THE RELATION BETWEEN FREEWAY AVERAGE SPEED

AND SPEED NOISE

by

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Abstract

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AND SPEED NOISE

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A significant amount of energy could be saved by applying traffic management policies. Many factors affect the fuel consumption rate, and the most important traffic-related ones include variables such as speed, number of stops, the speed noise, and the acceleration noise (acceleration standard deviation). Fuel consumption models for both urban and highway traffic are used to evaluate the effect of these factors. Previous literature shows the speed and the acceleration of the individual vehicles as well as the aero-dynamic effects are the most considered parameters in highway fuel consumption models. However, the existing models are based on the average or cruising speed and the effect of speed variation is not included.

Incorporating the speed standard deviation as a variable in the prediction models seems to be impractical because measuring the speed standard deviation is cumbersome. However, since the speed variance and the speed may be correlated, knowing the relation between those two, the speed noise can indirectly be included in the model.

Therefore, this study considers the new parameter of speed noise in the Vincent fuel consumption model. Also, in order to practically import the speed noise effects to the model, the relation between speed and the speed noise is evaluated. The equivalency equation of the speed noise in terms of the speed is the new term added to the existing model.

This thesis uses freeway speed data collected by TxDOT to find the relation between speed and the speed noise.

This study's findings show a strong relation between speed and speed noise. The outcomes also reveal the higher the speed, the lower the speed noise will be. Reflecting on these findings, this study recommends the modified form of the Vincent fuel consumption model for highway traffic.

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Chapter 1

Introduction

1.1 Background Information

The U.S. transportation sector is a major consumer of fossil fuels (Consumption of Oil for Transportation, 2013). In fact, the transportation sector in the U.S. accounts for about two-thirds of the liquid petroleum fuels consumed each year in the U.S. This energy use is concentrated primarily in the highway mode (Schipper & Saengerand & Sudardshan, 2010).

The factors that affect variation in the fuel consumption rate include traffic characteristics, vehicle performance characteristics, driver characteristics, environment conditions, pavement conditions, etc. (Ardekani & Hauer & Jamei, 1992). Among them, traffic-related factors are studied in this research. The studies show the traffic-related factors include but are not limited to variables such as speed, number of stops, speed noise, and acceleration noise.

The significance of this issue is emphasized when it is realized that all modes of transportation that consume fossil fuels contribute to air and water pollution of the environment, through burning and the refueling cycle (Consumption of Oil for Transportation). In the U.S., domestic transport contributed 34% of total carbon emissions from fossil fuel combustion in 2006. Transportation emissions account for about 60% of carbon monoxide, 40% of nitrogen oxides, and about 40% of volatile organic compounds including hydrocarbons emissions (Consumption of Oil for Transportation).

1.2 Problem Statement and Objectives

The primary objective of this research is to find the relation between speed and the speed noise (standard deviation of speed along time) to propose a new fuel consumption model for highway traffic. Most of the existing models offer simplified expressions to compute fuel consumption based on average link speeds without much regard to the transient effects of speed. However, this thesis addresses this issue, presenting the new parameter in the existing model to consider speed noise as an explanatory variable.

1.3 Research Questions

Addressing the above mentioned purposes of the study, the main questions are stated below:

- Is there any relation between speed and speed noise in highway traffic?
- Does this relation differ based on the number of lanes in the highway?
- How could this relationship be used to modify the current highway fuel consumption models?

1.4 Research Overview

This thesis is organized into five chapters. The first chapter provides the statement of the problem and objectives of this research. The second chapter reviews the existing literature on the subject. This chapter explains the contribution of motor vehicles to both air pollution and the energy consumption. It also discusses the factors affecting fuel consumption. Finally, it describes the various mathematical fuel consumption models for both urban and highway traffic.

The third chapter describes some of the data sources used in the model and the methodology used in the research. It also includes the main analysis on the relation between speed and speed noise. Chapter 4 is dedicated to discussion over an implementation of the findings in fuel consumption models. Finally, Chapter 5 summarizes the findings and presents a discussion of the limitations of the result and directions for future research.

