are expressed as:

$$PSL = MSSL \times f_1^{w_1} \times f_2^{w_2} \times f_3^{w_3} \times \Lambda \times f_i^{w_i} \qquad \text{(Eq. 3.10)}$$

where,

PSL : proposed speed limit (MPH),

MSSL : maximum statutory speed limit (MPH),

$f_1, f_2, \ldots, f_i$: factors to adjust for the effects of road geometry, traffic, and drivers,

$w_1, w_2, \ldots, w_i$: factors to weight to count for the different impact of variables to the speed limit model

To estimate the weighting factors, the equation is converted into the logarithm form.

$$Ln\ PLS = Ln\ MSSL + Ln\ f_1^{w_1} + Ln\ f_2^{w_2} + Ln\ f_3^{w_3} + \Lambda + Ln\ f_i^{w_i} \qquad \text{(Eq. 3.11)}$$

$$Ln\ (PLS / MSSL) = (w_1 \times Ln\ f_1) + (w_2 \times Ln\ f_2) + (w_3 \times Ln\ f_3) + \Lambda + (w_i \times Ln\ f_i) \qquad \text{(Eq. 3.12)}$$

The multivariate linear regression method was used to obtain the estimated weighting factors taking Ln (PSL / 60) as the dependant variable and Ln (f_i) as the independent variables. Significance of each independent variable at the level of 0.05 and correlationship between variables were tested if the variables were explainable. F-value and adjusted R-square value were also tested if the model was useful. After obtaining the weighting factors, Equation 3.12 was converted back to natural form. Finally, the proposed speed limit for the site j is:

$$PLS_i = 60\,MPH \times [1-(v_{1j} \times \alpha_1)/60]^{w_1} \times [1-(v_{2j} \times \alpha_2)/60]^{w_2} \times [1-(v_{3j} \times \alpha_3)/60]^{w_3} \times \mathrm{K} \times [1-(v_{ij} \times \alpha_i)/60]^{w_i} \qquad \text{(Eq. 3.13)}$$

Notating the weighted adjustment factor for a variable i as f^*_i, the Equation 3-11 can be simplified as:

$$PSL = MSSL \times f_1^* \times f_2^* \times f_3^* \times \Lambda \times f_i^* \qquad \text{(Eq. 3.14)}$$

Conceptually, a weighting factor should not have negative sign. A weighting factor with negative sign implies that the adjustment factor module was mis-specified. By adding the weighting factors, the relationship between f_i and v_i would not be linear in the speed limit model unless the corresponding weighting factor w_i is equal to 1.0.

A number of scenarios were tested statistically by taking alternative forms of variables, different combinations of variables, and different designs of adjustment factor module. The selection of the final model was based on model assessment during the modeling process. After the model was developed, an independent sample was used to validate the accuracy and applicability of the model. Revision to the model was made to ensure the quality of the final model.

In addition to the approach described, other mathematical model specifications were attempted including multinomial logit model, ordinal regression model, etc. The outcome of the multinomial logit model is the probabilities of each category of dependant variables, e.g., probabilities of a roadway having speed limit of 40, 45, 50, 55, and 60 MPH. From the set of choices, speed limit with the highest probability would be proposed as the speed limit for a given section. The ordinal regression model takes ordinal categories of dependent variable with a set of predictors, where the differences between the ordinal categories may not be quantifiable, e.g., the deviation between 40 MPH and 45 MPH may have a different meaning from the deviation between 55 MPH and 60 MPH. Those alternative models were tested based on statistical analyses to investigate their feasibility and potential as a speed limit model to be proposed.

CHAPTER 4: DATA COLLECTION

4.1. Site Selection Criteria

Site selection criteria for this project were based on a set of roadway sections that was assumed to have operated with proper speed limit. This research defined that the speed limit was appropriate when following conditions were satisfied:

(a) Less crash experience,

(b) Uniform traffic flow- smaller speed variation in traffic flow, and

(c) Driver's compliance to speed limit- smaller difference between operating speed and posted speed.

In order to select roadways with less crash experience, crash data were obtained from FDOT and analyzed. However, the other two conditions could not be used in the initial site selection because they were available only after analyzing the field collected traffic data. Therefore, the initial site selection considered only crash history on roadways.

Field observations were conducted on the selected sites in six counties in Florida State Highways (SR: State Road) including Hillsborough, Manatee, Pasco, Pinellas, Polk, and Sarasota, limited to major and minor arterials in urban and suburban areas. Access controlled highways such as freeways and interstate highways were not included in the study scope. Directional one-lane roads were also not considered due to the fact that traffic characteristics of those roadways might be considerably different from those of multi-lane roadways.

General details of roadways were obtained from the Roadway Characteristics Inventory (RCI) database at the FDOT. This information included roadway identification number (8 digits), State Road number, milepost, functional classification, average annual daily traffic (AADT), urban/rural indication, number of lanes, median type and posted speed limit as shown in Table 4.1. A roadway is segregated by 'traffic-break' and the breakpoints are indicated by mileposts (begin/end mileage) of the roadway. Traffic-break is defined as a segment of roadway with relatively uniform traffic characteristics [25], such as AADT, posted speed, number of lanes, etc. A traffic break may include several minor intersecting roadways on a similar highway and the length varies from several hundreds of feet to several miles depending on the site characteristics.

The roadway segments to be studied in this project were determined based on the traffic break, which was set by FDOT. Accordingly, a study area was defined as a segment of roadway with relatively uniform traffic characteristics no less than a quarter mile long with insignificant vertical and horizontal curvatures. In addition, the study sections have not undergone considerable development or any development in previous 5 years. Sections with special features such as a long bridge, interchange, and field construction were also not considered as data collection sites.

TABLE 4.1: An Example of Road Segment Data

ID	Segment	Begin	End	Length	State Road	Road Class	Side	# Lanes	Posted Speed	AADT
357	10030002	0.000	0.911	0.911	SR 553	16	R	3	45	15000
358	10030002	0.000	0.911	0.911	SR 553	16	L	3	45	15000
359	10030002	0.911	1.144	0.233	SR 553	16	R	3	45	15000
360	10030002	0.911	1.144	0.233	SR 553	16	L	3	45	15000
361	10030002	1.144	1.186	0.042	SR 553	16	R	2	45	15000
362	10030002	1.144	1.186	0.042	SR 553	16	L	3	45	15000
363	10030002	1.186	1.410	0.224	SR 553	16	R	2	45	15000
364	10030002	1.186	1.410	0.224	SR 553	16	L	2	45	15000

4.2. Crash Counts for the Site Selection

Crash records between 1996 and 1998 were analyzed to obtain the number of crashes on roadway segments. A summary of crash statistics for the selected year is given in Table 4.2. Each crash record consists of the identification number of the roadway and the milepost at which the crash occurred, accident type and cause, driver information, roadway geometry, weather, time, and so on.

Each crash that has occurred within a segment bounds was counted by using a data analysis tool, SAS, by matching the roadway ID and milepost from crash database and segment database. In addition to that, road name data (Table 4.3) from the Center of Urban Transportation Research (CUTR, University of South Florida) was used to match the roadway ID with the actual name of the roadway.

TABLE 4.2: Crash Statistic in Florida State Highway System (1996-1998)

Year	All Crashes	Fatal Crashes	Injury Crashes	All Crashes in 6 Counties
1996	128,389	1,488	79,608	28,863
1997	144,862	1,561	80,300	32,432
1998	146,859	1,619	80,376	30,769

TABLE 4.3: An Example of Road Name Data

Roadway ID	Road Name
10180000	SR573/S DALE MABRY
10200000	N WHEELER ST
10210000	US 301/FT KING HWY
10240000	ROWLETT PARK DR
10240501	SLIGH AVE

After the number of crashes was counted for each segment, crash rate was calculated as:

$$Crash\ Rate\ (crash/veh-mile) = \frac{Number\ of\ all\ crashes \times 100{,}000}{AADT \times Length\ of\ segment} \qquad \text{(Eq. 4.1)}$$

The segments were then ranked by the estimated crash rate and 25 % of segments with lower crash rate were selected for field observation. The number of segments with the lower crash rate is 269 out of a total of 1601 (6 counties, urban area, and major/minor arterials). Among 269 sites, isolated short segments that were shorter than 1500 ft were identified and combined with the adjacent segments to form a new study. Finally, 161 sites were selected and the total mileage of the selected sites was 146.6 miles.

4.3. Field Observation

Field observation and data collection was conducted between August 2001 and March 2002, which consisted of two parts: (a) visual observation and (b) collection of vehicle speeds, traffic counts, and vehicle composition by using speed measuring devices and a laptop computer.

4.3.1. Visual Observation

The 161 selected sites were marked on the FDOT Straight Line Diagram (SLD) to find the study sections with roadway mileposts. In the field, brief scanning of a site determined if there are certain specific features, such as deep curvature, bridge, and ongoing construction and, if so, the site was excluded from data collection. Although the characteristics of one direction of a roadway are not completely independent of those of the other direction, taking a roadway by direction would facilitate observation, interpretation and utilization of the collected variables. Therefore, data collection was based on directional sections. Finally, 104 directional roadways with a total of 74.0 miles were considered for data collection. The observation was filled up on a worksheet as shown in Figure 4.1, median type and width, number of lanes and width, number of left and right turning bays, number of signalized intersections, number of connecting roadways and driveways, lateral clearance, pavement type and condition, number of traffic signs, presence of pedestrians and parking, visibility, weather, land use, level of roadside development, and posted speed limit.

Segement ID:	Roadway ID:		Road Name:
SR Number:	Weather:	Visibility:	
Milepost From:	To:		Length:
Starting Date:	Time:	Ending Date:	Time:
Number of Signal Intersection:	Median Width:		Land Use:
	Median Type:		Density:

	Left Direction	Right Direction
Data Collector ID (App. Milepost)	Left-1:	Right-1:
	Left-2:	Right-2:
	Left-3:	Right-3:
Number of Lane		
Average Lane Width		
Number of Exclusive Turning Lanes	Left Turning:	Left Turning:
	Right Turning:	Right Turning:
Roadside Clearance		

Pedestrian or Cyclist Presence						
Parking						
Posted Speed						
Number of Traffic Signs		SL signs			SL signs	
Number of Minor Street Intersecting						
Number of Driveways						
Number of Median Opening		Directional			Directional	

Pavement Type		
Pavement Condition		
Pavement Roughness and Cracks		

Enforcement	

Note:

FIGURE 4.1: Visual Observation Worksheet

Details of the items included in the worksheet are as follows.

(1) Segment ID: Identification number given to each segment in ascending order. Total of 5343 segments (traffic-breaks) are located in 6 study counties including Hillsborough, Polk, Manatee, Sarasota, Manatee, Pinellas in Florida.

(2) Roadway ID: 8-digit identification number given by the FDOT. The first two-digits indicates the county, the next three-digits for the road section, and the last three-digits for the road subsection.

(3) Road Name: Actual name posted on the roadway (ex. Fowler Avenue)

(4) SR number: State Road number (ex. SR60)

(5) Weather: Choice of fine, rainy, or cloudy at the moment of the visual observation

(6) Visibility: Choice of good, fair, or poor at the moment of the visual observation

(7) Milepost: The milepost at the beginning and ending of the segment. The mileage starts mostly from west and directs to east or starts from south and directs to north.

(8) Length: Study site length measured by feet. The length can be computed as:

$$Segment\ length\ (feet) = \frac{End\ milepost - Begin\ milepost}{5280} \qquad \text{(Eq. 4.2)}$$

(9) Starting and Ending Date and Time: Date and time of the speed measurement

(10) Number of Signal Intersections: Number of signalized intersections within the study section. This includes signals exactly at the starting and ending points

(11) Median Width: Average median width along the segment by feet

(12) Median Type: Choice of traversal, non-traversal, or continuous left-turning lane (also known as two-way left-turning lane (TWLTL))

(13) Land Use: Choice of residential, business, or industrial. The land use type was determined by observing the dominant type of facilities along the segment.

(14) Density: Level of roadside development, choice of high, mid, or low. For example, where frequent residences or businesses were observed was assigned as high-density area, and where less number of those facilities was observed was assigned as low-density area. Mid-density areas were the intermediate density between high and low density.

(15) Left/Right Direction: Based on the orientation of the road, mostly eastbound and northbound had left-hand direction and westbound and southbound had right-hand direction.

(16) Data Collector ID: Sensor product ID

(17) Number of Lanes: Number of directional lanes

(18) Average Lane Width: Length between right and left solid lines in feet, divided by number of lanes. The width does not include the auxiliary turning lanes.

(19) Number of Exclusive Turning Lanes (left/right): Total number of left turning bays connected to median openings, and right turning bays connected to intersecting roads and driveways, located within the study section

(20) Roadside Clearance: Existence of a raised curb immediately next to roadway

(21) Pedestrians and Cyclists: Density of pedestrians or cyclists, choice of high, low or none

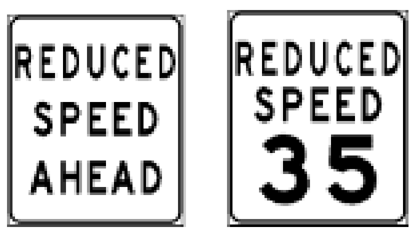
(22) Parking: Existence of roadside parking, choice of yes or no

(23) Posted Speed: Numerical value of the posted speed limit

(24) Number of Traffic Signs and SL signs: Number of traffic signs and number of speed-related signs counted separately. The speed-related signs include (a) speed limit signs, (b) advisory speed limit signs, (c) speed zone ahead signs, (d) reduced speed signs, and (e) other speed regulating signs as illustrated in Figure 4.2.

(25) Number of Minor Street: Number of minor streets intersecting in right-hand side excluding those at signalized intersections

(a) Speed Limit Sign (b) Advisory Speed Limit Sign



(c) Speed Zone Ahead Sign (d) Reduced Speed Sign

(e) Other Speed-regulating Signs

FIGURE 4.2: Speed-related Signs

(26) Number of Driveways: Number of driveways in right-hand side regardless of the amount of in/out-traffic

(27) Number of Median Openings (full/directional): Number of median openings accessible for both direction (full opening), and access allowed only for one direction (directional opening) as shown in Figure 4.3.

(28) Pavement Type: Choice of flexible or rigid pavement

(29) Pavement Condition: Choice of dry or wet

(30) Pavement Roughness and Cracks: Choice of good, fair, or poor

(31) Enforcement: Any notable enforcement activity

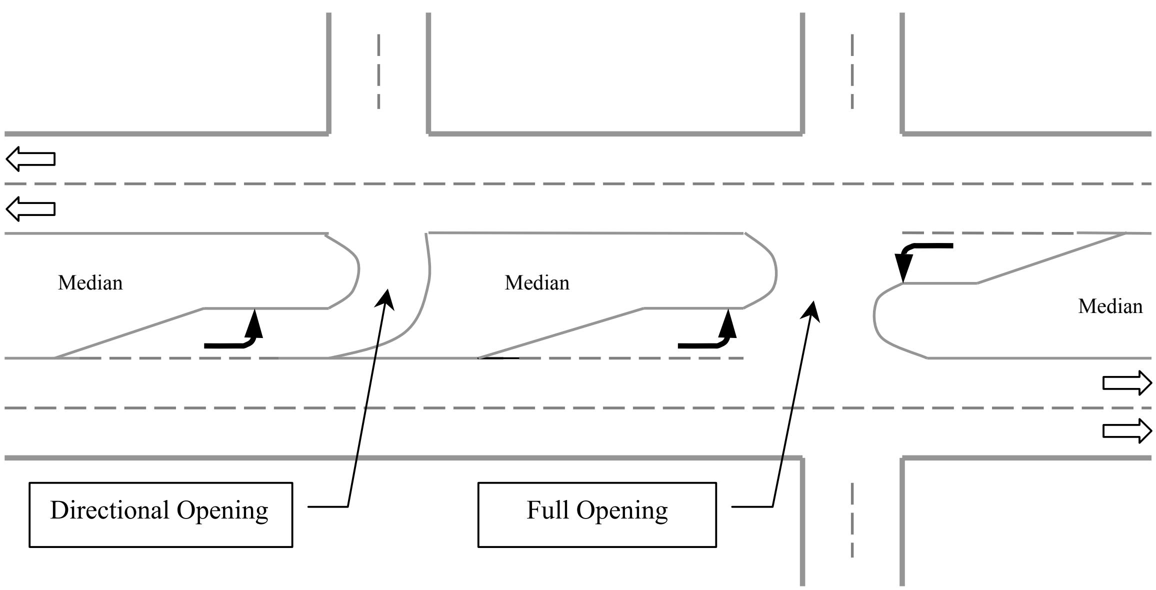
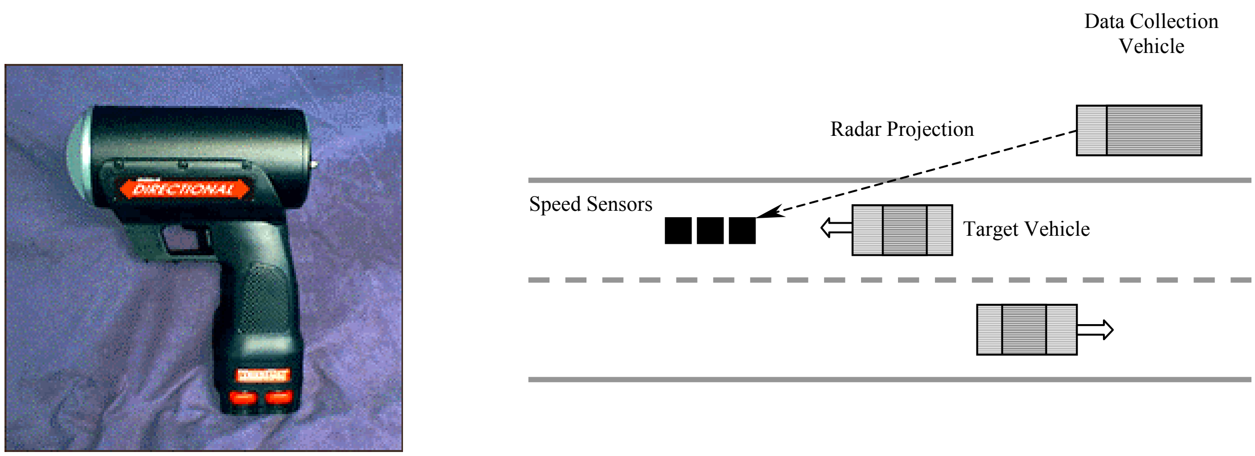


FIGURE 4.3: Directional Median Opening and Full Median Opening

4.3.2. Speed and Traffic Data Collection

During the field observation planning phase, a number of speed measuring devices were researched to select an appropriate product for this study. Those included speed measuring detectors using such technologies as air switch (tube), infrared, microwave, ultrasonic, radar, laser, video image, and magnetic field. In selecting a detector, studies on the non-intrusive and non-destructive traffic detectors [26] were also referenced to identify the merits of each type of detectors. After a thorough evaluation, the magnetic speed-measuring sensors from Nu-metrics, Inc (Hi-star, NC-97) was chosen due to its advantageous functions in installation, removal and mobility.



(a) Speed-Measuring Radar Device (b) Collecting Calibration Data

FIGURE 4.4: Calibration of Speed Sensors

4.3.2.1. Device Calibration

Prior to measuring the speed data for the model development, we needed to ensure the magnetic sensors had reliable accuracy to obtain dependable information. Hence, a hand-held radar speed-measuring device (GVP-D, Decatur Electronics) was used to examine the accuracy of the sensors. As the radar gun (Figure 4.4 (a)) used in this study was certified for its accuracy by the Florida Department of Highway Safety and Motor Vehicles, the sensors' speeds were adjusted on the basis of the radar gun's speeds. The sites to collect calibration data were chosen based on relatively low traffic volume area, stable vehicles speeds, and directional one-lane roadway. A total of four sites with different speed ranges were selected to obtain evenly distributed speeds. Vehicle speeds were measured simultaneously by the sensors and radar gun, illustrated in Figure 4.4 (b). The radar gun was hidden in the data collection vehicle to prevent target vehicles from decelerating, triggering on the target vehicles at the moment that they passed over the speed sensors.

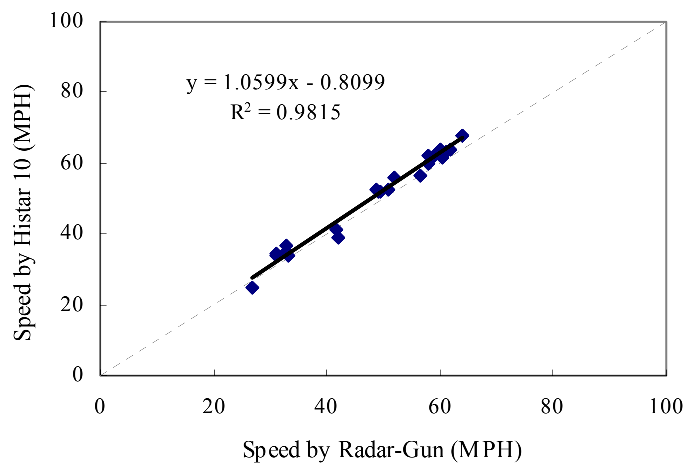


FIGURE 4.5: An Example of Sensor Calibration

Figure 4-1 is a plot of the 85th percentile speed in 15-minute intervals measured from the radar gun (X-axis) and a sensor (Y-axis). A fitted line was drawn on the plot and used to adjust the sensor's 85th percentile speeds. After examination of various calibration models, it was found that the linear line was sufficient for this purpose. For the particular sensor exampled in Figure 4.5, the 85th percentile speeds were adjusted as follows:

$$V = 0.8099 + (V_{raw} / 1.0599) \qquad \text{(Eq. 4.3)}$$

where,

V : 85th percentile speed calibrated, and

V_{raw}: 85th percentile speed from the sensor.