Chapter 2

Review of Literature

2.1 Contribution of Motor Vehicle Transportation to Energy Consumption

The magnitude of the impact of fuel consumption by individual cars is generally underestimated when looked at in isolation. However, the combined effects of emission and fuel consumption cannot be disregarded, given the enormous number of the motor vehicles in the U.S. In fact, personal automobiles are the single largest polluter in the U.S.

2.2 Transportation and Fuel Consumption

The transportation sector's primary energy source is petroleum, and it accounts for almost 35% of the total petroleum consumption in the U.S. Highway traffic contributes up to 75% of the total transportation energy use, with about 80% from automobiles, motorcycles, and light trucks and about 20 % from buses and heavy trucks (Kenworthy et al., 1986).

2.3 Factors Affecting Fuel Consumption Rates

The vehicle fuel consumption is a function of several variables. These variables have been categorized as follows (Ahn & Rakha, 2005; Ahn et al., 2002):

- traffic-related factors
- roadway-related factors
- environmental-related factors
- vehicle-related factors
- driver-related factors

The following paragraphs describe each of these factors in detail.

2.3.1 Traffic-related factors

The traffic-related factors include variables such as speed, number of stops, speed noise, acceleration noise, and the driving mode. The speed and acceleration of vehicles are significant factors contributing to the vehicle fuel consumption. According to the early models, below the speed of 55 (mph), as the cruising speed increases, the fuel consumption gradually decreases. After 55 (mph), however, the fuel consumption increases as the cruising speed grows. Therefore, the relationship between cruising speed and fuel consumption is recognized to be curvilinear (Kenworthy et al. 1986; Makberud, 1983). However, these estimates lack the acceleration information. For example, a sharp acceleration, which contributes to a jump in fuel consumption rate, is not explained in these traffic models.

The number of stops, speed noise, and acceleration noise are also important factors contributing to the fuel consumption rates. According to these models, there is a linear relation between the number of stops and fuel consumption. The studies show a higher number of stops results in higher fuel consumption rates (Herman & Ardekani, 1985).

2.3.2 Roadway-related factors

Roadway-related factors including roadway gradient and pavement roughness and, more generally, road surface appear to affect fuel efficiency. Many studies reveal, under steep upgrade conditions, vehicles require heavy power from their engines, which leads to more fuel consumption than under flat or downhill conditions (Organization for Economic Co-Operation and Development, 1982). Also, the rough surface of the roads can cause vehicles to consume more fuel by influencing the rolling resistance and the aerodynamic drag generated. Baker shows that a test vehicle on a rough road consumes 5% more fuel than a test vehicle on a normal condition road surface (Baker, 1994).

2.3.3 Environmental-related factors

Environmental conditions including wind condition, ambient temperature, elevation, and humidity influence the fuel consumption rate. Studies by Organization for Economic Co-Operation and Development (OECD) discuss the effects of ambient temperature on hot and cold engine fuel consumption. The discussion shows there is a linear relation between fuel consumption rate and ambient temperature. In this relation, a decrease in ambient temperature leads to increased fuel consumption. This impact is more severe in temperatures below 0° C (Organization for Economic Co-Operation and Development, 1982).The literature also indicates that ambient temperature has a severe impact on fuel consumption rate when an engine is operating under cold start conditions (Eccleston & Hurn,1978).

High wind conditions could also increase the fuel consumption rate because of the aerodynamic resistance (Murrell, 1980). In another study, Momani and Badran investigate the effect of altitude on fuel consumption. Their study shows the fuel consumption depends on the elevation above sea level. Based on their finding, when the elevation decreases, the engine efficiency will increase because of the increase in atmospheric pressure (Al-Momani & Badran, 2007).

2.3.4 Vehicle-related factors

The vehicle characteristics such as weight, engine size, transmission type, tire size and pressure, vehicle age, and engine tune-up affect the fuel consumption rate.

Studies show that larger and heavier vehicles consume more fuel (Murrell, 1980). Also, vehicles with an automatic transmission appear to have greater fuel consumption compare to manual transmission vehicles (Murrell, 1980).

The vehicles with larger engine sizes also consume more fuel compared to the small engine-size vehicles (Bigazzi & Clifton & Gregor, 2012). A study by Lam shows there is a positive relation between engine size and fuel consumption rate (Tenny & Lam, 1985). Also, the age of the vehicles influence the fuel consumption. Older vehicles consume more fuel compared to younger ones (Berry, 2010).