The same procedure was applied to the other sensors and corresponding calibration equations were obtained. Although the speeds were adjusted based on the radar gun speeds, the equations demonstrated that most sensors had quite reasonable ranges of error. This was indicated by the fact that the points distributed near a 45-degree line as shown in Figure 4.5. The series of those equations were later used to adjust the field collected data.

(a) Programming a Sensor

(b) Installing the Sensor on Pavement

(c) Sensor under Protective Cover

(d) Road Cleared

FIGURE 4.6: Sensor Installation

4.3.2.2. Speed Measurement

This section describes the method used to obtain the 85th percentile speed for the selected study roadways. In choosing a right location to install a sensor within a roadway segment, the major concern was to find a point where the vehicle speeds were representative over the segment. The representative speed was first defined as the highest speed approximately in the middle of a segment. Accordingly, appropriate points were selected in the field depending on the roadway geometry and roadside condition, generally at a reasonable distance from accesses or median openings and at the mid-point of two traffic signals. That was to prevent speed data from having any immediate influences by such features. In addition, it was necessary to select a representative lane because a sensor can only collect data on a single lane. Mostly sensors were installed on the faster lane. Speeds were measured over 2 days (more than 48 hours) at each site. Figure 4.6 shows the sensor installation procedure in the field.

4.3.2.3. Data Retrieval

The raw speed data were classified and saved in 5 MPH interval bins for every 15-minute. There were vehicle length classification bins corresponding to time intervals, as well. Vehicle lengths were used to deduce vehicle composition using the schema shown in Table 4.4. The overall structure of raw data is presented in Table 4.5.

TABLE 4.4: Vehicle Classification Schema

Vehicle Length (ft)	Vehicle Classification
0 - 21	Passenger Cars
22 - 28	Small Trucks
29 - 40	Trucks/Buses
> 40	Trailer Trucks

TABLE 4.5: Raw Data Structure

Time	Vehicle Length (FT)	Speed Range (MPH)							
		0-14	15-19	20-24	25-29	…	70-74	75-79	79<
Jan 01, 0:00 AM	0 - 20					…			
	21 - 27					…			
	28 - 39					…			
	40 >					…			
Jan 01, 0:15 AM	0 - 20					…			
	21 - 27					…			
	28 - 39					…			
	40 >					…			
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Jan 03, 0:00AM	0 - 20					…			
	21 - 27					…			
	28 - 39					…			
	40 >					…			

The MS-Excel spreadsheet was used to retrieve the 85th percentile speeds, mean speed, speed variance, vehicle composition, and average time headway in every 15-minute period. The 85th percentile speeds could be obtained by cumulating and interpolating the speed distributions. The mean and variance of the classified speeds were calculated by:

$$Mean\ speed\ (mile/hour) = \sum(x_i \times f_i)/n \qquad \text{(Eq. 4.4)}$$

$$Speed\ variance\ (mile^2/hour^2) = [\sum(x_i^2 \times f_i) - (\sum(x_i \times f_i))^2/n]/(n-1) \qquad \text{(Eq. 4.5)}$$

where

x_i : the midpoint,

f_i : the frequency of class i, and

n : number of speed class

Vehicle composition was expressed as the percentage of each class, and the average time headway was computed using Equation 4.6, in which (15 × 60) is the number of seconds in 15 minutes.

$$\textit{Avg. time headway (sec/veh)} = (15 \times 60)/(\textit{Number of vehicles in 15 min.}) \quad \text{(Eq. 4.6)}$$

4.4. Data Reduction

4.4.1. Free-flow Speed

In accordance with the guidance of TRB Special Report 254 [2], as well as the Florida Statues on speed zoning, the 85^{th} percentile speed, which is the primary basis to set speed limits, should be measured under free-flow condition. A number of studies defined the free-flow speed as similar to that of an average headway of more than 5 seconds. A speed study on suburban areas defined free flowing if headway was greater than 5 seconds and tailway is greater than 3 seconds [22]. This study defined average time headway equal or greater than 8 seconds as the free-flow speed. Relatively longer headway was utilized because the study scope is merely on urban and suburban arterial routes where vehicle platooning is common as a result of frequent traffic signals and accesses. Thus, the 15-minute time slots that had average time headway of more than 8 seconds data were compiled.

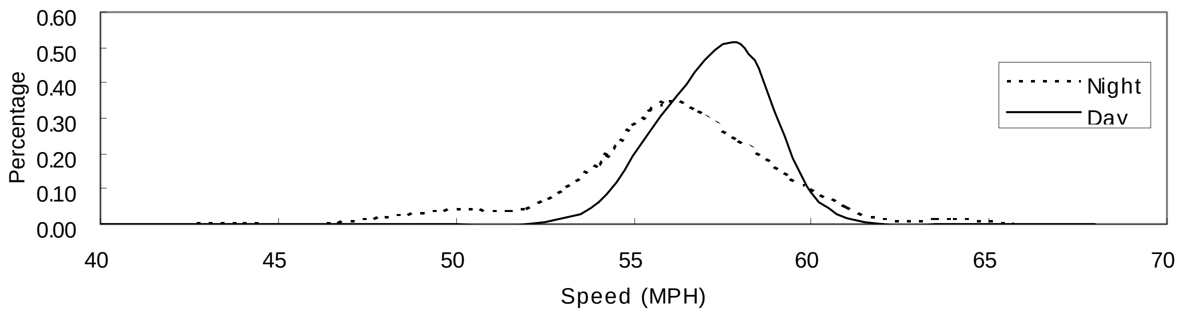
4.4.2. Nighttime Speed

It is probable that vehicle speeds in nighttimes differ from the speeds in daytimes. To verify this, three locations were selected with respect to the level of road illumination during night. Afterward, mean speeds under free-flow condition (average headway of greater than 8 seconds) were compared between daytimes and nighttimes. Figure 4.7 plots the mean speeds at roadways with relatively (a) dim, (b) intermediate, and (c) strong illumination. It was evident from the graphs that the daytime speeds were more centered (higher peak) than nighttime speed distribution in every location examined. The comparison between those sites confirmed obvious vehicular speed differences between nighttime and daytime, depending on the level of illumination. Hence, this study considered only daytime data between 6 AM and 6 PM. However, those three roadways studied were arbitrary and subjectively chosen; more investigation would be needed to affirm the relationship between speeds and road illumination.

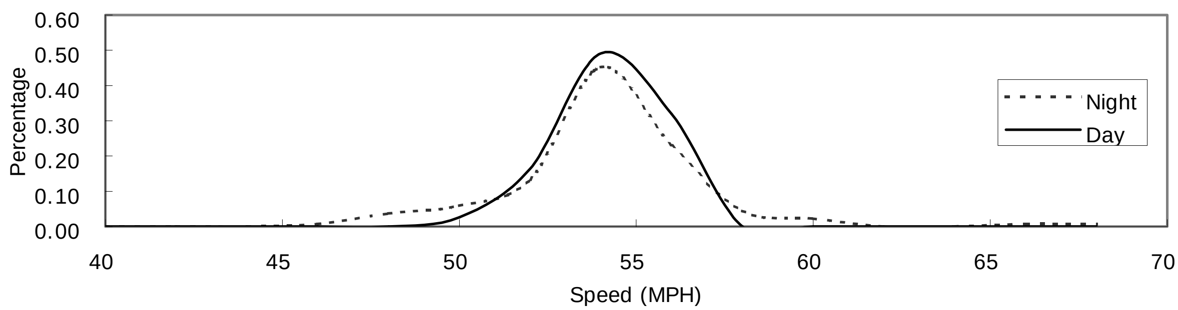
4.4.3. Data of Roadway as a Whole

Some intervals were also discarded in cases that had incomplete or missing speed data. In addition, a few study sites that did not have any free-flowing time interval during daytime were also not considered. Finally, 93 directional sites out of 104 sites, which have 7875 of 15-minute intervals, were compiled for further analyses and model development.

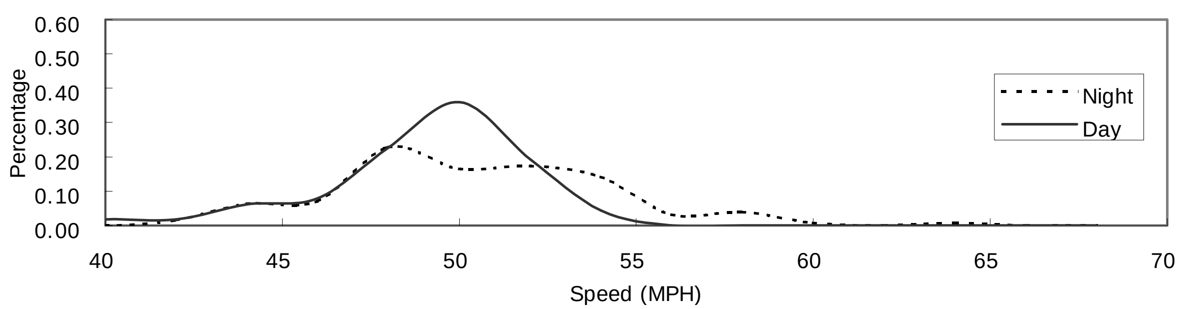
However, the proceeding data retrievals were to obtain parameters, such as 85th percentile speeds, vehicle composition, and average time headway, for each 15 minute-time interval. It was necessary to consider those parameters that represent a roadway as a whole. After the interval data were reduced based on free-flow condition and daytime speed, 15-minute time interval data were collapsed to obtain the parameters that represent a roadway as a whole. The parameters obtained for each roadway included 85th percentile speed, percentage of heavy vehicles, and variance in speed distribution.



(a) Under Dim Illumination (SR 45 at 0.5 mile-point)



(b) Under Intermediate Illumination (SR 580 at 0.6 mile-point)



(c) Under Strong Illumination (SR 679 at 6.0 mile-point)

FIGURE 4.7: Free Flow Speeds under Different Road Illumination Levels

CHAPTER 5: ANALYSES AND RESULTS

5.1. Assessment of Existing Speed Limits

Current performance of speed limits on multi-lane nonlimited-access arterial roads in urban and suburban areas in Florida was tested by comparing exiting speed limits and 85th percentile speeds in Figure 5.1. It shows that the 85th percentile speeds exceed the posted speed limits in most sites, at the level of 5 to 10 MPH above the posted speeds.

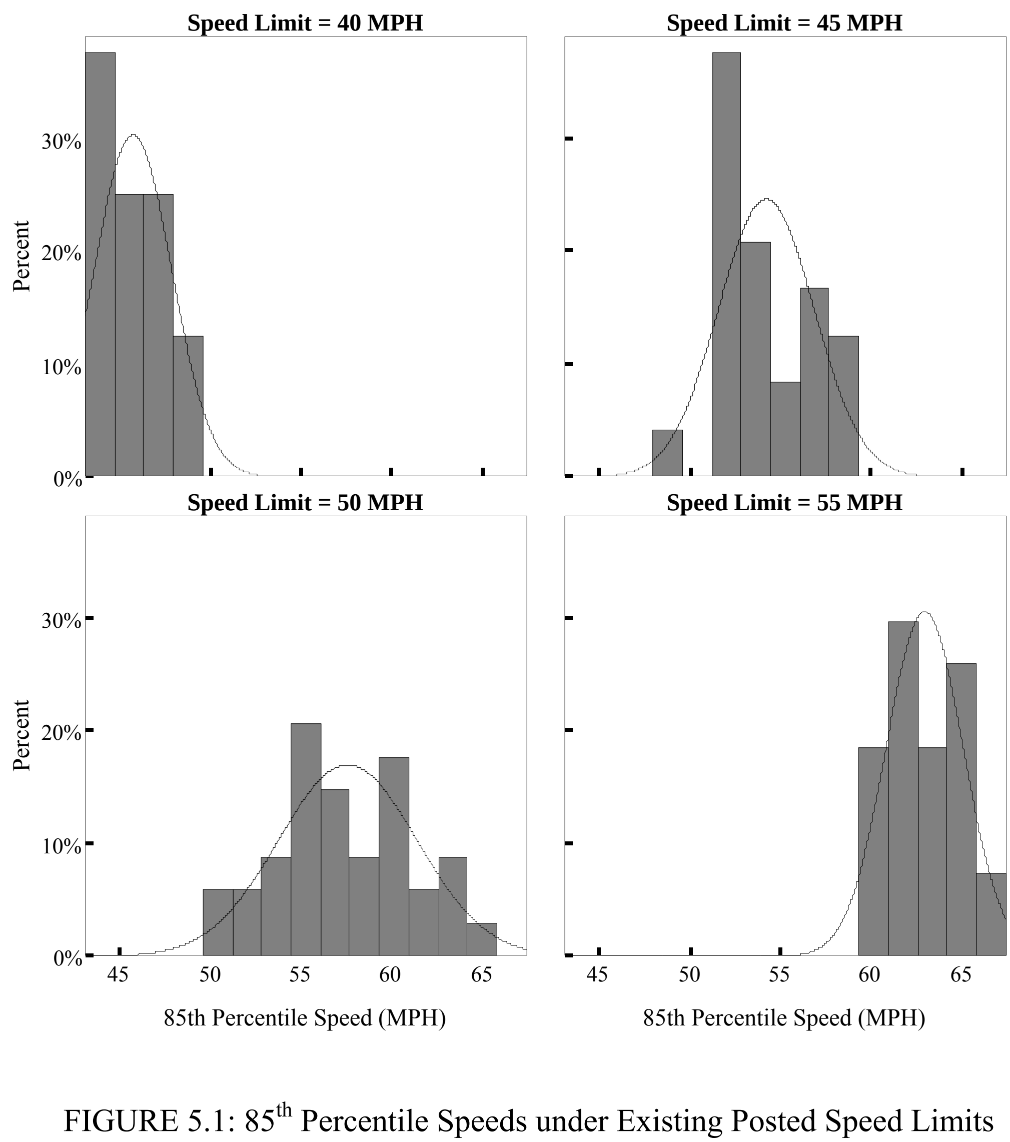


FIGURE 5.1: 85th Percentile Speeds under Existing Posted Speed Limits

Those differences may be caused due to one or more of following; (a) local differences were ignored (existing speed limits posted were merely set by the statutory maximum speed limit or the design speed, both of which cover a wide area), (b) speed limits were set by the 85th percentile speeds and were adjusted after taking other constraints such as crash rate, access density, and land use into consideration, or (c) speed limits by speed zoning investigation were higher than the maximum statutory speed.

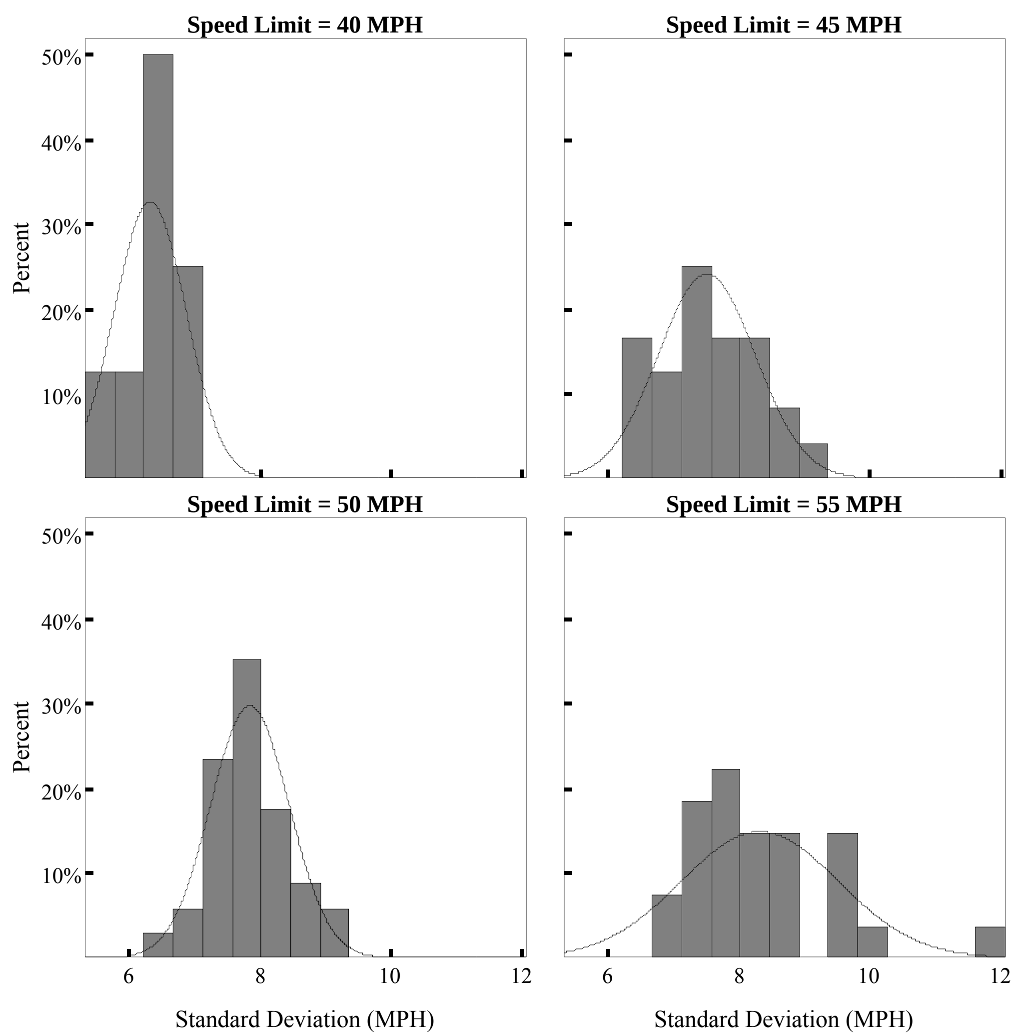
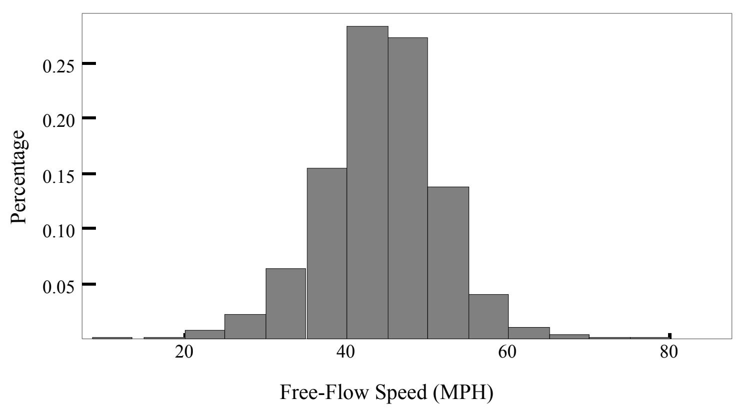


FIGURE 5.2: Speed Variances under Existing Posted Speed Limits

Additionally, speed dispersion in the traffic stream was examined on each category of speed limits, shown in Figure 5.2. The test parameter is the standard deviation in speed distribution. The graphs show that the higher speed limit incorporates with greater speed variance in traffic. This could be explained by the fact that there are always mixtures of those vehicles that travel fast and those that travel slowly in nonlimited-access arterials in urban areas. Thus, this study found that when the speed limit is higher, the speed variance increases in such type of roadways.

5.2. Discriminant Analysis

The compiled sample (the one described in previous chapter) needed to be further reduced to meet the conditions described in chapter 3; that are less crashes experienced, uniform traffic flow, and drivers' compliance to speed limit. The crash rate was already considered in site selection process. This section describes how to apply the other two conditions to sampling such that the sample satisfies the conditions assumed.



- Mean speed: 45.6 MPH
- 85th Percentile Speed: 52.9 MPH
- Posted Speed: 50 MPH
- Standard Deviation: 7.4 MPH
- Deviation (85th percentile speed – posted speed): 2.9 MPH

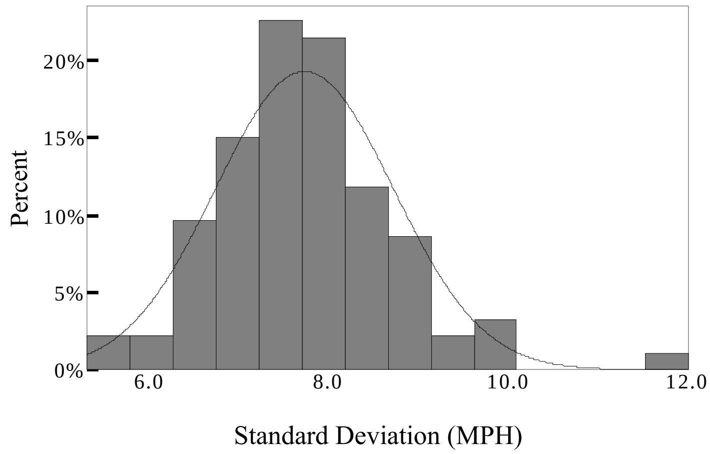
FIGURE 5.3: An Example of Free-Flow Speed Distribution

The level of uniformity of traffic flow was expressed as the standard deviation in the vehicle speed distribution. Figure 5.3 illustrates an example of daytime speed distribution under free-flow condition (headway ≥ 8 seconds). The speeds were measured on SR 60 westbound at 1,150 feet from the point that the roadway starts. This study found that most free-flow speeds are normally distributed.

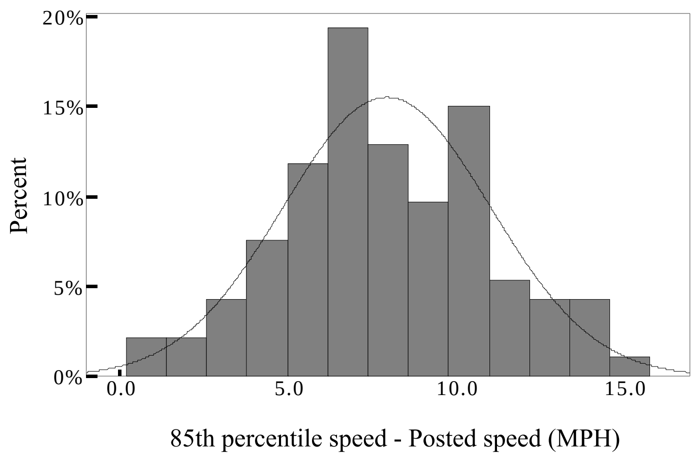
This study performed the discriminant analysis, which is a multivariate technique to find discriminants whose numerical values are such that the observations are separated as much as possible. The purpose of the discriminant function was to validate if traffic uniformity (standard deviation) and/or speed limit compliance (deviation of 85th percentile speed from posted speed) is a discriminant factor of the sample. In other words, it was to find distance between two groups separated by (a) traffic uniformity, (b) compliance to speed limit, and (c) combination of both. The breakpoints of separation were the mean values, which were 7.8 MPH for the standard deviation and 8.0 MPH for the deviation between 85th percentile speed and posted speed (Figure 5.4). Sum of fractional rank of (a) and (b) was used for the test (c) with a breakpoint of 1.0. The measure of effectiveness was Wilky's lambda. Wilky's lambda has a range between 1.0 and 0.0, with values close to 0.0 indicating a function providing the best separation between groups [24].

TABLE 5.1: Discriminant Analysis Results

Condition	Grouping Variable	Range of the Variable	Breakpoint	Wilky's Lambda
(a) Uniform Traffic Flow	Standard Deviation (MPH)	5.32 ~ 12.5 MPH	7.8 MPH	0.811
(b) Compliance to Speed Limit	(85th percentile Speed) - (Posted Speed) (MPH)	0.73 ~ 15.43 MPH	8.0 MPH	0.809
(c) Combined	(Fractional Rank of Standard Deviation) + (Fractional Rank of 85th percentile speed minus Posted speed)	0.00 ~ 2.00	1.00	0.813



(a) Traffic Flow Uniformity



(b) Speed Limit Compliance

FIGURE 5.4: Distributions of the Parameters-related to Vehicle Speed

Table 5.1 provides Wilky's lambda computed by the SPSS software. It is found that the compliance to speed limit has the best discriminant-ability (the lowest Wilky's lambda), whereas the speed variance has the highest value. It could be explainable in either way such that; (a) standard deviation is a safety factor that is comparable among study sites that share similar roadway configuration and environment (e.g., speed limit, roadway geometric condition, etc), or (b) the standard deviation may not be a reliable indicator for the level of traffic uniformity. Intuitively, drivers' compliance to speed limits would be a more straightforward factor to justify whether or not a speed limit is appropriate. Accordingly, two conditions (crash rate and drivers' compliance to speed limits) were used in this study to compile a sample to be used for modeling. This study defined the appropriate speed limit as when the 85th percentile speed is not more than 8 MPH above the posted speed, referred by the mean of speed differences between 85th percentile speed and posted speed. The number of sites under the two conditions considered was 51 out of 93 sites in the sample. From these sites, randomly selected 47 sites were used as a modeling sample and the four remaining independent sites were used for the model validation.

5.3. Variable Treatment

The purpose of the variable treatment was to control the information intensity, which was to obtain more proper determinants for the speed limit model. For instance, the sample includes variables for the number of driveways and the number of minor streets. Driveways were considered as the roadways that provide access to roadside developments. Minor streets were usually collectors or local roads that are intersecting the major roads (study roads) without traffic signal. In some cases, it was difficult in the field to distinguish driveways from minor streets in terms of their function and magnitude of influence to the traffic; thus, those two types of features were tested either separately or altogether. The original variables were assigned as the first aggregation level variables, and the combined variables are assigned as the second aggregation level variables.

Likewise, the same treatment was applied on other variables including the number of turning bays per mile in left or right sides, the number of median openings that could be fully opened or directionally opened, and the number of speed-related and other signs. The number of median openings, driveways and minor streets were further grouped together, taking into consideration the similar function (providing access) and influence (interruption to the through traffic) of those features to the through traffic. That variable was assigned as

TABLE 5.2: List of Variables and Ranges

<table>
<tr><th rowspan="2">Variables (1st Level)</th><th rowspan="2">Range</th><th colspan="3">Variable Aggregation</th></tr>
<tr><th>2nd Level</th><th>3rd Level</th><th>4th Level</th></tr>
<tr><td>Posted Speed Limit
(Independent Variable)</td><td colspan="4">40 mph (12.8 %), 45 mph (19.1%), 50 mph (40.4 %), 55 mph (27.7%)</td></tr>
<tr><td>Functional Classification</td><td colspan="4">1 (Major Arterial, 61.7 %), 0 (Minor Arterial, 38.3 %)</td></tr>
<tr><td>Land use</td><td colspan="4">1 (Residential, 44.7 %), 2 (Commercial, 51.1%), 3 (Industrial, 4.3 %)</td></tr>
<tr><td>Roadside Development</td><td colspan="4">1 (High, 40.4 %), 2 (Mid, 40.4 %), 3 (Low, 19.1 %)</td></tr>
<tr><td>Median Type</td><td colspan="4">1 (Divided, 87.2 %), 0 (TWLTL, 12.8 %)</td></tr>
<tr><td>Median Width</td><td colspan="4">12 ~ 85 (ft)</td></tr>
<tr><td>Number of Lanes</td><td colspan="4">2-lanes (72.3 %), 3-lanes (27.7 %)</td></tr>
<tr><td>Lane Width</td><td colspan="4">10.5 ~ 12.5 (ft)</td></tr>
<tr><td>Lateral Clearance
(Curb Presence)</td><td colspan="4">1 (With Curb, 46.3 %), 0 (Without Curb, 53.2 %)</td></tr>
<tr><td>Number of Signalized Intersection per mile</td><td colspan="3">0.0 ~ 6.9</td><td rowspan="9">Number of All Inter-irruptions per mile</td></tr>
<tr><td>Number of Left Turning Bays per mile</td><td>1.21 ~ 66.51</td><td colspan="2" rowspan="2">Number of All Turning Bays per mile</td></tr>
<tr><td>Number of Right Turning Bays per mile</td><td>0.00 ~ 8.45</td></tr>
<tr><td>Number of Speed Limit Signs per mile</td><td>0.00 ~ 6.24</td><td colspan="2" rowspan="2">Number of All Signs per mile</td></tr>
<tr><td>Number of the Other Traffic Signs per mile</td><td>0.00 ~ 16.06</td></tr>
<tr><td>Number of Street intersecting per mile</td><td>0.00 ~ 16.19</td><td rowspan="2">Number of Accesses per mile</td><td rowspan="4">Number of Accesses in Both Sides per mile</td></tr>
<tr><td>Number of Driveways per mile</td><td>0.00 ~ 43.58</td></tr>
<tr><td>Number of Full median Openings per mile</td><td>0.00 ~ 18.22</td><td rowspan="2">Number of All Median Openings per mile</td></tr>
<tr><td>Number of Directional Median Opening per mile</td><td>0.00 ~ 66.51</td></tr>
<tr><td>Pavement Type</td><td colspan="4">1 (Flexible, 94.1%), 0 (Rigid, 5.9%)</td></tr>
<tr><td>Pavement Condition</td><td colspan="4">1 (Good, 49.0%), 2 (Fair, 37.3%), 3 (Poor, 13.7%)</td></tr>
<tr><td>Accident Rate</td><td colspan="4">0.00 ~ 0.24</td></tr>
<tr><td>Pedestrian</td><td colspan="4">1 (high, 0.0%), 2 (low, 9.8%), 3 (None, 90.2%)</td></tr>
<tr><td>Percentage of Heavy Vehicles
(Length Longer than 28 ft)</td><td colspan="4">0.5 ~ 15 (%)</td></tr>
<tr><td>85th Percentile Speed</td><td colspan="4">43.09 ~ 62.45 (mph)</td></tr>
</table>

the third aggregation level variable. The last integration, the forth aggregation level, was grouping all possible interruptions against the through traffic movement into one variable, which included the number of driveways, minor streets, all types of median openings, all types of traffic signs, and all types of signals. The hierarchy of the variables assigned from the first to forth aggregation is expressed in Table 5.2. The table also provides the variable ranges and composition of data entities.

Other variable treatments include rounding data values, which was applied to lane width and median width, or changing continuous values into categorical form, which was applied to percentage of heavy vehicles and lane width. Additionally, a few outliers in some variables were truncated at reasonable levels (e.g., percentage of heavy vehicles). The purpose of the variable treatments was to obtain more useful variables: less correlationship between variables and more predictability.

5.4. Correlation Analysis

The goal of this analysis was to eliminate redundancy and possible misbehavior in model development by observing the level of correlationship between variables. Correlation coefficient was the test parameter to examine the tendency of a pair of variables moving together. The correlation coefficient ranges between –1.0 and 1.0 and a negative sign implies moving in the opposite direction, while a value of zero means no correlation between two variables.

In the first aggregation level, the analysis showed that there were relatively strong correlationships between the number of directional median openings, the number of full median openings, and the number of left-turning bays. In the second aggregation level, the number of all types of median openings was correlated with number of all turning bays. In the third aggregation level, the number of access points in both sides (median openings, driveways and minor streets) was correlated with number of left/right turning bays and roadside development. Lastly, in the forth aggregation level, the correlation existed between the number of all interruptions and median type. Therein, this study considered a pair of variables with a correlation coefficient of more than 0.5 or less than –0.5 have relatively strong correlationship. Details on the correlation analysis results in each aggregation level are presented in Appendix B.

5.5. Examination of Variables

The purpose of this analysis was to test each variable's ability to explain the operating speed (85th percentile speed). To do so, each variable was regressed against 85th percentile speed. The p-value with 0.05 of significant level was used to determine whether a variable could be a determinant in speed limit model. The curve estimation function with SPSS generated ten different forms of models including linear, logarithmic, inverse, quadratic, cubic, power, compound, S-curve, growth, and exponential curves. Table 5.3 presents the specification of models, in which the 85th percentile speed substitutes Y and each variable substitutes X. The b_0, b_1, b_2, and b_3 are the parameters to be estimated.

TABLE 5.3: Model Specifications in the Curve Estimation

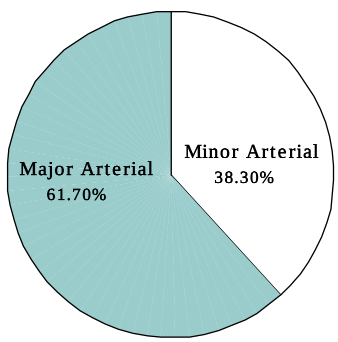
Models		Model Equations
Binary Linear Equation		$Y = b_0 + (b_1 \times X)$
Non-linear Equations	Logarithmic	$Y = b_0 + (b_1 \times Ln\ X)$
	Inverse	$Y = b_0 / X$
	Quadratic	$Y = b_0 + (b_1 \times X) + (b_2 \times X^2)$
	Cubic	$Y = b_0 + (b_1 \times X) + (b_2 \times X^2) + (b_3 \times X^3)$
	Power	$Y = b_0 + X^{b_1}$
	Compound	$Y = b_0 \times b_1^X$
	S-curve	$Y = EXP(b_0 \times b_1 / X)$
	Growth	$Y = EXP[b_0 + (b_1 \times X)]$
	Exponential	$Y = b_0 \times EXP(b_1 \times X)$

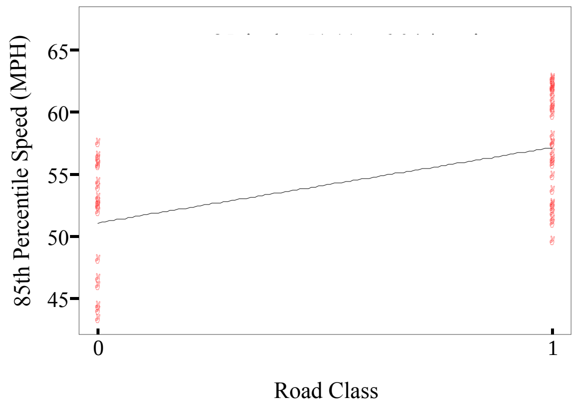
Some variables had better fits (higher R-square) with non-linear models rather than the linear model. Those variables were further tested to examine the validity of using a non-linear model in designing the adjustment factor module. The tests of non-linear curves are explained in following subchapters. This study employed only the linear model in this process due to its simplicity and clarity. By using the linear form, we could obtain the sensitivity (α_i) and intercept (β_i), the slope and constant of the linear equation as described in Chapter 3.3. The following subsections present the results of the curve estimation analyses.

5.5.1. Road Functional Class

The functional classification assigned to roadways is based on the characteristics of service they provide in relation to the total road network. FDOT uses the Federal Functional Classification System [25]. In urban areas, roads are classified as (a) principal arterial - interstate, (b) principal arterial-other freeways and expressways, (c) principal arterial-other (with no access control), (d) minor arterial, (e) collector, and (f) local. This study focuses on principal arterial-other (termed as major arterial in this report) and minor arterial with regard to the study scope. The identification of the split between the principal arterial-other and the minor arterial is based on such factors as service to urban activity centers, system continuity, land use considerations, spacing between routes, average trip length, traffic volume, control of access, and vehicle-miles of travel and mileage [26].

The variable was coded as 1 for the major arterials and 0 for the minor arterials. For the binary choice variables, it was not necessary to investigate the non-linear models as shown in Figure 5.5 (b). The vertical dispersion of data-points in each category could be explained by the other variables that also influence the 85^{th} percentile speed. The graph shows that major arterials in the sample generally have higher 85^{th} percentile speed than minor arterials. Also the estimation indicated that the road class was a significant determinant of the 85^{th} percentile speed (Table 5.4).





(a) Composition (b) Distribution

FIGURE 5.5: Road Class Composition and Distribution

TABLE 5.4: Linear Model for Road Functional Class

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Road Class*	Linear	0.318	45	21.01	0.000	51.1050	6.0416

* 1 if major arterial, 0 otherwise (minor arterial)

5.5.2. Level of Roadside Development

The level of roadside development is somewhat subjective variable because it was determined by visual observations. It is a categorical variable (ordinal) that has three categories: high density, mid density, and low density. The level of the development was determined based on the number of houses, businesses, and other facilities related to human activities. For example, where frequent residences or businesses were observed was assigned as high-density area, and less number of those facilities was observed was assigned as low-density area. The mid-density areas were the intermediate between the high density and the low density. Figure 5.6 presents the composition of roadside development levels.

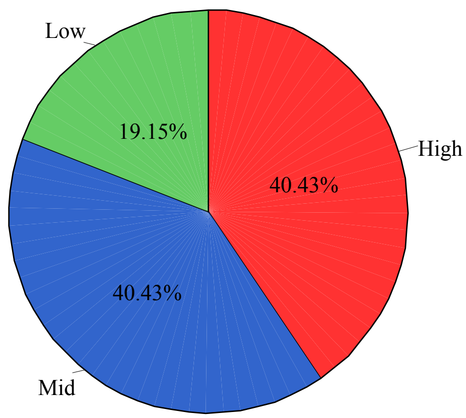


FIGURE 5.6: Composition of the Level of Roadside Development

The higher density was coded as 1, middle density as 2, and lower density as 3 for the analysis purpose. The result showed that the higher roadside developments incorporate with the lower 85^{th} percentile speeds. It is reasonable that drivers would pay more attention and maintain lower speeds to process more roadside information. Also the variable was statistically significant at the level of 0.05 as indicated in Table 5.5. However, the previous analysis indicated that there was a significant correlationship between roadside development and access density. This relationship should be considered in modeling process. The non-linear models were not investigated, as they did not suggest better fit (not considerably higher R-square than linear model).

TABLE 5.5: Linear Model for Level of Roadside Development

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Road Class	Linear	0.166	45	8.95	0.004	49.7245	2.8582

5.5.3. Land Use

Land use is a categorical variable that has residential, commercial, and industrial area as the entity (Figure 5.7). It is also a nominal variable. Thus, dummy variables were made for each category having values as 1 for 'yes' and 0 for 'no'. Each residential and commercial area has lower 85th percentile speeds and industrial areas have higher 85th percentile speeds than the other types of areas.

TABLE 5.6: Linear Models for Land Use

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Residential	Linear	0.000	45	1.8E-03	0.966	54.8623	-.0661
Commercial	Linear	0.011	45	0.51	0.481	55.3935	-1.0981
Industrial	Linear	0.077	45	3.73	0.060	54.5291	7.1359

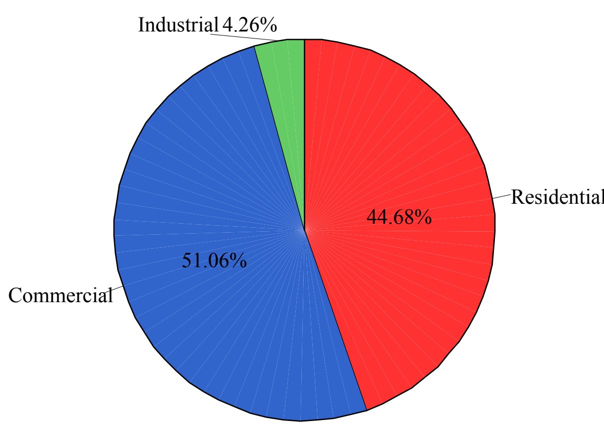


FIGURE 5.7: Composition of Land Use

When comparing residential areas and commercial areas by using slopes, the commercial areas are more sensitive than the residential areas. However, land use was found to be an insignificant determinant of the 85th percentile speed due to their higher p-values (Table 5.6).

5.5.4. Median Type

In the field observation, there were found only two types of median that were the divided median (non-traversal) and the continuous left-turning lane (also known as TWLTL, two-way left-turning lane). Traversal medians may exist but none was selected in the site selection process. Approximately 87 percent of the observed sites have the divided medians and 13 percent have the TWLTL. Some divided median have a curb, while some do not.

The variable of median type was coded as 1 for the divided median and 0 for the continuous left-turning lane. The high p-value indicates that median type is not significant factor in determining the 85th percentile speeds (Table 5.7).

TABLE 5.7: Linear Model for Median Type

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Median Type*	Linear	0.000	45	0.00012	0.991	54.8550	-0.255

* 1 if divided median, 0 otherwise (TWLTL)

5.5.5. Median Width

The median width is a continuous variable. For the roadways with the continuous left-turning lanes, the median width was assumed to be 13 feet. This variable has the highest goodness-of-fit with the cubic model (R-square of 0.246). The linear model is not a significant determinant of the 85th percentile speeds (p-value more than 0.05) as seen in Table 5.8.

From the results, quadratic and cubic models were chosen by their relatively high R-squares to test the validity of non-linear forms of adjustment factor module. The non-linear models were graphically illustrated in Figure 5.8, taking the actual range of median width (from 12 to 85 ft) and the predicted 85th percentile speed from the two non-linear models. The quadratic model may be acceptable, provided that the 85th percentile speed increases relatively continuously as the median width increases. However, the cubic model may not be applicable because it has an obvious peak at the median width of 50 feet. Conclusively, it would be valuable to examine a quadratic model in designing the adjust factor module for the median width.