Studies by Baker show that bad engine tuning could lead to an increase of average fuel consumption by about 10%. This study also shows that misalignment in wheels can result in an increase of 3% in fuel consumption rate due to tire rolling resistance (Baker, 1994).

2.3.5 Driver-related factors

Finally driver-related characteristics such as aggressiveness and driving cycle could affect the fuel consumption rate. Recently, a large number of studies have been conducted measuring the impact of driver behaviors on fuel consumption rate (Sivak & Schoettle, 2012; Agency et al. 2003; Ericsson, 2001; Kim & Choi, 2013). In most of these studies, the driver behavior is quantified by an aggressiveness factor and a vehicle jerk factor. In the report issued by Berry, the relation between the fuel consumption and the highway aggressiveness factor is evaluated. Based on the findings, a higher driver aggressiveness factor would cause a higher fuel consumption rate (Berry, 2010). Studies show that a higher vehicle jerk factor would also lead to a higher fuel consumption rate (Berry, 2010).

2.4 Different Types of Fuel Consumption Models

Fuel consumption models are mathematical relationships using contributions of different types of factors to predict the fuel consumption. These models quantify the contribution of the stated factors in the previous section such as average speed, number of stops, average acceleration, etc. Various models have been developed to predict vehicular fuel consumption. These models mostly are known as instantaneous fuel consumption models, average speed fuel consumption models, and modal fuel consumption models. These various models are discussed below.

2.4.1 Instantaneous fuel consumption models

An instantaneous fuel consumption model is a microscopic model. This model attempts to measure the amount of energy required to overcome the aerodynamic and rolling resistance. Power-based fuel consumption models are derived from the instantaneous relationship, which relates the fuel consumption rate to the power requirement of the vehicles (An & Rosse, 1993).

The predictor variables in this type of model are mostly those of vehicle-related factors such as vehicle mass, frontal area, tire resistance, transmission type or efficiency, engine displacement, and also traffic-related factors, such as speed and acceleration (detailed speed and acceleration/deceleration profile is used in this model). Other road condition characteristics might be used as an input in this model (Baker, 1994). Baker, in his studies, mentions that “since there is no aggregation of data, this model type is the most fundamental and accurate for predicting fuel consumption” (Baker, 1994).

2.4.2 Modal fuel consumption models

The modal fuel consumption model is also a microscopic model. The assumption in this model is that the different driving modes are affecting the total fuel consumption independently and the total fuel consumption is the sum of the fuel consumption in each mode. There are three driving modes in this model: duration of travel at constant speed, phase of acceleration and deceleration (full or partial stop-and-go from the constant speed) and the stopped time or time spent idling. The total fuel consumption is the sum of fuel consumption in each mode.

The simplicity, availability of data (constant speed and acceleration), generality, and conceptual clarity, as well as the direct relationship to existing traffic modeling techniques make this type of model popular (Ahn, 1998).

2.4.3 Average speed fuel consumption models

Average speed models are considered macroscopic models. The predictor factors in these models are average trip times, average trip distance and average speed. This model is generally useful for travel speeds below 30mph due to its inefficiency in capturing effects of drag resistance at high speeds (Al-Momani & Badran, 2007). However, with some modification, they are being used in higher speeds.

2.5 Overview of Existing Fuel Consumption Models

Many models have been developed considering some of the influential variables in fuel consumption. Most of the time, a study's specific objectives define which variables to be included and which not. The study by Evans, Herman, and Lam shows that the speed alone accounts for more than 70% of the variability in fuel consumption for a given vehicle (Evans, Herman & Lam, 1976). Later, other research introduces other explanatory variables such as acceleration and deceleration. An example could be entering and exiting at a toll station where the average speeds may be the same, but the fuel consumption in those situations is substantially different (Song & Yu, 2009). Akcelik considers the fuel consumption as a function of three explanatory variables: the cruising speed, the delay time, and the number of stops (Akcelik, 1981). Song and Yu consider the parameter of vehicle-specific power (VSP) as a measurement for vehicle activities in the fuel consumption model (Song & Yu, 2009).

Ahn et al. introduce a model that uses instantaneous speed and acceleration. Their proposed model includes a combination of linear, quadratic, and cubic speed and acceleration terms (Ahn et al., 2002). Chang and Morlok show there is a linear relation between fuel consumption and travel time (Chang & Morlok, 2005). Herman and Ardekani (Herman & Ardekani, 1985) have shown the influence of stops on vehicle fuel consumption in urban traffic. Other studies have attempted to quantify the impact of vehicle stops and speed on vehicle fuel-consumption and emission rates in a wider range (Rakha & Ding, 2003).

Evans et al. investigate the relationship between fuel consumption rate and different variables including speed noise (Evans & Herman & Lam, 1976). Based on this article's findings, the fuel consumption rate and speed noise are highly correlated, but this variable is not included in their proposed model since they found that 82 percent of variability in fuel consumption can be accounted for by average trip time, distance, and the work per unit distance to accelerate.

In some fuel consumption studies, models are categorized into two traffic conditions as urban (speed less than 40 mph) versus highway (speed greater than 40 mph). The highway condition, which is of interest in this study is the condition under which average speed is so high (more than 40 mph) that aero-dynamic effects on fuel consumption become important. (Ardekani et al., 1992)

2.5.1 Existing steady-state speed models

The two well-known highway steady-state speed models are the models introduced by Vincent et al. and Post et al. (Ardekani et al., 1992)

Vincent et al. introduce the following model for highway traffic condition (Vincent, Mitchell & Robertson, 1980):

(2.1)

$$f_c = a + bV_c + cV_c^2$$

Where,

f_c : Steady-state fuel consumption rate at cruising speed (ml/km)

V_c : Steady-state cruising speed (km/hr)

a = 170 ml/km,

b = - 4.55 ml-hr/km

c = 0.049 ml-hr /km

Vincent et al. uses TRANSYT/8 to provide an approximate estimate of the fuel consumption in a network when a particular set of signal timings is operating. Their proposed equation for fuel consumption is valid at constant cruise speed (Vincent, Mitchell & Robertson, 1980).

Post et al. include the aero-dynamic effects in their proposed model (Ardekani et al., 1992):

(2.2)

$$f_c = b_1 - b_2/V_c + b_3{V^2}_c$$

Where,

$b_1 = 15.9 \text{ ml/km}$

$b_2 = 2{,}520 \text{ ml/hr } 2$

$b_2 = 0.00792 \text{ ml} - \text{hr /km}$

Among these two, the Vincent et al. model is considered in this research because it is valid at any speed range, and because this model is used in several simulation packages such as TRANSYT.

The speed in this model is the cruising speed, and the aim of this thesis is to revise it to reflect the speed variation in the model.

2.6 Effects of Speed Variation on Fuel Consumption

Hopkins, Hazel and McGrath in their research, report that a non-uniform velocity profile can result in 5-15% more fuel consumption than a constant speed profile (Hopkins, Hazel & McGrath, 1978). In another study by Chang and Morlok, the effect of increasing standard deviation of speedf on fuel consumption is evaluated for land transport vehicle (road or rail). Figure 2-1 is the standard deviation of speed plotted against fuel consumption for the three scenarios Chang et al. considers in their study. The simulated result indicates a positive linear relation between the speed standard deviation and fuel consumption rate (Chang & Morlok, 2005).