TABLE 5.8: All Models for Median Width

Model*	R-square	DF	F-value	Sig.	b_0	B_1	b_2	b_3
Linear	0.078	45	3.81	0.057	52.4634	0.0888	-	-
Logarithmic	0.149	45	7.87	0.007	42.7375	3.8561	-	-
Inverse	0.183	45	10.07	0.003	59.7658	-100.61	-	-
Quadratic	0.221	44	6.26	0.004	46.7198	0.4708	-0.005	-
Cubic	0.246	43	4.68	0.006	38.3749	1.3441	-0.029	0.0002
Power	0.084	45	4.13	0.048	52.1116	1.0017	-	-
Compound	0.155	45	8.27	0.006	43.2709	0.074	-	-
S-curve	0.188	45	10.39	0.002	4.0935	-1.9154	-	-
Growth	0.084	45	4.13	0.048	3.9534	0.0017	-	-
Exponential	0.084	45	4.13	0.048	52.1116	0.0017	-	-

* Dependant Variable: 85th Percentile speed

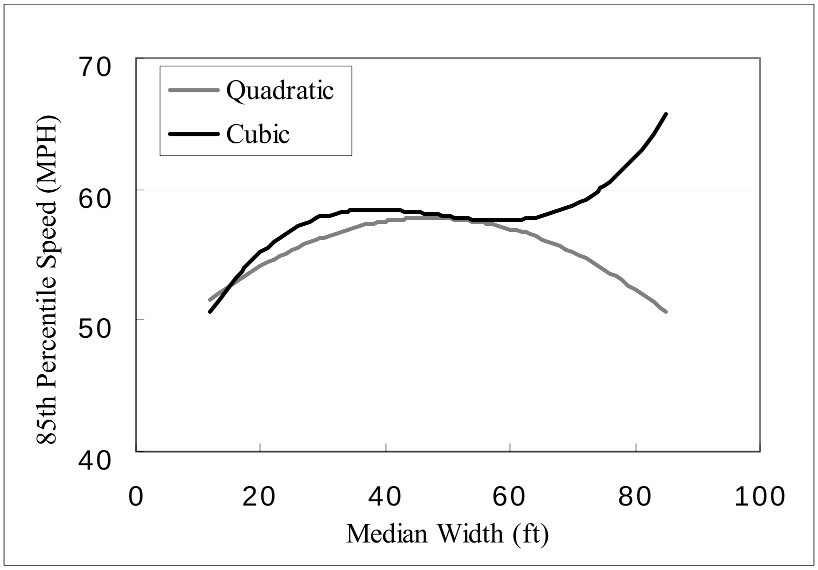


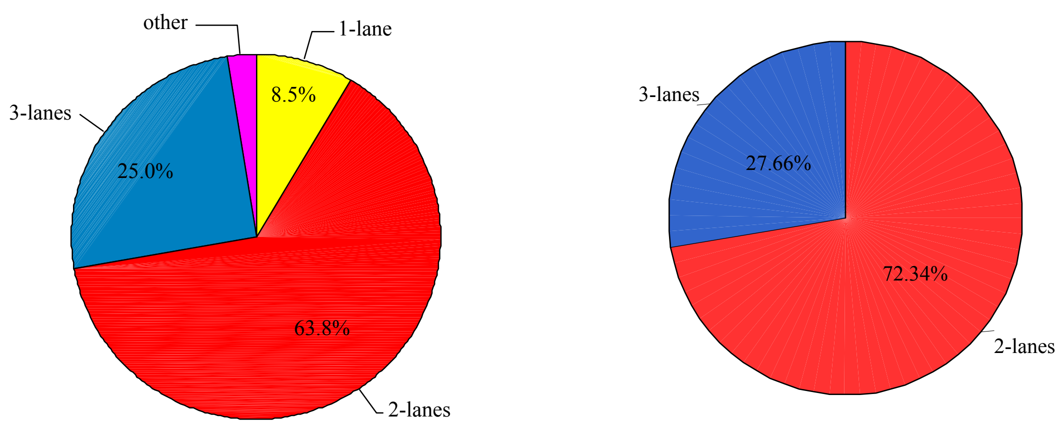
FIGURE 5.8: Non-linear Models for Median Width

5.5.6. Number of Lanes

Arterial roads in Florida can have directional three-lanes at maximum. Nearly 2.6 percent of roadways have more than 3 lanes up to 6 lanes, according to the database provided by FDOT. This may be because there are some sections of roadways that have lengthy continuous right or left turning lanes, and which were considered as the through-lanes. The composition of the number of lanes (directional) in Florida State Road (SR) is presented in Figure 5.9 (a). Approximately two-third are 2-lanes, slightly less than one-third are 3-lanes, and there is a small portion of 1-lane roads in each direction. However, the directional 1-lane roadways may have unique traffic characteristics compared to the multi-lane roadways. The major reason is that vehicles cannot pass slow moving vehicles, resulting in the following vehicles' speeds often being controlled by the leading vehicle's speed. This situation brings frequent vehicle platooning. This study focused on only roadways with 2 and 3-lanes in each direction; therefore, the number of lanes became a binary choice variable shown in Figure 5.9 (b). The result indicated that the number of lanes is not a significant factor to explain the 85th percentile speed (Table 5.9).

TABLE 5.9: Linear Model for Number of Lanes

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Number of Lanes	Linear	0.045	45	2.10	0.154	49.2421	2.4557



(a) Entire Florida State Urban Arterial Roadways (b) Sample

FIGURE 5.9: Composition of Number of Lanes

5.5.7. Lane Width

Lane width was treated as either continuous or categorical variable. In the sample, we had the lane width ranging between 10.5 ft and 13.0 ft. To convert the continuous variable to categorical, the widths were classified into two groups: (a) lane width less than 12 ft, and (b) equal to or more than 12 ft. Table 5.10 is estimation of linear equations by continuous and categorical forms and shows that the continuous form has slightly better fit than the categorical form.

TABLE 5.10: Linear Models for Lane Width

Variable Form	Model	R-square	DF	F-value	Sig.	b_0	b_1
Continuous	Linear	0.167	45	9.03	0.004	-4.532	5.0112
Categorical*	Linear	0.146	45	7.7	0.008	53.0442	4.0029

* 1 if lane width ≥ 12 ft, 0 otherwise

5.5.8. Number of Left and Right Turning Bays per Mile

The number of left and right turning bays were counted separately in the field and tested either separately (1st aggregation level) or taken altogether (2nd aggregation level). Where the continuous left tuning lane (TWLTL) is installed, it could be considered as a continuous left turning bay. Under such configuration, to quantify the number of left turning bays, we considered the total number of accesses in the opposite direction: the sum of the number of driveways and minor streets. Illustrated in Figure 5.10 as an example, the number of left turning bays on the westbound side can be counted as two and the number on the eastbound side can be four.

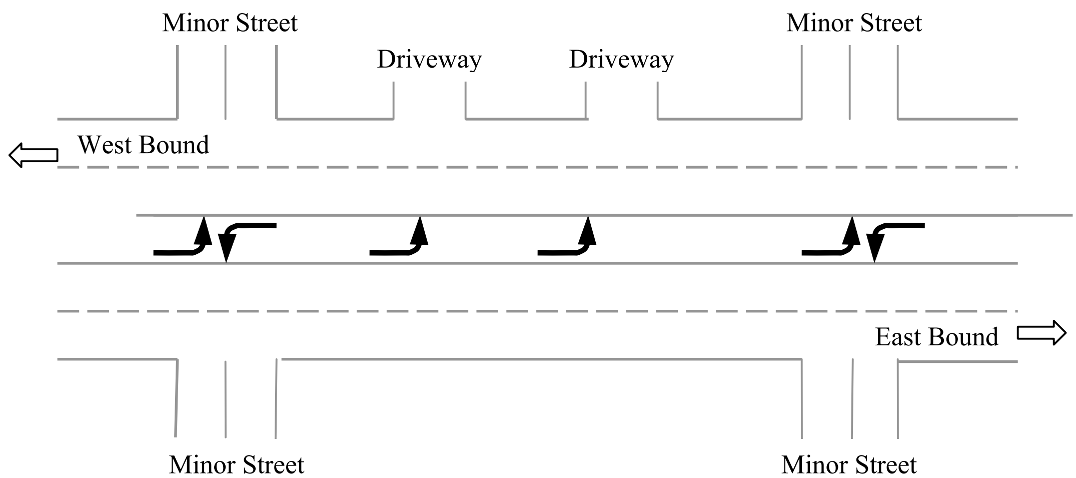


FIGURE 5.10: Number of Left-Tuning Bays under TWLTL Configuration

In Table 5.11, the number of left-turning bays was a significant factor in determining 85th percentile speed, while the number of right turning bays was not. In case both turning bays were considered together, it was also a significant factor. The slopes indicated that the more left or all turning bays, the lower 85th percentile speed. However, the number of turning bays had strong relationships with the access density, which is reasonable result because the turning bays are always presented with accesses, median openings, or intersections. The correlation analysis has already indicated a relatively high correlation coefficient.

In addition, the logarithm model has the highest fit for the number of left-tuning bays (R-square = 0.261, p-value = 0.0004), the cubic model for the right-turning bays (R-square = 0.135, p-value = 0.041), and the power model for the all-turning bays (R-square = 0.180, p-value = 0.003).

TABLE 5.11: Linear Models for Turning Bays

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Left-Turning Bays	Linear	0.149	45	7.9	0.007	56.5153	-0.1812
Right-Turning Bays	Linear	0.057	45	2.7	0.107	53.8093	0.557
All Turning Bays	Linear	0.12	45	6.15	0.017	56.6819	-0.1662

5.5.9. Existence of Shoulder Curb

This variable is a treated variable to quantify roadside clearance. The reason was that study sites often do not have constant distance from the side obstructs from traffic along the roadway. The raised shoulder curb was considered as the factor to determine the level of roadside clearance because it may influence drivers' speeds to avoid hitting the curb. The existence of a curb is a binary variable that has two choices, yes or no. In the field, more than the half of sites (53.2 %) do not have the curb. The presence of curb was determined to be a significant factor that decreases the 85th percentile speeds as shown in Table 5.12.

Table 5.12: Linear Model for Existence of Shoulder Curb

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Shoulder Curb*	Linear	0.471	45	40.01	0.000	58.1828	-7.1569

* 1 if curb exists, 0 otherwise

5.5.10. Number of Signs per Mile

The signs were observed in the field by the number of speed-related signs and the number of other traffic signs separately. The speed-related signs included advisory speed limit signs, speed zone ahead signs, and reduced speed ahead signs. Other traffic signs include regulatory signs, marker signs, warning signs, and guide and informational signs. Similar to the number of turning bays, two different types of signs were tested either separately (1st aggregation level) or taken altogether (2nd aggregation level). Because the speed-related signs were not observed in considerable number in the field, it was treated as a categorical variable, that is whether any speed-related sign exists or not. The results indicated that the number of other signs and the number of all signs were significant. The 85th percentile speed is decreased where more signs are installed (Table 5.13). It can be said that speed is sensitive to the amount of information that a driver faces.

TABLE 5.13: Linear Models for Number of Signs

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Number of Speed-related Signs	Linear	0.021	45	0.95	0.336	55.6835	-0.5201
Number of Other Signs	Linear	0.148	45	7.84	0.008	57.4622	-0.483
Number of All Signs	Linear	0.16	45	8.54	0.005	58.0903	-0.4601
Existence of Speed-related Signs*	Linear	0.004	45	0.18	0.673	54.2717	0.7535

* 1 if any speed-related sign exists, 0 otherwise

5.5.11. Number of Traffic Signals per Mile

The number of signals is synonymous with the number of signalized intersections in a mile. Sometimes it is also termed as signal density or signal spacing. There were a few signals that were not operating (with blinking lights) at the moment of field observation. Those were newly built signals that were not still configured, signals located near fire stations that were used to halt traffic for the emergency situation, or those simply malfunctioned. Those signals were ignored.

It was found that the number of traffic signals has a relatively higher goodness-of-fit than the other variables (Table 5.14), and the shorter spacing between signals incorporate with the lower 85th percentile speeds. It is quite reasonable, as vehicles cannot have enough chance to accelerate on shortly signal-spaced roadways and consciously and/or subconsciously the drivers had to prepare the signal turning.

TABLE 5.14: Linear Model for Number of Traffic Signals

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Number of Traffic Signal	Linear	0.335	45	22.66	0.000	57.7415	-1.8975

5.5.12. Number of Driveways and Minor Streets per Mile

A driveway was defined as the short entrance/exit path that provides accesses between roadside developments and roadways. A minor street was defined as a roadway intersecting arterial roads (study roadway) at which vehicles were not controlled by a traffic signal but usually by stop signs. Sometimes there is not an obvious indicator to distinguish between a driveway and a minor street with respect to the roadway configuration and appearance. In such cases, roadways with long extension or with posted road name were considered as the minor streets.

Similar to the turning bays, the number of driveways and minor streets were tested either solely (1st aggregation level) or taken altogether (2nd aggregation level). There were non-linear models that had better fits than the linear model for some variables in this category but the R-square differences were not considerable in every case. The result indicated higher 85th percentile speed when there are fewer access points (Table 5.15).

TABLE 5.15: Linear Models for Number of Driveways and Minor Streets

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Driveways	Linear	0.229	45	13.4	0.001	57.6916	-0.2349
Minor Streets	Linear	0.188	45	10.4	0.002	57.1781	-0.5067
All	Linear	0.289	45	18.26	0.000	58.4317	-0.2142

5.5.13. Number of Median Openings per Mile

A median opening could be a full median opening or a directional median opening. Full median opening is where vehicles could have access from both directions, whereas directional openings allowed only one direction’s ingress to make a left-turn or a U-turn. The median openings were tested as each type of median opening (1st aggregation level) or taken altogether (2nd aggregation level).

Where the continuous left-turning lane (TWLTL) is installed, the number of full median openings takes zero; instead, the number of directional median openings takes the sum of accesses in opposite direction. That is the same way applied to the count of the number of left-turning bays under the TWLTL configuration as shown in Figure 5.10. The median discontinuations, where two roadways were intersecting and controlled by a signal, were not considered as a median opening. That type of opening was considered as the number of signals.

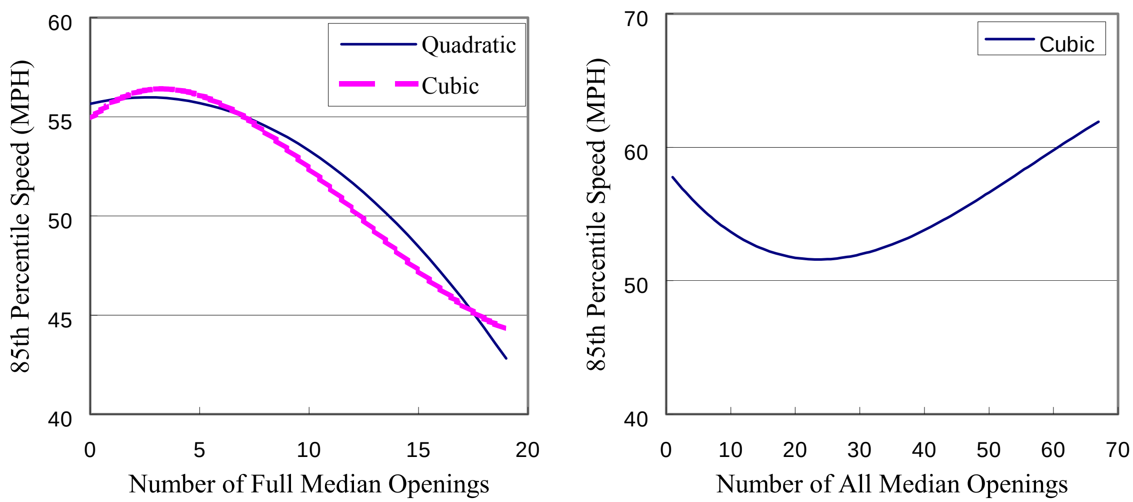
It was found that the number of full median openings had considerably higher R-squares with quadratic (R^2 = 0.240) and cubic (R^2 = 0.252) models than the linear model (R^2 = 0.184). For the number of directional median openings, all models tested were not statistically significant to predict 85th percentile speed, provided by p-values that were greater than 0.05. Table 5.16 presents the linear model results.

The number of all median openings was tested as the 2nd aggregation level variable. The test result showed that it had its highest fit with the cubic model (R2 = 0.165). These non-linear models were graphically examined in Figure 5.11, whether or not they have meaningful insights in designing adjustment factor modules to build a better (but more complicated) speed limit model.

The quadratic model for the number of full median openings may be sound, as the 85th percentile speed decreases as the number of full median openings increases (more interruption to the traffic) as seen in Figure 5.11 (a). The cubic model for the all types of median openings would not be useful because it has a minimum of the 85th percentile speed near 25 median openings (Figure 5.11 (b)). Linear models had intuitively correct orientation, which is the more median openings, the lower 85th percentile speed. Conclusively, the non-linear test suggested considering quadratic model for the number of full median openings afterward.

TABLE 5.16: Linear Models for Number of Median Openings

Variable	Model	R-square	DF	F-value	Sig.	b_0	b_1
Full Median Openings	Linear	0.184	45	10.17	0.003	57.2842	-0.5154
Directional Median Openings	Linear	0.029	45	1.33	0.255	55.1469	-0.0744
All	Linear	0.121	45	6.2	0.017	56.2956	-0.1629



(a) (b)

FIGURE 5.11: Non-linear Models for Number of Median Openings

5.5.14. Percentage of Heavy Vehicles

Information on the percentage of heavy vehicles was collected by the speed measuring sensors (Hi-Star, NC-97). Vehicle lengths were classified and stored in each length bin. Then vehicles longer than 29 ft were defined as the heavy vehicles in this study. The light vehicle category (length less than 29-ft) may include passenger cars and small trucks, and the heavy vehicle category may include trucks with more than 2 axles, buses, and trailer trucks.

The distribution of the percentage of heavy vehicles in the sample is presented in Figure 5.12 (a), where approximately 90 % of the study sites had heavy vehicles making up less than 10 % out of all vehicles passed. However, there are two significant outliers in the sample; therefore, the variable was truncated to 20 percent of heavy vehicles in order to eliminate the influence of outliers. The distribution of the truncated variable is presented in Figure 5.12 (b).

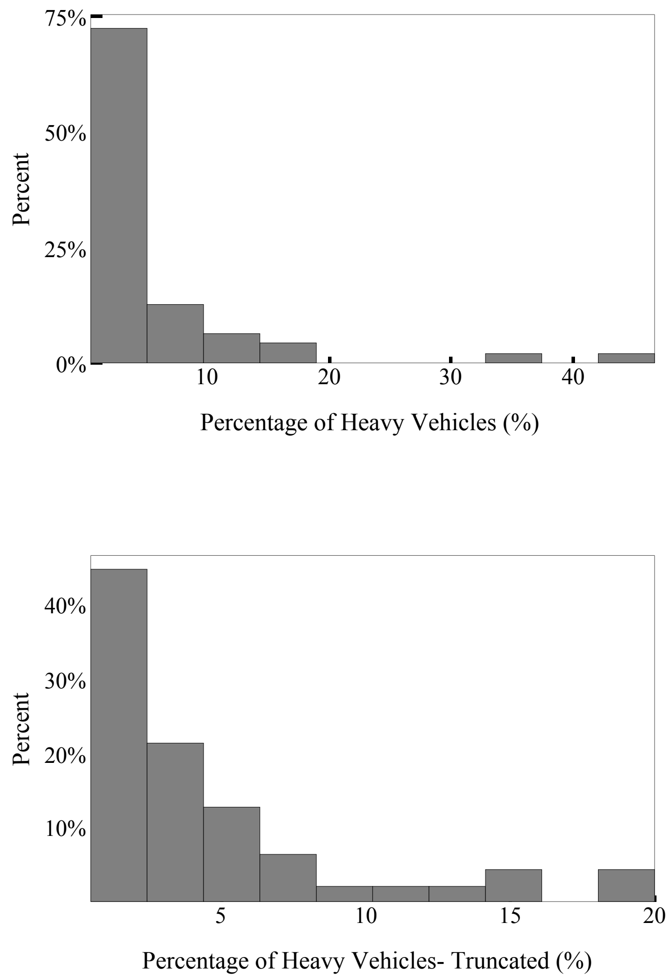


FIGURE 5.12: Distribution of the Percentage of Heavy Vehicles

This variable was also tested either as a continuous variable or a categorical variable. To convert to a categorical variable, the percentage was divided into less percentage of heavy vehicles (less than 5%) and more percentage of heavy vehicles (more than 5%). Results indicated that neither the continuous form nor the categorical form is able to be statistically a determinant (Table 5.17). Non-linear models also did not have an acceptable level of predictability. It was thought that under free-flow condition the presence of heavy vehicles in traffic would affect the overall vehicle speeds irrespective to the number of heavy vehicles.

TABLE 5.17: Linear Models for the Percentage of Heavy Vehicles

Variable Form	Model	R-square	DF	F-value	Sig.	b_0	b_1
Continuous	Linear	0.011	45	0.48	0.492	55.2006	-6.4983
Continuous (Truncated)	Linear	0.000	45	0.00	0.945	54.8877	-1.1495
Categorical*	Linear	0.001	45	0.03	0.86	54.9221	-0.3000

* 1 if percentage of heavy vehicle more than 5%, 0 otherwise

5.5.15. Number of Accesses in Both Sides per Mile (Access Density)

This variable was made in the way that the accesses in left side of roadway (median openings) and the accesses (driveways and minor streets) in right side of roadway were combined together. It was also called access density. Shown in Table 5.2, the number of accesses in both sides was assigned to the 3rd aggregation level. Figure 5.13 is a scatter plot of the access density versus 85th percentile speed, where an obvious negative pattern can be observed. This implies that the more accesses incorporate with the lower 85th percentile speed. The linear model shown in Table 5.18 confirms the tendency.