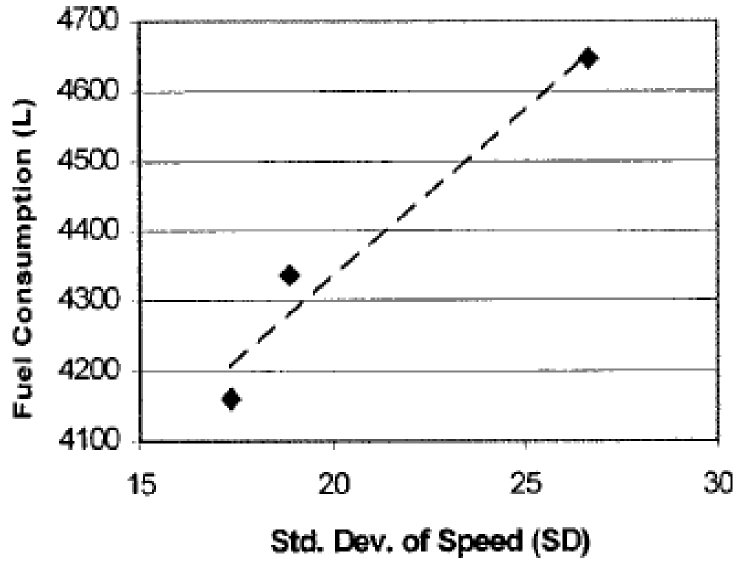

Figure 2-1 Effects of increasing standard deviation of speed on fuel consumption over test route

2.7 Relation between Speed Standard Deviation and Speed

Speed standard deviation is a measure of speed fluctuation. There are rarely any studies focused on finding the relation between speed and speed deviation (standard deviation of speed). Shankar and Mannering evaluate the relation between lane-mean speed and lane-speed deviation. Based on their findings, the relationship between lane-mean speed and lane-speed deviation is statistically valid (Shankar & Mannering, 1998). However, the aim of their research is providing a better understanding of mean speeds and speed deviations across the lanes of a multilane highway rather than finding this relation along the time axis which is the focus of this study.

2.7.1 Average speed

Usually, average speed is the flow-weighted speed calculated based on the formula below:

$$\bar{V} = \frac{\sum v_i q_i}{\sum q_i} \tag{2.3}$$

Where,

$\bar{V}$ is the flow-weighted speed in the minute of interest

v_i is the average speed of vehicles on lane i on the minute of interest

q_i is the flow on lane i in the minute of interest

2.7.2 Speed variance (standard deviation)

In the process of evaluating the relationship postulated to exist between speed variance and speed, two different types of speed variances could be considered. They are defined below in more detail:

1. Variance over time of flow-weighted speeds. The variance over time of the aggregate speed is the variance of the flow-weighted speed in every time interval of t minutes (Blandin, Salam & Bayen, 2011). Usually the time interval depends on the objective of the study and the availability of the associated data. However, the time interval should be long enough to have sufficient values of speed for computing the variance and short enough to satisfy the consistency of the assumption of a stationary traffic state (Bulteau et al. 2013).

This variance is computed according to the following equation:

(2.4)

$$Var_t = \sigma_V{}^2 = \frac{\sum f_i \bar{V}_i^2 - (\sum f_i \bar{V}_i)^2/n}{n-1}$$

Speed standard deviation is computed according to the following equation.

(2.5)

$$\sigma_{V=} \sqrt{\frac{\sum f_i \bar{V}_i^2 - (\sum f_i \bar{V}_i)^2/n}{n-1}}$$

where:

$\sigma_V{}^2$ is the flow-weighted variance of speed in the minute of interest

σ_V is the flow-weighted standard deviation of speed in the minute of interest

$\bar{V}_i$ is the average speed of vehicles in lane i in the minute of interest

f_i is the flow in lane i in the minute of interest

2. Variance of the flow-weighted average speed across the lanes. Variance over flow of the speed calculates the variance of average speed across the lanes. In other words, this is the variance between average speeds on each of the lanes i during the time interval of interest.

Finally, the total variance incorporates both of the components involved, more explicitly the variance over time of the aggregated (individual) speed in each unique lane and also the variance over the average speed among lanes during the time interval of interest.

2.8 Summary of Chapter 2

The provided review of the literature has shown the complex nature of the several factors that affect the vehicle fuel consumption. These factors include traffic-related factors, roadway-related factors, environmental conditions, vehicle characteristics, and driver behavior, especially, the factors such as vehicle speed and acceleration, start-up emissions, and engine characteristics. Several models that predict the fuel consumption rate, and are based on different groups of factors, are highlighted. The few studies on the relation between the speed standard deviation and the fuel consumption indicate there is a positive relation between the fuel consumption rate and the speed standard deviation, with the understanding that higher speed leads to a larger fuel consumption rate.

The next chapter describes the methodology of this study and the data sources used. The main part of the chapter is dedicated to investigation of the relation between speed and the speed standard deviation.

Chapter 3

Methodology

3.1 Introduction

This chapter first describes some of the data sources that are used in the research. Then it continues by discussing the research methodologies. Finally, the chapter provides the preliminary data analysis for further discussion in Chapter 4.

3.2 Data Description

The first group of data used for assessing the relation between speed and speed noise (speed standard deviation) is derived from TxDOT traffic data. That data is in the form of daily traffic counts data, which is filed for all DFW detector stations. The data includes speed and counts for each lane in 5 minute intervals. For the purpose of this research, different highways have been considered, and the traffic speed data for highways with two, three, four, and five lanes (in each direction) have been gathered. In order to have more observations, more than one day for each type of highway is analyzed (DFW Traffic Data, 2013).

The raw data includes aggregated traffic data (date and time, detector status, speed, volume, and occupancy the) for five-minute intervals and for the entire day. The data are converted to 30-minute interval data. In each 30-minute interval, the average speed of the six 5-minute aggregate-speeds, and the speed standard deviation of these six 5-minute aggregate-speeds are calculated. It should be noted that because of using the aggregated data some of the micro level characteristics might be lost.

The other set of data is derived from the research by Ardekani and Sumitsawan (Ardekani & Sumitsawan, 2010). This data is used to find the correlation coefficient between speed standard deviation and fuel consumption rate. In this research two different driving modes (cruise and varying speed) are used. In the constant speed mode, the test car maintains a cruise speed of 30 (mph). In the other case, the test car speeds up from zero to 30 (mph) in 10 seconds. For both cases the fuel consumption data are collected (Ardekani & Sumitsawan, 2010).

3.3 Methodology

The approach for conducting this research from a methodological perspective is quantitative. Regression models and statistical analysis are used to find the relation between speed and speed noise. Later, a mathematical approach is used to enter the effect of speed noise into the fuel consumption model.

The F-test and t-test are used to identify whether or not the model and the coefficients in the model are statistically significant. Later, to formulate the final model, a semi-standardized residuals test is used to define the outliers and remove them from the data set. The initial assumption of this analysis is that the residuals are normally distributed and have a constant variance.

3.4 The Relation between Speed and Speed Noise

A regression model is developed to model the relationship between speed and speed-noise. The conventional method of finding any correlation is based on a linear regression. Data is gathered for speed and speed standard deviation.

The initial assumption is that speed noise decreases as the speed increases. In this modeling effort, the speed is the independent variable and speed noise is the dependent variable. Also, the regression allows the estimation of the coefficients of the following model:

$$\sigma_V = a + bV \tag{3.1}$$

Where,

σ_V : Speed noise (mph)

a : Intercept

b: Coefficient of equation

V: Average speed (mph)

The primary regression analysis is applied to four highways (from 2 lanes per direction to 5 lanes per direction). Later, the reliability of the results and the significance of the model are tested using different methods including the generalized F-test and evaluation of the p-values. To formulate the final model, the statistical outliers are defined by using the natural version of Cook’s D Statistic techniques. The final model includes all the observations excluding the outliers.

In Figures 1 to 15, the speed standard deviation in miles-per-hour is plotted versus speed in miles-per-hour for each of the lanes of all highways. The first highway is the two-lane per direction highway of eastbound SH 114 at O’Connor which is located in Dallas County, Texas.