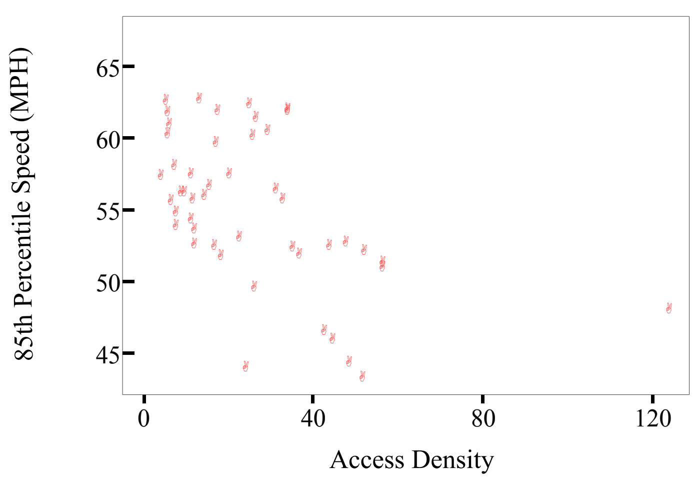


FIGURE 5.13: 85th Percentile Speed Versus Access Density

TABLE 5.18: All Models for the Number of Accesses in Both Sides

Model	R-square	DF	F-value	Sig.	b_0	B_1	b_2	b_3
Linear	0.265	45	16.20	0.000	58.0967	-0.1266	-	-
Logarithmic	0.262	45	15.96	0.000	64.8067	-3.3784	-	-
Inverse	0.189	45	10.51	0.002	51.9694	40.5621	-	-
Quadratic	0.295	44	9.21	0.000	59.4393	-0.2196	0.0009	-
Cubic	0.324	43	6.86	0.001	56.9122	0.0943	-0.0071	4.60E-05
Power	0.272	45	16.78	0.000	58.075	0.9976	-	-
Compound	0.269	45	16.59	0.000	66.0028	-0.0644	-	-
S-curve	0.193	45	10.74	0.002	3.9453	0.7689	-	-
Growth	0.272	45	16.78	0.000	4.0617	-0.0024	-	-
Exponential	0.272	45	16.78	0.000	58.075	-0.0024	-	-

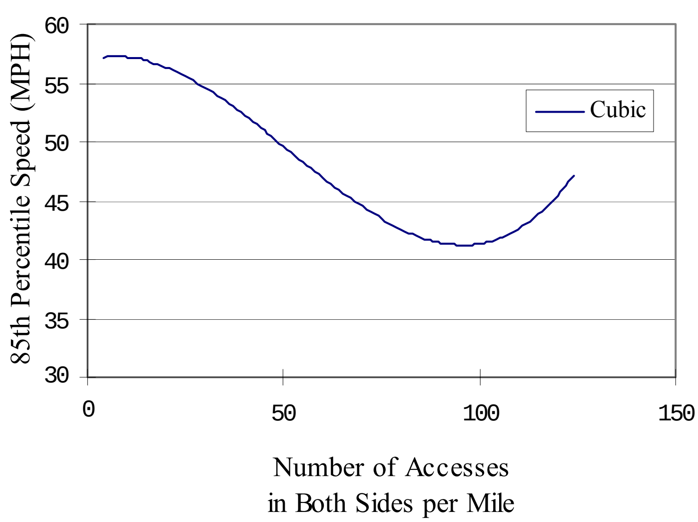


FIGURE 5.14: Non-Linear Model the Number of Accesses in Both Sides

The linear model performed well to predict 85th percentile speed (R^2 = 0.265). The cubic form was investigated as it had the highest fit among the tested models. In Figure 5.14, however, the cubic model for the number of accesses in both sides seems not to be acceptable; the 85th percentile speed increases with the number of accesses increase in a certain range (with 90 accesses and more), which is not reasonable.

5.5.16. Number of Interruptions per Mile

The interruptions were defined as all countable roadway features that drivers face while traveling. It includes the number of median openings (both full and directional openings), driveways, minor streets, signals, all type of signs, and left and right turning bays. The number of interruptions per mile belongs to the 4th aggregation level variable. Again the hierarchical description of the aggregation levels was presented in Table 5.2. Figure 5.15 plots a clear pattern of the relationship between the 85th percentile speed and the number of all interruptions.

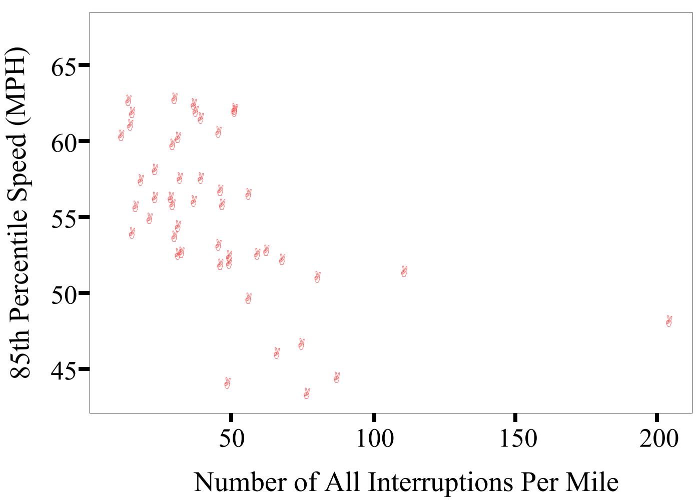


FIGURE 5.15: 85th Percentile Speed Versus the Number of All Interruptions

The figure shows clearer relationship than the 3rd aggregation level variable, the number of accesses in both sides. As the aggregation level goes up, the variable may encounter less detail, but may possess higher predictability in the adjustment factor module. The relationship is strong in a region of more than 50 MPH but it disperses as the 85^{th} percentile speed becomes lower. Presumably, vehicular speeds are influenced more by other factors than the interruptions where the 85^{th} percentile speed of lower than 50 MPH.

However, this variable should be used carefully because there is strong correlationship between the access density and the number of turning bays. In fact, a turning bay functions to help traffic flow to help smooth out traffic flow. Even though the 85^{th} percentile speeds decrease where more turning bays are installed, that is probably because turning bays mostly accompany accesses. We extended the examination to the influence of the turning bays with accesses on the 85^{th} percentile speed. Two variables were compared- (a) number of accesses without considering turning bays and (b) number of accesses that do not accompany the turning bays. To obtain the second variable, the number of turning bays was extracted from the number of accesses. Indeed, the new variable does not reflect the real situation because not all turning bays are connected to accesses. There are also some turning bays that are connected to signalized intersections, where roadways at the intersection were not defined as accesses in this study. Thus, the variable (b) was again calculated as:

$$Variable\ (b) = Accesses + Intersections - Turning\ bays \qquad \text{(Eq. 5.1)}$$

The new variable (b) in Equation 5.1 was a rough count as well because some intersections also do not accompany turning bays. Nonetheless, the results indicated that the variable (b) was more significant to predict the 85^{th} percentile speed ($R^2 = 0.299$) than the variable (a) ($R^2 = 0.265$). It is recommended here for future study that the turning bays are counted separately by those connected to accesses and others connected to intersections to obtain more precise information.

The number of all interruptions was tested in the same way, regardless, as were the other variables. The linear model showed a significant relationship between 85^{th} percentile speed and the number of all interruptions (Table 5.19). The negative slope of the model is reasonably indicating that the 85^{th} percentile speed decreases as the interruption increases.

TABLE 5.19: All Models for the Number of All Interruptions

Model	R-square	DF	F-value	Sig.	b_0	B_1	b_2	b_3
Linear	0.303	45	19.59	0.000	58.9693	-0.0909	-	-
Logarithmic	0.352	45	24.44	0.000	74.0078	-5.2665	-	-
Inverse	0.257	45	15.57	0.000	50.5178	138.922	-	-
Quadratic	0.398	44	14.52	0.000	62.5622	-0.2169	0.0007	-
Cubic	0.410	43	9.95	0.000	60.2451	-0.0773	-0.0013	7.00E-06
Power	0.309	45	20.1	0.000	59.0295	0.9983	-	-
Compound	0.357	45	24.93	0.000	78.4365	-0.0996	-	-
S-curve	0.257	45	15.57	0.000	3.9185	2.6107	-	-
Growth	0.309	45	20.1	0.000	4.078	-0.0017	-	-
Exponential	0.309	45	20.1	0.000	59.0295	-0.0017	-	-

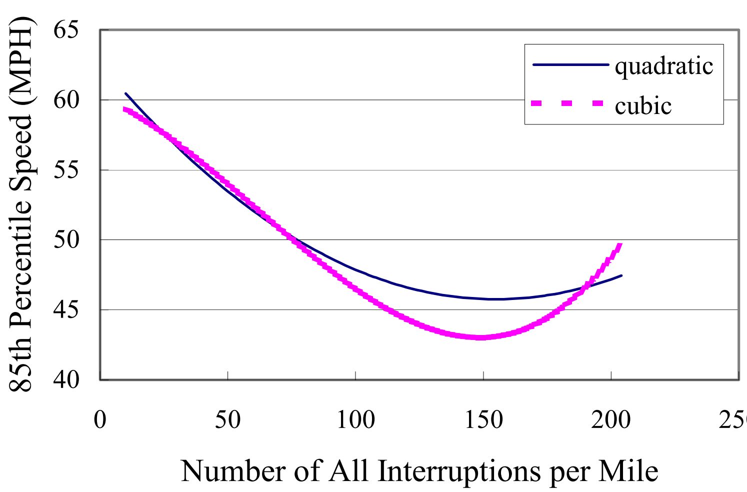


FIGURE 5.16 Non-linear Models for Number of All Interruptions

Similar to the number of accesses in both sides, two non-linear models that have higher fits were selected for further investigation (Figure 5.16). Both curves showed the minimums at near 150 interruptions and then the 85th percentile speed increased with increase of the number of interruptions. As a result, the curves by two models would probably not suitable to be applied to adjustment factor module design.

5.5.17. Other Variables

In addition to the variables tested previously, there were some variables that were not considered for examination. The reason was primarily that an insufficient number of sites were observed that have pedestrians and bicyclists, and roadside parkings. That was probably because this study focused on the arterial roads. In case of pavement type, the majority of roadways (94 %) have asphalt pavement. Those excluded variables must be examined once the scope of study is widened to lower class roads such as collectors or local roads. Besides, it was difficult for some variables to be quantified (e.g., enforcement level), or the variable values change from time to time (e.g., weather and visibility).

5.5.18. Summary

Through the curve estimations tests, several variables were selected to include in adjustment factor module computation. The criteria for variable selection were that (a) there should not be strong correlationship between variables (the correlation coefficient should belong to the range between - 0.5 and 0.5), and (b) the p-value in linear regression should be less than 0.05. For some variables that have higher fit with a non-linear model than with linear model, the non-linear models were examined to check if the directions of curves are intuitively reasonable. If so, the non-linear model was suggested for future development in adjustment factor module design. Among the variables tested, the median width and the number of full median openings were found to have potential with the quadratic model. Table 5.20 summarizes all the variables tested and their performances with the linear model estimation. Conclusively, the variables in shaded rows in the table are the factors selected for the adjustment factor design phase. Lane width was a significant variable in either continuous or categorical form. We decided to use the categorical form since it would facilitate utilization. Through the tests, the variables were analyzed in various ways. This report presents only the tests that have meaningful outcomes.

TABLE 5.20: Summary of Curve Estimation

Variable	Variable Type[1]	Aggregation Level	R-square	Significance[2]	Intercept	Slope
Road Functional Class	C	1	0.318	Y	51.1050	6.0416
Roadside Development	C	1	0.166	Y	49.7245	2.8582
Land Use - Residential	C	1	0.000	N	-	-
Land Use - Commercial	C	1	0.011	N	-	-
Land Use - Industrial	C	1	0.077	N	-	-
Median Type	C	1	0.000	N	-	-
Median Width	S	1	0.078	N	-	-
Number of Lanes	C	1	0.045	N	-	-
Lane Width (Continuous Form)	S	1	0.167	Y	-4.532	5.0112
Lane Width (Categorical Form)	C	1	0.146	Y	53.0442	4.0029
Number of Left-turning Bays Per Mile	S	1	0.149	Y	56.5153	-0.1812
Number of Right-turning Bays Per Mile	S	1	0.057	N	-	-
Number of All turning Bays Per Mile	S	2	0.120	Y	56.6819	-0.1662
Existence of Curb	C	1	0.471	Y	58.1828	-7.1569

1. S (Continuous Variable), C (Categorical Variable)

2. Y (p-value ≤ 0.05), N (p-value > 0.05)

TABLE 5.20: (Continued)

Variable	Variable Type[1]	Aggregation Level	R-square	Significance[2]	Intercept	Slope
Number of Speed-related Signs Per Mile	S	1	0.021	N	-	-
Existence of Speed-related Signs	C	1	0.004	N	-	-
Number of Other Signs Per Mile	S	1	0.148	Y	57.4622	-0.483
Number of Signals Per Mile	S	1	0.335	Y	57.7415	-1.8975
Number of Driveways Per Mile	S	1	0.229	Y	57.6916	-0.2349
Number of Minor Streets Per Mile	S	1	0.188	Y	57.1781	-0.5067
Number of Driveways and Minor Streets Per Mile	S	2	0.289	Y	58.4317	-0.2142
Number of Full Median Openings Per Mile	S	1	0.184	Y	57.2842	-0.5154
Number of Directional Median Openings Per Mile	S	1	0.029	N	-	-
Number of All Median Openings Per Mile	S	2	0.121	Y	56.2956	-0.1629
Percent Heavy Vehicles (Continuous Form)	S	1	0.011	N	-	-
Percent Heavy Vehicles (Categorical Form)	C	1	0.001	N	-	-
Number of Accesses in Both Sides Per Mile	S	3	0.265	Y	58.0967	-0.1266
Number of All interruptions Per Mile	S	4	0.303	Y	58.9693	-0.0909

1. S (Continuous Variable), C (Categorical Variable)

2. Y (p-value ≤ 0.05), N (p-value > 0.05)

5.6. Adjustment Factor Module

The variables chosen to develop adjustment factor modules were road functional class, existence of curb, signal density, access density, and lane width, based on the curve estimation tests. After testing numerous scenarios to build the final speed limit model, the 3rd aggregation level was chosen based on the tradeoff between variable details and practicality. This section presents designing adjustment factor modules for the variables that belong to the 3rd aggregation level.

In the 3rd aggregation level, the number of left/right turning bays and the level of roadside development were excluded from the analysis because of strong correlationship with the number of accesses in both sides (with significance at the 0.01 level) as described in the Section 5.2. Additionally, the number of traffic signs was omitted from the modeling taking into consideration that, although there is a significant relationship between 85th percentile speed and the number of traffic signs, it was questionable to lower/raise speed limits just because of the number traffic signs. For notation purposes, the variable names were abbreviated as shown in Table 5.21.

Table 5.21: Variable Codes

<table>
<tr><th>Variable Name</th><th>Code</th><th>Variable Name</th><th>Code</th></tr>
<tr><td>Road Functional Class</td><td>FC</td><td>Existence of Shoulder Curb</td><td>SC</td></tr>
<tr><td>Number of Signals
(Signal Density)</td><td>SD</td><td>Lane Width</td><td>LW</td></tr>
<tr><td colspan="3">Number of Median Openings, Driveways and Minor Streets Per Mile
(Access Density)</td><td>AD</td></tr>
</table>

5.6.1. Adjustment Factor for the Road Functional Class, f_{FC}

The first step of designing the adjustment factor module was to draw the linear equation on the X-Y coordination. Herein, the road class was assigned on X-axis and the 85th percentile speed was on Y-axis. The estimated slope of the equation was 6.0416 and constant was 51.1050 (Table 5.20) from the previous analysis, which is illustrated in Figure 5.17 as the dotted line. The slope of the linear equation is then considered as the sensitivity of the road classes to the 85th percentile speed.

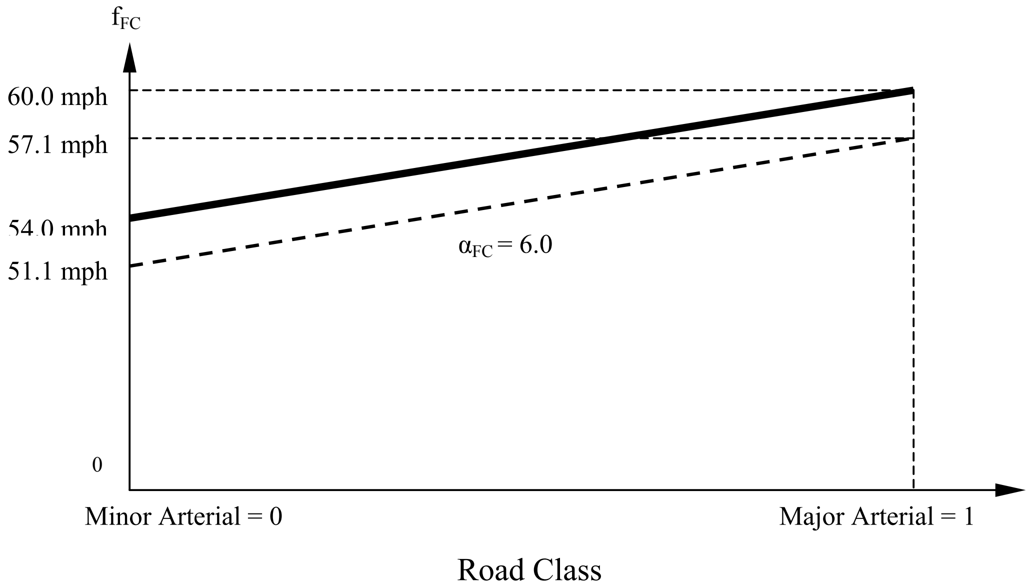


FIGURE 5.17: Development of Adjustment Factor Module for Road Class

The major arterial will be a superior road to the minor road, which implies that speed limit should not be lowered if the road class is a major arterial. Accordingly, the major arterial roads will have the adjustment factor of 1.000, at which the proposed speed limit remains of the maximum value, 60 MPH. To place the major arterial road X = 1.000 and Y = 60 MPH, the dotted line needs to be transferred vertically up until the right end of the line meets 60 MPH. The projected line is illustrated as the solid line in Figure 5.17. The projected line has the same sensitivity and intercepts with Y-axis at:

$$60.0\ MPH - 6.0\ MPH = 54.0\ MPH$$

The next step was to standardize the projected line. The road class is a categorical variable with binary choices, meaning that it has only 0 and 1, the minor street and the major street, respectively. This implied in such a way that the X-axis does not need to be standardized.

The variable of road functional class, V_{FC}, is equal to the standardized variable, SV_{FC}. For the case of Y-axis, the intercept can be standardized by:

$$(54\ MPH \times 1.000)/60\ MPH = 0.900$$

Figure 5.18 graphically expresses the completed adjustment factor module for the road class. The final adjustment factor of f_{FC} in a site j can be expressed by:

$$f_{FCj} = 0.90 + 0.10 \times V_{FCj} \qquad \text{(Eq. 5.2)}$$

where, V_{FCj} = 1 if major arterial, 0 otherwise.

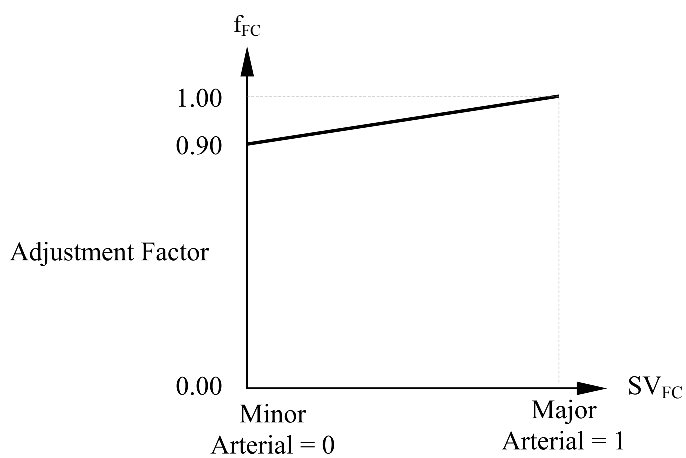


FIGURE 5.18: Standardization of Adjustment Factor Module for Road Class

It would be worth it to note here that the adjustment factor modules are independent of each other within the combined model- speed limit model and can have different specification including non-linear model or different parameters depending on the regional and/or temporal conditions. This study had employed the linear relationship between the adjustment factor and variables for the purpose of simplicity. However, the linear relationship will change after adding weighting factor in the following step.