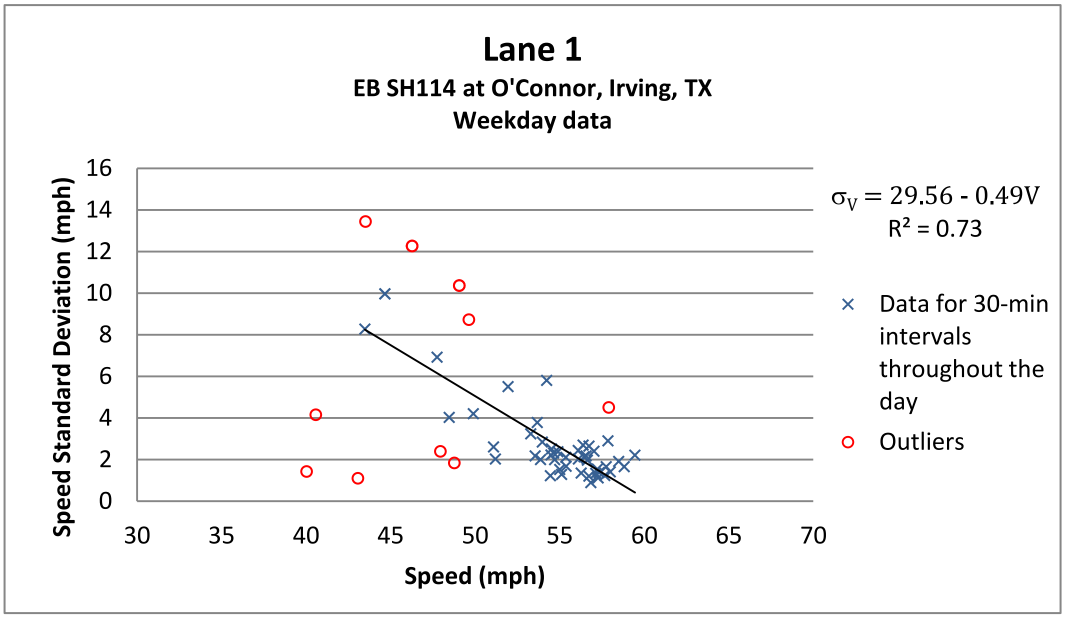

Figure 3-1 Speed Variation and Speed Relation for a Two-lane per Direction Highway

(Lane 1)

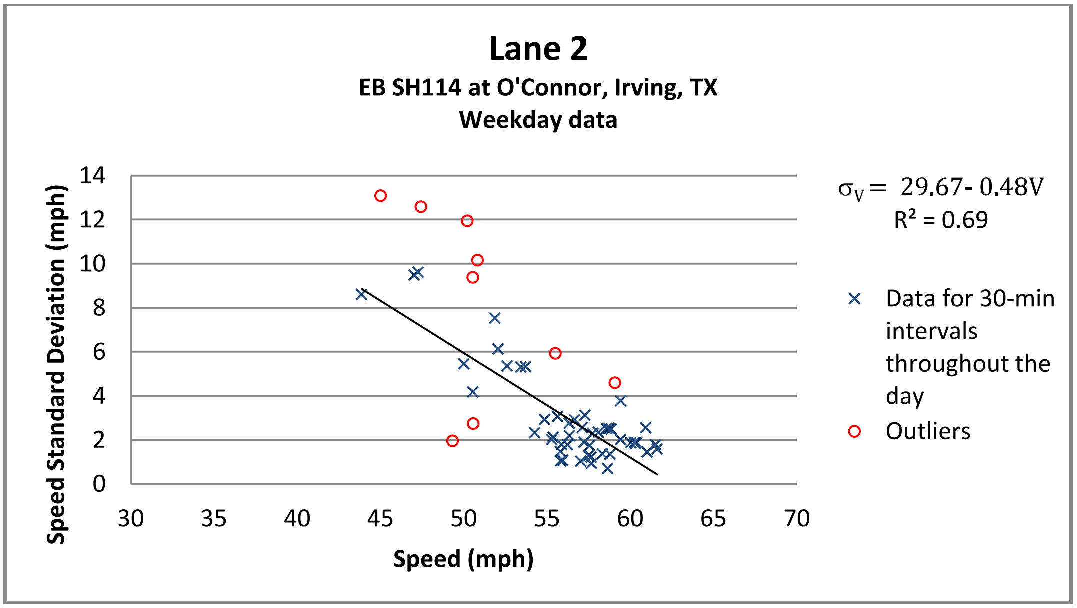

Figure 3-2 Speed Variation and Speed Relation for a Two-lane per Direction Highway

(Lane 2)

The speed varies between 40 (mph) and 65 (mph), and the linear relation is fairly strong and similar in both lanes. The second highway is the three-lane per direction highway of Northbound US 175 at Pine St. US 17 is located in Dallas County, Texas.