5.6.2. Adjustment Factor for Existence of Shoulder Curb, f_{SC}

The existence of a curb is also a binary choice variable similar to the road class. The same calculation was applied as described in the case of the road class. The estimated slope of the model is –7.1569, and the intercept is 58.1828 (Figure 5.19). The estimated slope indicated that the 85th percentile speed is higher where a curb is installed. Although the direction of the slope was different from the case of road class, the overall procedure was the same.

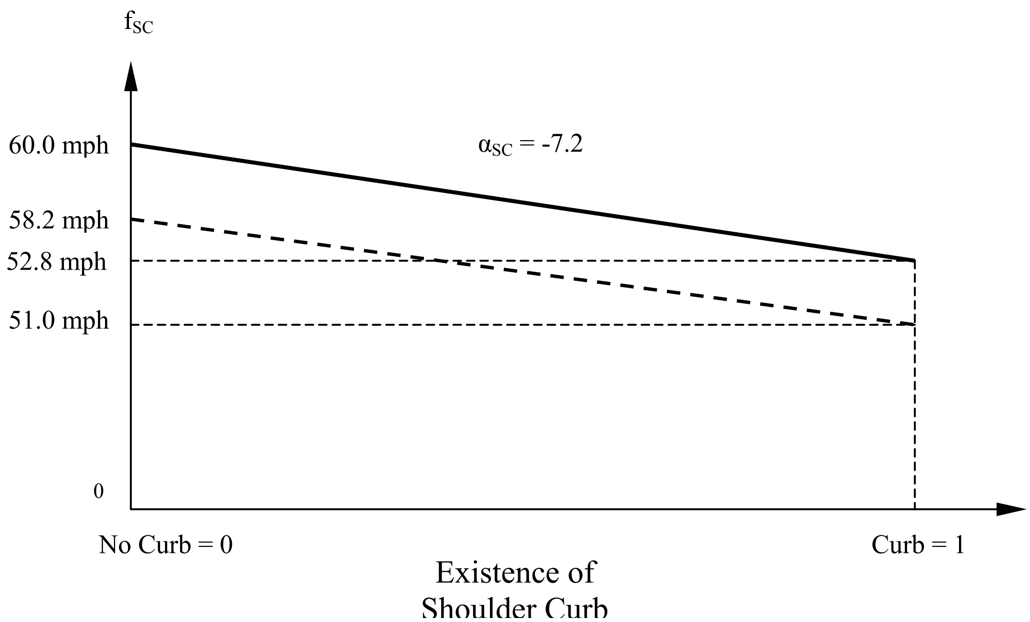


FIGURE 5.19: Development of Adjustment Factor Module for Shoulder Curb

The site without a curb will have the adjustment factor of 1.00, which means the maximum allowed limit of 60 MPH will be maintained. In other words, the roadways with a shoulder curb would be considered to have lower speed limits. Induced from the same computation described earlier, the adjustment factor for the sites where curb is installed becomes 0.88 (Figure 5.20). Again f_{SC} in a site j can be expressed as:

$$(52.8\ MPH \times 1.000) / 60 MPH = 0.88$$

Therefore,

$$f_{\mathrm{SC}j} = 1.00 - 0.12 \times V_{\mathrm{SC}j} \qquad \text{(Eq. 5.3)}$$

where, V_{SCj} = 1 if curb exists, 0 otherwise.

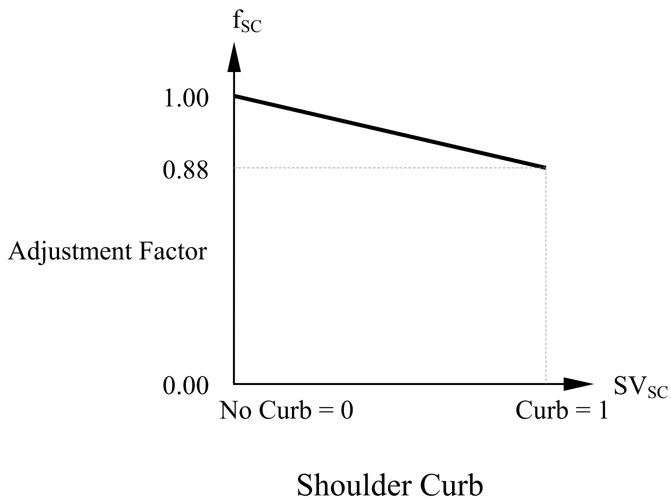


FIGURE 5.20: Standardization of Adjustment Factor Module for Shoulder Curb

5.6.3. Adjustment Factor for Access Density, f_{AD}

The variable V_{AD} is a continuous variable, but the concept of building adjustment factor module is the same as previous cases. It also needs the linear regression equation to obtain the sensitivity of the access density to the 85th percentile speed. However, this type of variable has an intercept with X-axis as well as the one with Y-axis. The methodology described in Chapter 3 actually explains the development of an adjustment factor module for a continuous variable.

The dotted line in Figure 5.21 is the estimated fit line of 85th percentile speed regressed by the access density, of which the model was:

$$85^{th} \text{ percentile speed} = 58.0967 - 0.1266 \times V_{\mathrm{AD}} \qquad \text{(Eq. 5.4)}$$

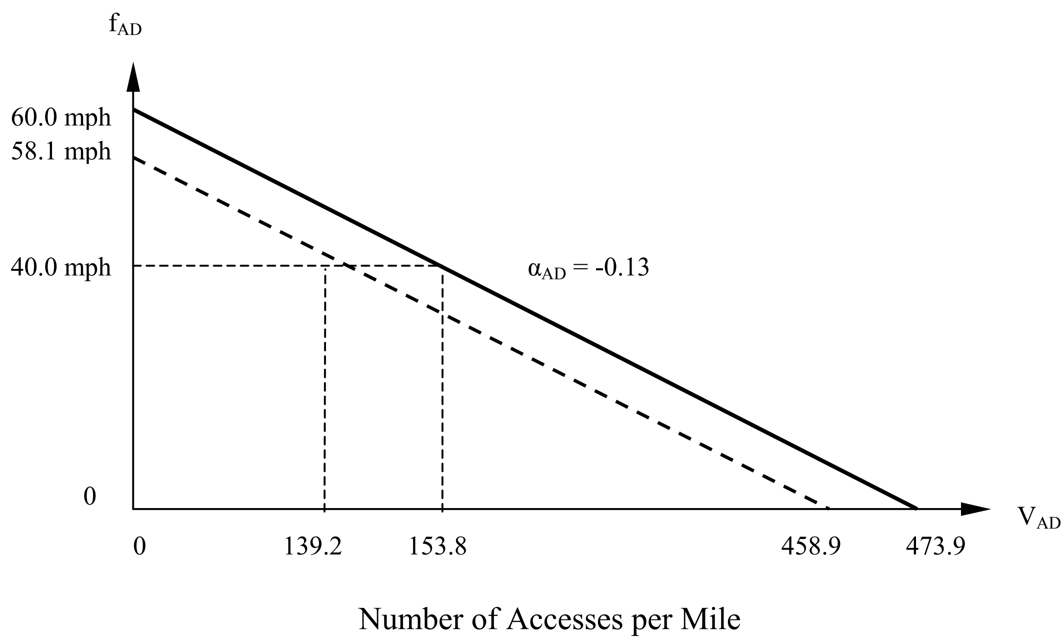


FIGURE 5.21: Development of Adjustment Factor Module Access Density

In Equation 5.4, the Y-intercept (58.0967) substitutes to β_{AD}, and the slope (0.1266) substitutes to α_{AD} as seen in Equation 3.4. Additionally, the intercept to the X-axis, y_{AD}, was computed from the Equation 5.4, which is 458.9 accesses per mile. Theoretically, the 85th percentile speed is zero where the number of accesses counts 458.9 per mile; consequently, speed limit should be zero, too. However, because the highest 85th percentile speed (58.1 MPH, rounded) is still less than the maximum allowable limit of 60 MPH, the dotted line needs to be moved vertically upward until the 85th percentile speed become 60 MPH. The projected line (solid line) will allow a bit more accesses to make the 85th percentile speed reach to zero. That number of accesses was notated as δ_{AD}, which can be computed by Equation 3.5, therefore:

$$\delta_{AD} = 60 / \alpha_{AD} = 60 / 0.13 = 473.9 \, (accesses) \quad \text{(Eq. 5.5)}$$

The predicted values from the projected line were compared with the actual access density. The actual number observed in the field was between 4.2 and 123.9 accesses a mile under the speed limits ranging between 40 and 55 MPH. With the same speed limits range, the projected line produced accesses ranging between 0 and 153.8 accesses. The next step is to standardize the projected line, which will be framed into the unit square as shown in Figure 5.22. Each ends of the line will move proportionally to meet the unit point. Equation 5.6 is used to obtain the standardized value of access densities from the observations, that is:

$$SV_{\mathrm{AD}\,j} = V_{\mathrm{AD}\,j} / \delta_{\mathrm{AD}} \qquad \text{(Eq 5.6)}$$

$$\begin{aligned} f_{\mathrm{AD}j} &= 1.0 - SV_{\mathrm{AD}j} \\ &= 1.0 - (V_{\mathrm{AD}\,j} / \delta_{\mathrm{AD}}) \end{aligned} \qquad \text{(Eq 5.7)}$$

where,

SV_{Adj}: standardized access density in site j,

V_{Adj} : observed access density in site j, and

δ_{AD} : intercept on X-axis of the transferred equation.

Combining Equation 5.5 and 5.7, the final adjustment factor for the site j is:

$$\begin{aligned} f_{\mathrm{AD}j} &= 1 - (V_{\mathrm{AD}j} \times \alpha_{\mathrm{AD}}) / 60 \\ &= 1 - (V_{\mathrm{AD}j} / 473.9) \end{aligned} \qquad \text{(Eq. 5.8)}$$

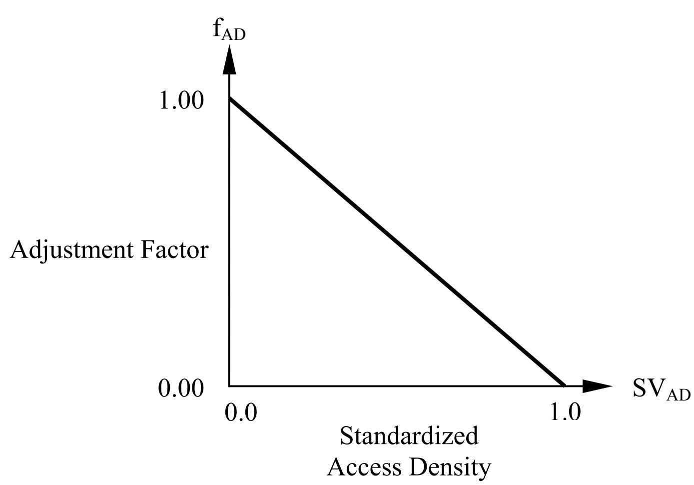


FIGURE 5.22: Standardization of Adjustment Factor Module for Access Density

5.6.4. Adjustment Factor for Signal Density, f_{SD}

The methodology of building adjustment factor for the signal density is exactly the same as the access density as it is a continuous variable. The linear estimation (Equation 5.8) indicated that higher 85th percentile speed incorporated with low signal density, the longer signal spacing.

$$85^{th}\ \text{percentile speed} = 57.7415 - 1.8975 \times V_{SD} \qquad \text{(Eq 5.9)}$$

Therefore, α_{SD} = -1.90, β_{SD} = 57.7, and y_{SD} = 30.4. The δ_{SD} (intercept to X-axis) for the projected line (solid line) is:

$$\delta_{SD} = 60 / \alpha_{SD} = 60 / 1.9 = 31.6\ (signals) \qquad \text{(Eq 5.10)}$$

The development of the module was graphically expressed in Figure 5.23 and 5.24.

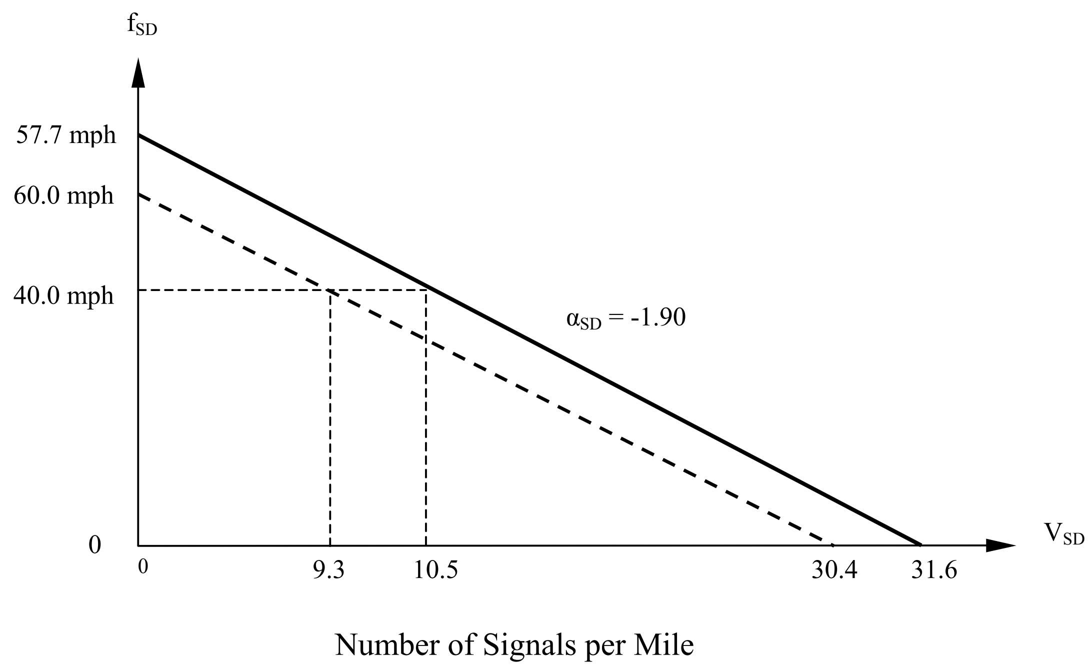


FIGURE 5.23: Development of Adjustment Factor Module for Signal Density

The range of signal density in the sample was observed between 0 and 6.9 signals under the speed limits range between 40 and 55 MPH, while the new line projects signal density between 0 and 10.5. For standardization, the followings were calculated:

$$SV_{\mathrm{SD}\,j} = V_{\mathrm{SD}\,j} / \delta_{\mathrm{SD}} \qquad \text{(Eq 5.11)}$$

$$\begin{aligned} f_{\mathrm{SD}j} &= 1.0 - SV_{\mathrm{SD}j} \\ &= 1.0 - (V_{\mathrm{SD}\,j} / \delta_{\mathrm{SD}}) \end{aligned} \qquad \text{(Eq 5.12)}$$

where,

SV_{Sdj}: standardized signal density in site j,
V_{Sdj}: observed signal density in site j, and
δ_{SD}: intercept on X-axis of the transferred equation.

Again, the final adjustment factor for the site j is induced by combining Equation 5.10 and 5.12, as shown below:

$$\begin{aligned} f_{\mathrm{SD}j} &= 1 - (V_{\mathrm{SD}j} \times \alpha_{\mathrm{SD}}) / 60 \\ &= 1 - (V_{\mathrm{SD}j} / 31.6) \end{aligned} \qquad \text{(Eq. 5.13)}$$

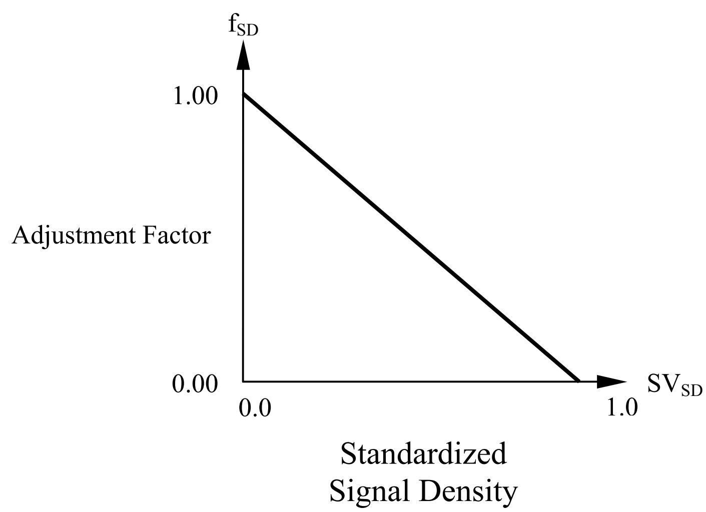


FIGURE 5.24: Standardization of Adjustment Factor Module for Signal Density

5.6.5. Adjustment Factor for Lane Width, f_{LW}

Lane width was treated as a categorical variable that had two choices: (a) lane width equal to or greater than 12ft and (b) less than 12 ft. This specification permitted building the adjustment factor module in the same way as with the road class. The estimated relationship with 85th percentile speed indicated that the 85th percentile speed increases approximately by 4 MPH when the lane width change from less than 12 ft to more than 12 ft, expressed as:

$$85^{th}\ percentile\ speed = 53.0442 + 4.0029 \times V_{LW} \quad \text{(Eq 5.14)}$$

where, V_{LW} is equal to 1 if average lane width is wider than 12 ft, 0 otherwise. Average lane width wider than 12 ft will have the adjustment factor of 1.00. From Equation 5.13, α_{LW} = 4.00 and β_{SD} = 53.0. Because this type of variable does not have intercept with X-axis, y_{SD} and δ_{SD} do not exist (Figure 5.25).

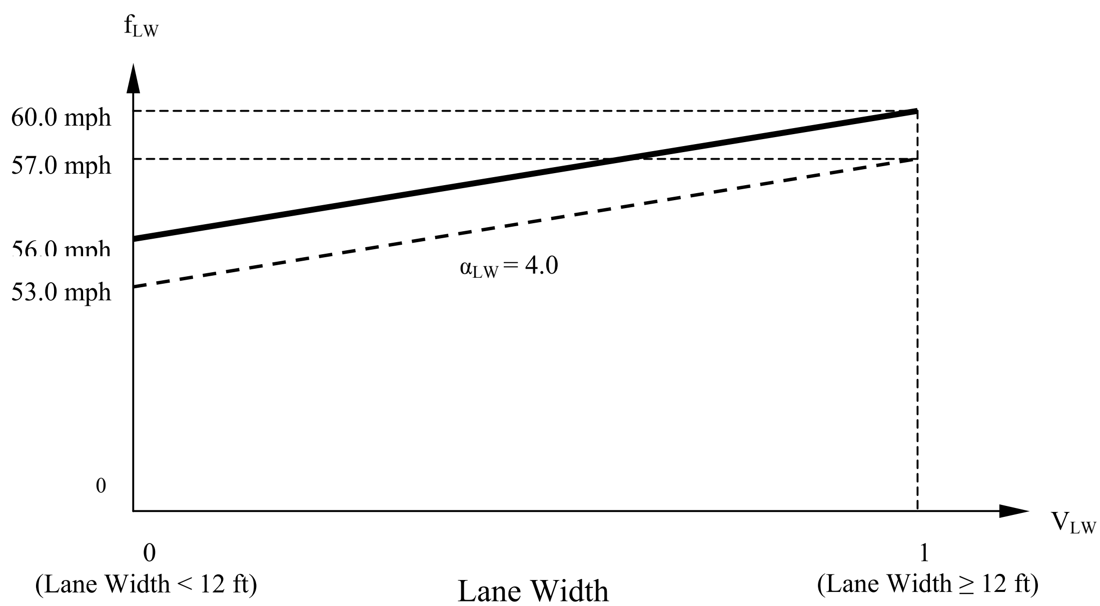


FIGURE 5.25: Development of Adjustment Factor Module for Lane Width

However, the projected line's Y-intercept can be computed by subtracting 4 MPH from 60 MPH of the maximum allowed speed limit.

$$\textit{Projected line's Y - intercept} = 60\ MPH - 4.0 = 56.0\ MPH$$

The projected line is again framed into standardized coordination raging 0.00 to 1.00 (Figure 5.26). The new Y-intercept in the standardized coordination is computed as

$$\textit{Standard Y - intercept} = 56 / 60\ MPH = 0.933$$

and the value is considered as the adjustment factor where the lane width is less than 12 ft. Finally, the adjustment factor module for f_{LW} can be expressed by:

$$f_{LWj} = 0.93 + (0.07 \times V_{LWj}) \qquad \text{(Eq 5.15)}$$

where, V_{LWj} = 1 if Lane Width ≥ 12 ft in a site j, 0 otherwise.

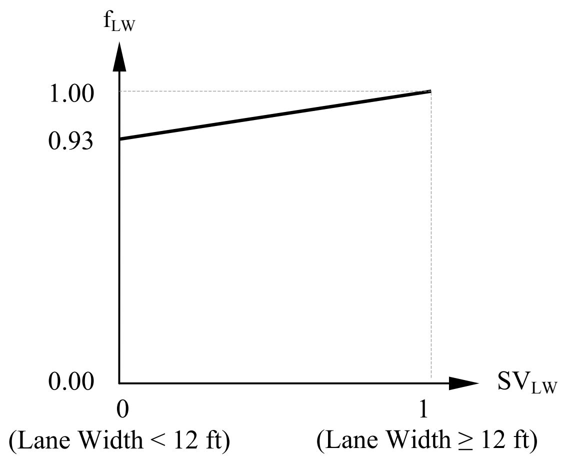


FIGURE 5.26: Standardization of Adjustment Factor Module for Lane Width

5.7. Estimating Weighting Factors

The adjustment factors for each variable were designed by reflecting the relationship between 85th percentile speed and a variable. However, when those adjustment factors are gathered together to make a combined equation, the speed limit model (Equation 5.16), each adjustment factor might have different magnitude of impact to the combined equation.

$$PSL = MSSL \times f_1 \times f_2 \times f_3 \times \Lambda \times f_i \qquad \text{(Eq. 5.16)}$$

where,

PSL : proposed speed limit (MPH),

MSSL : maximum statutory speed limit (MPH), 60 MPH for the nonlimited-access highways in Florida State Road, and

f_1, f_2, …, f_i: factor to adjust for the effects of road geometry, traffic, and drivers.

There was a need to assign importance to each variable differently in the model. This study employed the second parameters that power each variable with different magnitude. These parameters were defined as weighting factors, and Equation 5.16 is transformed to:

$$PSL = MSSL \times f_1^{w_1} \times f_2^{w_2} \times f_3^{w_3} \times \Lambda \times f_i^{w_i} \qquad \text{(Eq. 5.17)}$$

Substituting the designed adjustment factor modules (Equation 5.2, 5.3, 5.8, 5.13 and 5.15) to the combined equation, it can be again written as:

$$PSL_j = MSSL \times (f_{FC_j})^{w_{FC}} \times (f_{SC_j})^{w_{SC}} \times (f_{AD_j})^{w_{AD}} \times (f_{SD_j})^{w_{SD}} \times (f_{LW_j})^{w_{LW}} \qquad \text{(Eq. 5.18)}$$

$$= 60\ MPH \times [0.90 + (0.01 \times V_{FC_j})]^{w_{FC}} \times [1 - (0.12 \times V_{SC_j})]^{w_{SC}}$$
$$\times [1 - (V_{AD_j} / 473.9)]^{w_{AD}} \times [1 - (V_{SD_j} / 31.6)]^{w_{SD}} \times [0.93 + (0.07 \times V_{LW_j})]^{w_{LW}} \qquad \text{(Eq. 5.19)}$$

where,

PSL_j: proposed speed limit in the site j,

V_{FCj} : 1 if the site j is major arterial, otherwise 0,

V_{SCj}: 1 if the site j has curb on roadside, otherwise 0,

V_{ADj}: access density in the site j,

V_{SDj} : number of signalized intersections per mile in the site j,

V_{LWj}: 1 if lane width ≥ 12 ft in the site j, otherwise 0, and

w_i : weighting factor for the variable i.

To obtain the weighting parameters, multivariate linear regression technique was considered in this study. The linear model has an advantageous property, that it is applicable as long as the model can be transformed into a form that maintains linearity in the unknown parameters. To estimate the weighting factors, Equation 5.18 was transformed into logarithm:

$$
\begin{aligned}
Ln\ PSL &= Ln\,[60\ MPH \times (f_{FC})^{w_{FC}} \times (f_{SC})^{w_{SC}} \times (f_{AD})^{w_{AD}} \times (f_{SD})^{w_{SD}} \times (f_{LW})^{w_{LW}}\,] \\
&= Ln\ 60 + Ln\,(f_{FC})^{w_{FC}} + Ln\,(f_{SC})^{w_{SC}} + Ln\,(f_{AD})^{w_{AD}} + Ln\,(f_{SD})^{w_{SD}} + Ln\,(f_{LW})^{w_{LW}} \\
&= Ln\ 60 + [w_{FC} \times Ln\ f_{FC}] + [w_{SC} \times Ln\ f_{SC}] + [w_{AD} \times Ln\ f_{AD}] + [w_{SD} \times Ln\ f_{SD}] \\
&\quad + [w_{LW} \times Ln\ f_{LW}]
\end{aligned}
$$

(Eq. 5.20)

In Equation 5.20, the explanatory variables are Ln f_{FC}, Ln f_{SC}, Ln f_{AD}, Ln f_{SD}, and Ln f_{LW}, and Ln (PSL/60) becomes the dependant variable. The error term was assumed to be normally distributed and the least square method was used to obtain the parameters. The size of the sample was 47, and four additional independent sites were reserved for the purpose of validation.

Adjusted R-square was used to test the model's goodness-of-fit, and the analysis of variance (ANOVA) was used to test the significance of individual model parameters. The other tests included correlation coefficients, and residual analysis to examine if a model was mis-specified and if there exists unequal error variances (heteroscedasticity). Lastly, the validation sample was applied to the speed limit model to see the model performance and the Kolmogorov-Smirov test was performed to check if the model is biased.

The weighting factors were estimated two different methods: with and without the constant. With constant, the speed limit model may not have a maximum value of 60MPH unless the constant is not significant. Without constant, the model is forced to intersect the origin, so that the model performance will be lessen depending on how the constant interact in the model.

5.7.1. Multivariate Regression Estimation

Multivariate linear regression estimates the coefficients of the linear equation (including more than one independent variable) that best predict the value of the dependent variable. Table 5.22 presents the estimated weighting factors for (a) with-constant model and (b) without-constant model by the multivariate regression technique. A statistics tool, SPSS was used for the analyses.

Table 5.22: Weighting Factor Estimation Results

w_i	Coefficient	Std. Error	t	Sig.
(Constant)	-0.070	0.013	-5.172	0.000
w_{SC}	0.463	0.157	2.942	0.005
w_{LW}	0.739	0.224	3.293	0.002
w_{FC}	0.639	0.167	3.820	0.000
w_{SD}	0.545	0.153	3.560	0.001
w_{AD}	0.437	0.164	2.659	0.011

(a) With-Constant Model: Adjusted R-Square: 0.772

w_i	Coefficient	Std. Error	t	Sig.
w_{SC}	0.568	0.198	2.864	0.006
w_{LW}	1.171	0.264	4.427	0.000
w_{FC}	0.714	0.197	3.617	0.001
w_{SD}	0.688	0.191	3.596	0.001
w_{AD}	0.734	0.211	3.478	0.001

(b) Without-Constant model: Adjusted R-Square: 0.925

The SPSS provides a stepwise analysis, by which variables can be entered or removed from the model depending on the significance (probability) of the F-value. The p-value of 0.05 was used as the threshold. Theoretically, the weighting factor of an adjustment factor module closer to 1.000 implies that the assumption (linearity) in developing the module is satisfied in the speed limit model.

Table 5.22 shows that all the variables were statistically significant in both models at the significance level of 0.05. The weighting factors (coefficients in the table) have positive values, indicating that none of each adjustment factor modules was mis-specified in terms of the direction. A negative weighting factor will let the adjustment factor be greater than 1.00, which possibly permits a speed limit to be greater than the maximum statutory limit. It is important to note that adjusted R-square of the without-constant model should not be compared quantitatively with adjusted R-square of the model with constant term. The estimation indicated that the constant in the with-constant model is also a significant factor.

5.7.2. Analysis of Variance (ANOVA)

ANOVA test was performed to test significance of individual model parameters. Table 5.23 is the results of ANOVA test from two speed limit models. The higher F-values in both models reject the null hypotheses, meaning that the models are useful for predicting the dependant variable, Ln (PSL/60) in Equation 5.21.

5.7.3. Correlation Coefficients

This study already presented the results of correlation analysis for the traffic, geometric, and environmental variables in Chapter 5.4. However, it was necessary to perform another correlationship analysis for the variables used in weighting factor estimation because the variables had a common internal parameter, the 85th percentile speed. This study defined a significant correlationship to be the absolute value of correlation coefficient greater than 0.5. The correlationship between the independent variables that belong to Equation 5.21

was presented in Table 5.24. It showed that only LN (f_{SC}) and LN (f_{FC}) in the without-constant model have slight correlationship (correlation coefficient of –0.503).

TABLE 5.23: ANOVA Test Results

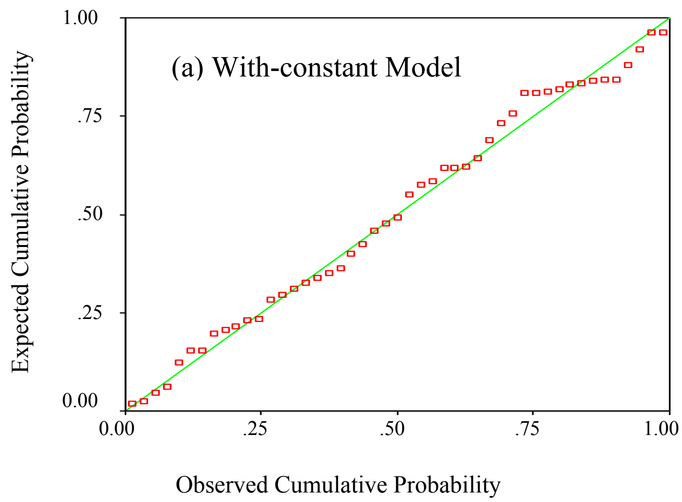
Model		Sum of Squares	df	Mean Square	F	Sig.
With-Constant	Regression	2.2957	5	0.4591	116.50	2E-23
	Residual	0.1655	42	0.0039	-	-
	Total	2.4613	47	-	-	-
Without-Constant	Regression	2.2957	5	0.4591	116.50	2E-23
	Residual	0.1655	42	0.0039	-	-
	Total	2.4613	47	-	-	-

TABLE 5.24: Correlation Coefficients

Model		LN f_{SC}	LN f_{LW}	LN f_{AD}	LN f_{SD}	LN f_{FC}
With-Constant	LN f_{SC}	1.000	-	-	-	-
	LN f_{LW}	0.181	1.000	-	-	-
	LN f_{AD}	-0.482	-0.115	1.000	-	-
	LN f_{SD}	-0.388	-0.284	0.074	1.000	-
	LN f_{FC}	-0.338	-0.214	-0.029	0.023	1.000
Without-Constant	LN f_{SC}	1.000	-	-	-	-
	LN f_{LW}	0.144	1.000	-	-	-
	LN f_{AD}	-0.405	-0.382	1.000	-	-
	LN f_{SD}	-0.421	-0.385	-0.039	1.000	-
	LN f_{FC}	-0.503	-0.169	-0.069	0.056	1.000

5.7.4. Residual Normality Test

To test the assumption that the error term was normally distributed, probability-probability plot (P-P plot) was drawn as shown in Figure 5.27. This test is an informal graphical tool, in which the dots closer to 45-degree line indicates the more satisfaction of the assumption. Two graphs show that the with-constant model is better model than the without-constant model. It seemed that because the without-constant model was forced to pass through the origin, the assumption of normality was somewhat violated.



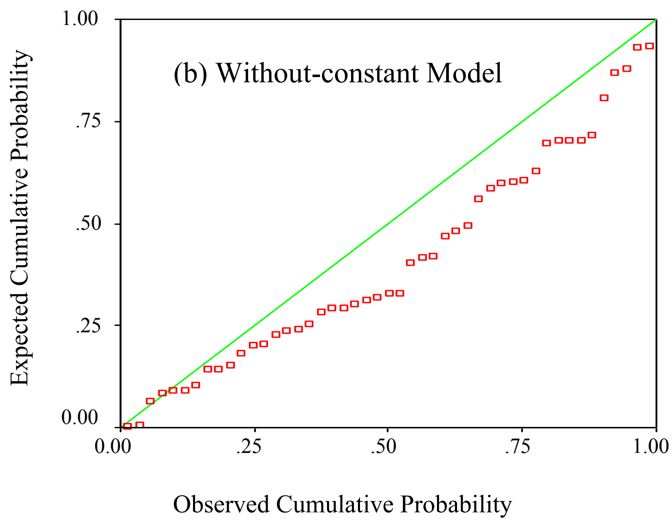


FIGURE 5.27: Probability-Probability Plots

5.7.5. Test of Unequal Variance

This test was to examine one of the linear regression properties, constant error variance. The residuals were plotted against the predicted value of the dependant variable and were investigated to determine whether there is any systemic pattern on the plot. If an obvious pattern is found (heteroscedasticity), the assumption was violated. The test plots are given in Figure 5.28. Again, the with-constant model satisfies the assumption better than the without-constant model does.

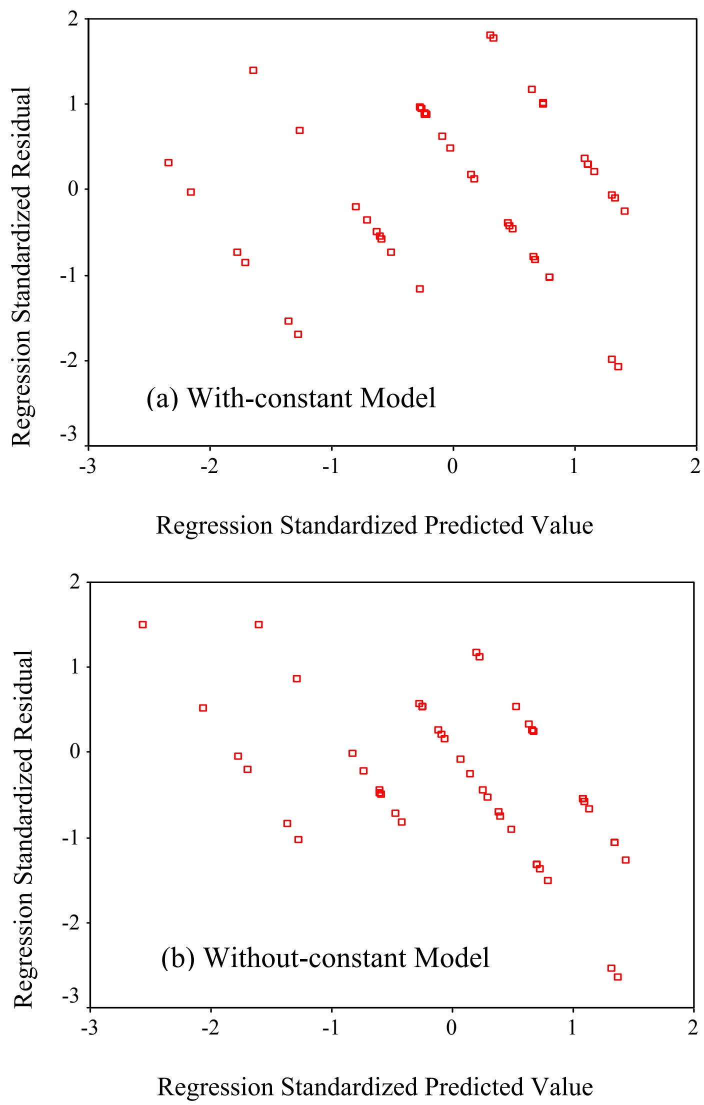


FIGURE 5.28: Test Graphs for Unequal Variance

5.7.7. Summary of the Tests

Because of the different role of each variable (different magnitude of impact to setting speed limit), we added the second parameters exponentially to each variable. These parameters were named as weighting factors, and estimated by the multivariate linear regression technique. Therein, two methods were performed: with constant and without constant in the regression equation. Due to the constant term, the interpretation of the speed limit model will be differently applied. In this report, models from these two approaches were presented. Overall, the model with-constant model had better performance than the without-constant model.

5.8. Selection of a Speed Limit Model

After converting the logarithm (Equation 5.20) to the natural form (Equation 5.18), the with-constant model became:

$$PSL = MSSL \times (const.) \times (f_{FC})^{w_{FC}} \times (f_{SC})^{w_{SC}} \times (f_{AD})^{w_{AD}} \times (f_{SD})^{w_{SD}} \times (f_{LW})^{w_{LW}}$$

$$= 60\ MPH \times EXP\ (-0.070) \times [0.90 + (0.01 \times V_{FC})]^{0.639} \times [1 - (0.12 \times V_{SC})]^{0.463}$$
$$\times [1 - (V_{AD} / 473.9)]^{0.437} \times [1 - (V_{SD} / 31.6)]^{0.545} \times [0.93 + (0.07 \times V_{LW})]^{0.739}$$

(Eq. 5.21)

If the two constant terms in the model are combined, the maximum value of speed limit that the model can produce is:

$$60\ MPH \times EXP\ (-0.070) = 60\ MPH \times 0.9324$$
$$= 55.9\ MPH$$

Similarly, the without-constant model can be rewritten as:

$$PSL = 60\ MPH \times [0.90 + (0.01 \times V_{FC})]^{0.734} \times [1 - (0.12 \times V_{SC})]^{0568}$$
$$\times [1 - (V_{AD} / 473.9)]^{0.714} \times [1 - (V_{SD} / 31.6)]^{0.688} \times [0.93 + (0.07 \times V_{LW})]^{1.171}$$

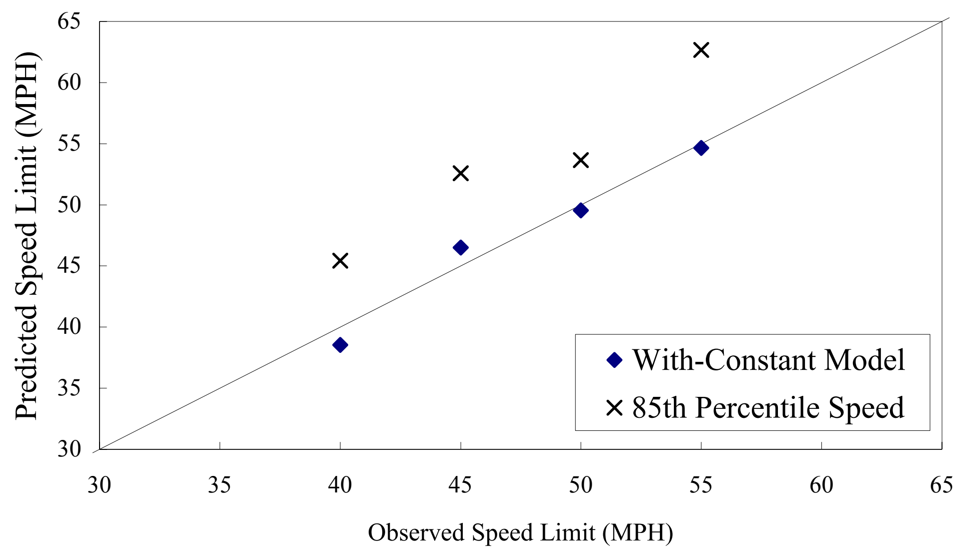
(Eq. 5.22)

Two models were presented in this report as the final model. The models in Equation 5.21 (with-constant model) and 5.22 (without constant model) have showed fair performance by various statistical examinations. Equation 5.21 may be a better model than the Equation 5.22 as determined by the results from the statistical tests but it has limited ability to produce the maximum speed limit. The highest speed limit from this model is near 55 MPH. On the other hand, the model in Equation 5.22 provides full range of utilization in arterial roads in Florida where speed limits range between 40 and 60 MPH. We would suggest Equation 5.22 as the final selection due to its advantageous practicability. Because the outcome of the model is a real number, it needs to be rounded to the nearest 5 MPH increment speed limit as suggested by the documents on speed zoning practice [4, 21].

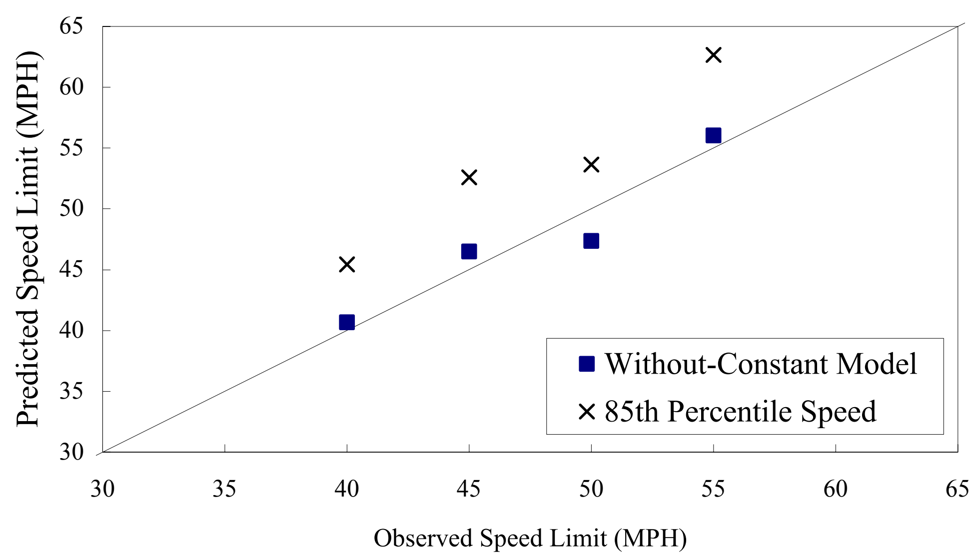
5.9. Validation of the Final Model

For the validation purpose, that is to ensure if the models explain well the phenomenon, four randomly selected sites were reserved as a validation sample. Those sites are also considered to have proper speed limits. The validation site was selected from each category of speed limits between 40 and 55 MPH. The entities of the validation sample were then entered into the speed limit model and the outcomes were graphically presented in observed-predicted plot in Figure 5.29. The with-constant model had a precise accuracy to predict speed limits, and the without-constant model also seems to have an acceptable range of residuals within 2.5 MPH. The observed 85^{th} percentile speeds in the validation sites were also plotted. It was found that the model outcomes have moved correspondingly with the 85^{th} percentile speed but scattered near the posted speeds.

Additionally, the Kolmogorov-Smirov test was performed to statistically check the normality of residuals. The Kolmogorov-Smirnov Test compares an observed cumulative distribution function to a theoretical cumulative distribution. Table 5.25 shows the test outcomes from SPSS. Both models have large significance values (Kolmogorov-Smirnov Z value) at the level of 0.05, meaning that the observed distribution corresponds to the normal distribution. Conclusively, it can be said the two models are not biased. However, this result should be conservatively interpreted because of the small sample size.



(a) With-constant Model



(b) Without-constant Model

FIGURE 5.29: Validation Plots

TABLE 5.25: One-way Kolmogorov-Smirnov Test Result

Test		With-constant Model	Without-constant Model
Sample Size	-	4	4
Normal Parameters*	Mean	-0.2197	0.8075
-	Std. Deviation	0.73273	2.9851
Most Extreme Differences	Absolute	0.240	0.238
-	Positive	0.240	0.238
-	Negative	-0.166	-0.219
Kolmogorov-Smirnov Z		0.480	0.480
Asymp. Sig. (2-tailed)		0.97491	0.97491

* Test distribution is Normal.

CHAPTER 6: SUMMARIES, CONCLUSIONS AND RECOMMENDATIONS

6.1. Summaries

For a reasonable level of safe and efficient travel on highways and streets in urban and suburban areas, appropriate speed limit is an important factor. The process of determining roadway speed limits has been based on guidelines specified by state departments of transportation or local transportation departments. In the U.S., the well-known method of setting speed limits includes maximum statutory limit by road class and geometric area and speed limit established by speed zoning practice for the roadways where the legislated limit does not fit to reflect local differences.

Speed limits in speed zones are suggested to be set based on 85th percentile speed and adjusted periodically on the basis of such factors as crash experience, roadside development, and roadway geometry. However, reflecting these factors into posted speed limit often rely on the practitioner's subjective decision-making. For some roadways in urban and suburban areas, speed limits determined by this way may not be appropriate for safe and efficient movement of vehicles. In addition to that, it is required to justify the speed limits that were set on empirical basis, in order to mitigate safety concerns from local developments or residents. Therefore, there is a need to assess the approaches that determine speed limits on roadways in such areas and to develop methodologies or models that can establish criteria for setting speed limits based on more objective factors and approaches.

This research project explored the possibility of building a mathematical model to set speed limits on the basis of not only the 85th percentile speed but also using other decisive factors quantified, such as geometric, environmental, and traffic related factors. This project focused on nonlimited-access arterial roads in urban and suburban areas in Florida. These roads are characterized by a great variation in geometry, roadside development, and traffic movements, where speed zoning based on engineering investigation would be more appropriate rather than the legislated limit which covers a wide area.

In this project, information databases were searched to identify whether or not there were any past similar studies that could be reviewed as references, especially on technical reports and papers related to roadway speed limit determinations. Existing models and methodologies used by other states and countries to establish posted speed limits were surveyed. However, it was difficult to obtain sufficient information on setting speed limits on mathematical basis.

This research started modeling using the conceptual idea from the methodology used in speed zoning, which is to set a speed limit based on 85th percentile speed and adjusted accordingly based on other factors such as roadway geometric characteristics, land use, area development, crash history, environmental impact, vehicle composition and traffic progressive performance, etc. However, there existed a mathematical disadvantage of modeling in which both 85th percentile speed and other factors were included; that is, they are mutually correlated.

This research proposed a new concept of setting speed limit: speed limits will be the maximum allowable limit, then the speed limits are adjusted by actual traffic, geometric and roadside development conditions. The maximum allowable speed limit is defined as the statutory speed limit of 60 MPH in urban nonlimited-access arterial roads in Florida. The maximum statutory speed limit gets decreased depending on actual conditions, which were expressed as adjustment factors. Development of the model to be used for setting speed limits was based on statistical analyses of data of operating speeds and other important factors on different types of facilities. Statistical tests were also used to identify the important factors that have significant impacts on speed limits.

In addition to the approach described, various mathematical model specifications were attempted including multinomial logit model, ordinal regression model, and other innovative approaches, in order to investigate their feasibility as a speed limit model to be proposed. However, it was not successful to acquire useful results from those approaches. The primary reason was that a rather small size of the sample prevented the alternative models from estimating parameters properly. Also, some mathematical assumptions could not be maintained in some alternative models.

Information data on vehicle speed and composition, geometric data, roadside information were collected in 104 sites in Florida. The criteria in this study were such roadways that had lesser crash experienced, more drivers' compliance to speed limit, and smaller vehicular variance in traffic stream. Afterwards, 47 sites were selected for data collection for modeling and four additional independent sites were reserved as a control sample for model validation purpose.

A number of variables were selected by testing their significance levels in determining 85th percentile speed. The variables utilized in the speed limit model were access density, signal spacing, lane width, functional road class, and shoulder condition. Some variables were omitted from the speed limit model, e.g., land use, number of lanes, and median type were not significant factors influencing vehicle speed, roadside development was strongly correlated with access density, and the number of turning bays in a roadway section also had unacceptable level of correlationship with access density.

The selected variables were transformed into adjustment factor modules, which became the entities in the speed limit model. The concept of adjustment factor modules was introduced as a criterion to compute the adjustment factor in a specific roadway. The adjustment factor module can be configured as a table or an equation depending on the characteristics of the variable. After all the modules were built and plugged into the combined model (speed limit model), the model was further refined by adding weighting factors to adjust the each module's magnitude of the impact to the combined model. Multivariate linear regression technique was used to estimate the weighting factors.

Hundreds of scenarios were tested, taking into consideration alternative forms of variables, different combinations of variables, and different approaches to design the adjustment factor module. Equation 6.1 is the speed limit model finally selected. This model applies to non-limited access arterials in urban and suburban areas in Florida. Also, the application is limited to divided roadways with either standard medians or two-way left-turning lane, and with two or three lanes in each direction. Applying this model to roadways beyond those scopes should be considered conservatively. The validation test showed proper predictability of speed limit by the final model.

$$\begin{aligned}\text{Proposed Speed Limit} = 60\ MPH &\times[0.90+(0.01\times V_{FC})]^{0.734} \\ &\times[1-(0.12\times V_{SC})]^{0568} \\ &\times[1-(V_{AD}/473.9)]^{0.714} \\ &\times[1-(V_{SD}/31.6)]^{0.688} \\ &\times[0.93+(0.07\times V_{LW})]^{1.171}\end{aligned} \quad \text{(Eq. 6.1)}$$

where,

V_{FC}: 1 if the site is major arterial, otherwise 0,

V_{SC}: 1 if the site has a curb on roadside, otherwise 0,

V_{AD} : total number of driveways, minor streets, and median openings in a mile,

V_{SD} : number of signalized intersections in a mile, and

V_{LW} : 1 if lane width ≥ 12 ft, otherwise 0.

Conclusively, this study was expected to resolve some of the concerns that FDOT and its district offices have regarding the determination of posted speed limits in urban and suburban areas. Results of this study may help FDOT and its districts to quantify the speed limits and provide more objective justifications for setting speed limits.

6.2. Conclusions

This study showed that most multi-lane nonlimited-access arterial roadways in urban and suburban areas in Florida currently have 85th percentile speeds approximately 5-10 miles higher than the posted speed limits. That may implied that; (a) local differences were not encountered (existing speed limits posted were merely set by the statutory maximum speed limit or the design speed, both of which cover a wide area), (b) speed limits were set by the 85th percentile speeds and were adjusted after taking other constraints into consideration such as crash rate, access density, and land use, or (c) speed limits by speed zoning investigation were higher than the maximum statutory speed.

This study developed a mathematical model based on engineering investigations to establish speed limit criteria with an acceptable level of accuracy. The main idea of the proposed model is that a speed limit shall be set at the maximum speed limit that the Statue allows as long as the conditions are ideal. Since then, the maximum limit decreases depending on the actual road, roadside, and traffic conditions to set a realistic speed limit. Drivers' speed selection was also considered when designing the adjustment factor modules that are used in the model. The factors included in the model are access density, roadside clearance, lane width, functional road class, and signal spacing. The advantage of this model is its open-structure that allows other methodologies to design adjustment factor modules. The modified adjustment modules can replace the existing ones and will permit to correct regional and temporal differences. In that regard, this model could be a good start to develop more complex and accurate models.

Though this study, other findings include:

- There are discrimination of mean speeds between nighttime and daytime. It seems that the differences were dependant on the nighttime visibility, mainly road lighting. This would suggest the further study on speed limits exclusively for nighttimes.
- Turning bays have a positive affect to the through movements, that is, the higher 85^{th} percentile speeds. This is probably due to the fact that turning bays help to separate the cruising vehicles from decelerating/accelerating vehicles.
- Drivers' compliance to speed limit (the difference between 85^{th} percentile speed and posted speed limit) was not statistically correlated with speed variance in vehicular movements in this study.
- In arterial roads in urban areas, studies showed that vehicle speeds were rather less sensitive to the posted speed than in other types of roadways [6], which implies

lowering speed limit would not necessarily reduce vehicular speeds. In other words, at locations with frequent speed-related crashes in such type of roadways, lowering speed limits may not help in decreasing crashes. Therefore, the crash experiences would not be a vital factor in a speed limit model for the urban arterial roads.

- Because of limited number of pedestrian and bicyclists on arterial roads in Florida, it is questionable whether setting speed limits should consider those factors. It would be more reasonable to consider pedestrians and bicyclists in lower classes of roads. Where notable number of pedestrians and bicyclists are presented, separating those from the traffic may help other than lowering speed limits.

6.3. Recommendations

It would be possible to develop mathematical models for other classes of roadways, such as limited-access highways and rural highways based on the approach used in this project. Also, the approach can be extended to modeling the 'variable speed limit', by which the speed limit changes timely and repeatedly to an appropriate level depending on weather, traffic, and other unstable conditions. Visibility, weather, and road surface condition can be the factors added to the proposed speed limit model to encounter the temporal differences.

The proposed speed limit model made a realistic and reasonable level of speed limits for the given roadway conditions but it still remains questionable if this model will compromise better safety and drivers' comfort, when applied. Periodical investigations on the effects of newly set speed limits on operating speed and safety may ensure the true reliability of any methodologies used in setting speed limits including the model proposed in this project.

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APPENDIX A

FLORIDA STATUTES ON TRAFFIC CONTROL

Appendix A.1: Unlawful speed (Florida Statues: 316.183)

(1) No person shall drive a vehicle on a highway at a speed greater than is reasonable and prudent under the conditions and having regard to the actual and potential hazards then existing. In every event, speed shall be controlled as may be necessary to avoid colliding with any person, vehicle, or other conveyance or object on or entering the highway in compliance with legal requirements and the duty of all persons to use due care.

(2) On all streets or highways, the maximum speed limits for all vehicles must be 30 miles per hour in business or residence districts, and 55 miles per hour at any time at all other locations. However, with respect to a residence district, a county or municipality may set a maximum speed limit of 20 or 25 miles per hour on local streets and highways after an investigation determines that such a limit is reasonable. It is not necessary to conduct a separate investigation for each residence district. The minimum speed limit on all highways that comprise a part of the National System of interstate and Defense Highways and have not fewer than four lanes is 40 miles per hour.

(3) No school bus shall exceed the posted speed limits, not to exceed 55 miles per hour at any time.

(4) The driver of every vehicle shall, consistent with the requirements of subsection (1), drive at an appropriately reduced speed when:

(a) Approaching and crossing an intersection or railway grade crossing;

(b) Approaching and going around a curve;

(c) Approaching a hill crest;

(d) Traveling upon any narrow or winding roadway; and

(e) Any special hazard exists with respect to pedestrians or other traffic or by reason of weather or highway conditions.

(5) No person shall drive a motor vehicle at such a slow speed as to impede or block the normal and reasonable movement of traffic, except when reduced speed is necessary for safe operation or in compliance with law.

(6) No driver of a vehicle shall exceed the posted maximum speed limit in a work zone area.

(7) A violation of this section is a noncriminal traffic infraction, punishable as a moving violation as provided in chapter 318.

Appendix A.2: Establishment of state speed zones (Florida Statues: 316.187)

(1) Whenever the Department of Transportation determines, upon the basis of an engineering and traffic investigation, that any speed is greater or less than is reasonable or safe under the conditions found to exist at any intersection or other place, or upon any part of a highway outside of a municipality or upon any state roads, connecting links or extensions thereof within a municipality, the Department of Transportation may determine and declare a reasonable and safe speed limit thereat which shall be effective when appropriate signs giving notice thereof are erected at the intersection or other place or part of the highway.

(2) (a) The maximum allowable speed limit on limited access highways is 70 miles per hour.

(b) The maximum allowable speed limit on any other highway which is outside an urban area of 5,000 or more persons and which has at least four lanes divided by a median strip is 65 miles per hour.

(c) The Department of Transportation is authorized to set such maximum and minimum speed limits for travel over other roadways under its authority as it deems safe and advisable, not to exceed as a maximum limit 60 miles per hour.

(3) Violation of the speed limits established under this section must be cited as a moving violation, punishable as provided in chapter 318.

APPENDIX B

CORRELATION COEFFICIENTS OF VARIABLES

	Major Arterial	Residential Area	Commercial Area	Side Development	Divided Median	Median Width	Number of Lanes	Lane Width	Left Turning Bays	Right Turning Bays	Curb
Major Arterial	1	-0.260	0.192	0.246	-0.039	0.046	0.096	0.187	-0.169	0.294	-0.489
Residential Area	-0.260	1	-0.918	0.142	0.216	0.206	0.018	0.034	0.000	-0.428	0.186
Commercial Area	0.192	-0.918	1	-0.166	0.008	-0.128	0.034	-0.046	-0.059	0.496	-0.105
Side Development	0.246	0.142	-0.166	1	0.148	0.561	-0.143	0.355	-0.402	0.093	-0.421
Divided Median	-0.039	0.216	0.008	0.148	1	0.343	0.237	-0.056	-0.664	0.249	-0.152
Median Width	0.046	0.206	-0.128	0.561	0.343	1	-0.217	0.216	-0.386	0.194	-0.500
Number of Lanes	0.096	0.018	0.034	-0.143	0.237	-0.217	1	-0.019	-0.214	0.056	-0.008
Lane Width	0.187	0.034	-0.046	0.355	-0.056	0.216	-0.019	1	-0.134	0.145	-0.059
Left Turning Bays	-0.169	0.000	-0.059	-0.402	-0.664	-0.386	-0.214	-0.134	1	-0.211	0.366
Right Turning Bays	0.294	-0.428	0.496	0.093	0.249	0.194	0.056	0.145	-0.211	1	-0.534
Curb	-0.489	0.186	-0.105	-0.421	-0.152	-0.500	-0.008	-0.059	0.366	-0.534	1
Speed Signs	0.041	0.134	0.012	0.292	0.068	0.228	-0.074	0.139	-0.038	-0.113	0.060
Other Signs	-0.132	-0.102	0.213	-0.054	0.224	-0.031	0.222	-0.170	0.008	0.095	0.203
Signals	-0.198	-0.115	0.197	-0.117	0.088	-0.307	0.013	-0.263	0.149	-0.160	0.473
Minor Streets	-0.308	0.211	-0.122	-0.529	-0.027	-0.345	-0.147	-0.341	0.385	-0.192	0.436
Driveways	-0.217	-0.299	0.259	-0.431	-0.370	-0.471	-0.294	-0.228	0.464	-0.275	0.406
Full Median Openings	-0.253	0.135	-0.040	-0.417	0.420	-0.064	-0.224	-0.443	0.004	-0.065	0.201
Dir Median Openings	-0.065	-0.048	-0.043	-0.216	-0.785	-0.303	-0.168	0.043	0.925	-0.186	0.230
Heavy Vehicle	0.084	-0.257	0.076	-0.103	-0.303	-0.131	0.040	-0.205	0.121	-0.069	-0.009
85th Percent Speed	0.564	-0.006	-0.105	0.407	-0.002	0.279	0.211	0.351	-0.386	0.238	-0.686
Posted Speed	0.626	-0.063	-0.040	0.362	-0.067	0.307	0.254	0.327	-0.381	0.253	-0.711

Appendix B.1: Correlation Coefficients (1st Aggregation Level)

	Speed Signs	Other Signs	Signals	Minor Streets	Driveways	Full Median Openings	Dir Median Openings	Heavy Vehicle	85th Percent Speed	Posted Speed
Major Arterial	0.041	-0.132	-0.198	-0.308	-0.217	-0.253	-0.065	0.084	0.564	0.626
Residential Area	0.134	-0.102	-0.115	0.211	-0.299	0.135	-0.048	-0.257	-0.006	-0.063
Commercial Area	0.012	0.213	0.197	-0.122	0.259	-0.040	-0.043	0.076	-0.105	-0.040
Side Development	0.292	-0.054	-0.117	-0.529	-0.431	-0.417	-0.216	-0.103	0.407	0.362
Divided Median	0.068	0.224	0.088	-0.027	-0.370	0.420	-0.785	-0.303	-0.002	-0.067
Median Width	0.228	-0.031	-0.307	-0.345	-0.471	-0.064	-0.303	-0.131	0.279	0.307
Number of Lanes	-0.074	0.222	0.013	-0.147	-0.294	-0.224	-0.168	0.040	0.211	0.254
Lane Width	0.139	-0.170	-0.263	-0.341	-0.228	-0.443	0.043	-0.205	0.351	0.327
Left Turning Bays	-0.038	0.008	0.149	0.385	0.464	0.004	0.925	0.121	-0.386	-0.381
Right Turning Bays	-0.113	0.095	-0.160	-0.192	-0.275	-0.065	-0.186	-0.069	0.238	0.253
Curb	0.060	0.203	0.473	0.436	0.406	0.201	0.230	-0.009	-0.686	-0.711
Speed Signs	1	0.003	-0.054	-0.187	-0.140	-0.260	0.062	-0.361	0.063	0.098
Other Signs	0.003	1	0.301	-0.046	0.025	0.087	-0.085	0.062	-0.385	-0.384
Signals	-0.054	0.301	1	0.217	0.290	0.103	0.050	0.194	-0.579	-0.591
Minor Streets	-0.187	-0.046	0.217	1	0.401	0.588	0.146	-0.183	-0.433	-0.482
Driveways	-0.140	0.025	0.290	0.401	1	0.184	0.390	0.073	-0.479	-0.502
Full Median Openings	-0.260	0.087	0.103	0.588	0.184	1	-0.348	-0.187	-0.429	-0.471
Dir Median Openings	0.062	-0.085	0.050	0.146	0.390	-0.348	1	0.140	-0.169	-0.153
Heavy Vehicle	-0.361	0.062	0.194	-0.183	0.073	-0.187	0.140	1	-0.103	-0.048
85th Percent Speed	0.063	-0.385	-0.579	-0.433	-0.479	-0.429	-0.169	-0.103	1	0.946
Posted Speed	0.098	-0.384	-0.591	-0.482	-0.502	-0.471	-0.153	-0.048	0.946	1

Appendix B.1: (Continued)

	2^{nd} Aggregation				3^{rd} Aggregation	4^{th} Aggregation
	All Turning Bays	All Signs	Minor Streets + Driveways	All Median Openings	Minor Streets +Driveways +Median Openings	All Interruptions
Major Arterial	-0.112	-0.141	-0.281	-0.167	-0.261	-0.244
Residential Area	-0.087	-0.123	-0.171	0.001	-0.105	-0.123
Commercial Area	0.041	0.255	0.169	-0.062	0.071	0.1089
Side Development	-0.392	-0.026	-0.531	-0.393	-0.534	-0.502
Divided Median	-0.628	0.092	-0.310	-0.673	-0.545	-0.564
Median Width	-0.355	-0.036	-0.501	-0.348	-0.492	-0.472
Number of Lanes	-0.208	0.125	-0.289	-0.266	-0.318	-0.266
Lane Width	-0.108	-0.093	-0.302	-0.126	-0.252	-0.233
All Turning Bays	1	0.108	0.461	0.965	0.791	-
Curb	0.265	0.286	0.479	0.323	0.465	0.468
All Signs	0.108	1	0.044	0.031	0.043	-
Signals	0.119	0.259	0.310	0.094	0.240	-
Minor Streets + Driveways	0.461	0.044	1	0.528	-	-
All Median Openings	0.965	0.031	0.528	1	-	-
Heavy Vehicle	0.110	0.003	-0.003	0.076	0.038	0.073
85^{th} Percent Speed	-0.347	-0.399	-0.537	-0.348	-0.51	-0.550
Posted Speed	-0.338	-0.392	-0.573	-0.347	-0.535	-0.561

Appendix B.2: Correlation Coefficients (2^{nd} - 4^{th} Aggregation Level)