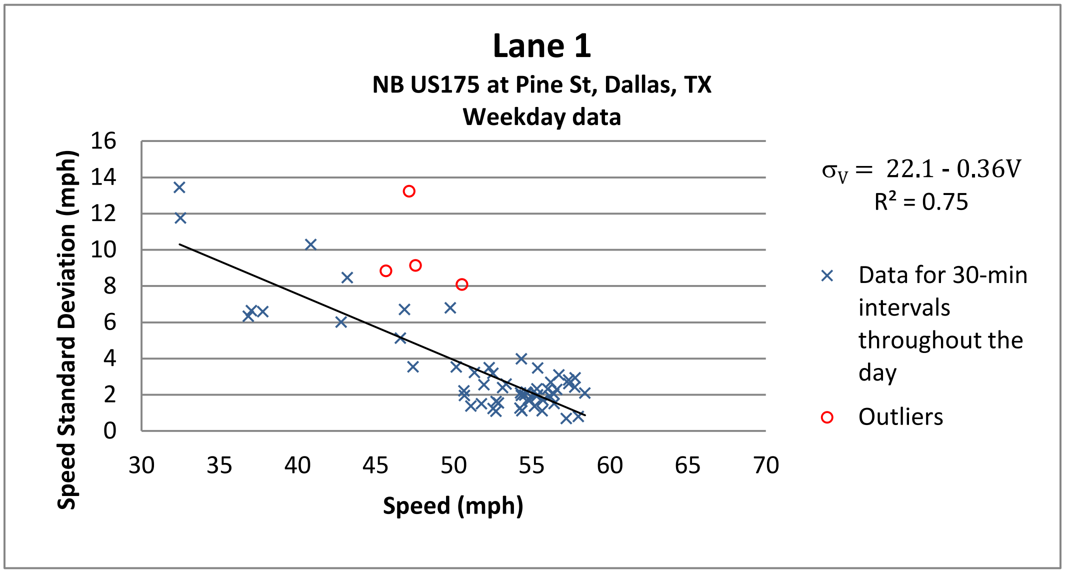

Figure 3-3 Speed Variation and Speed Relation for a Three-lane per direction Highway (Lane 1)

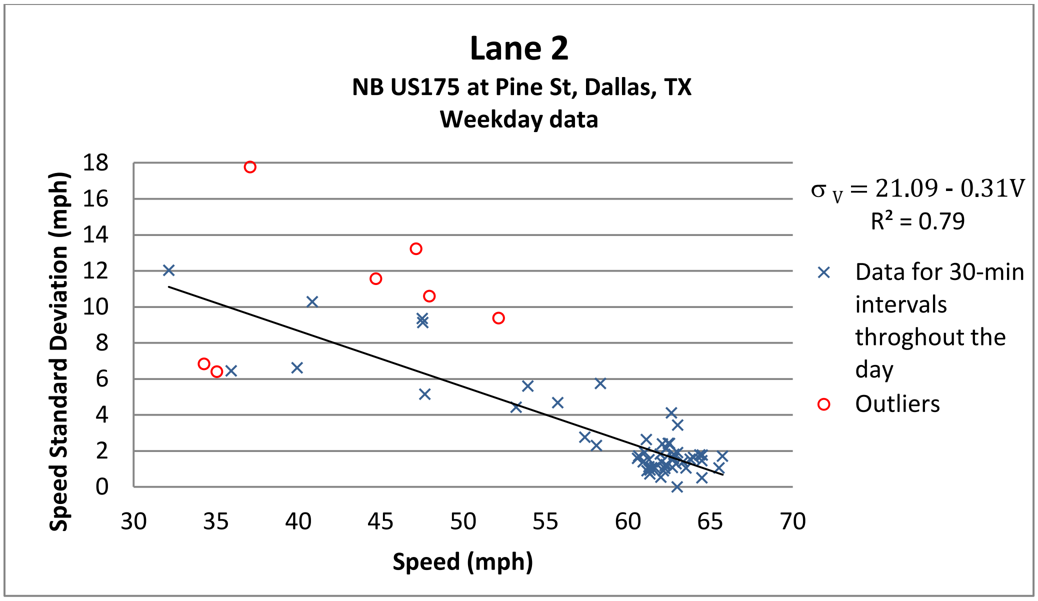

Figure 3-4 Speed Variation and Speed Relation for a Three-lane per direction Highway

(Lane 2)

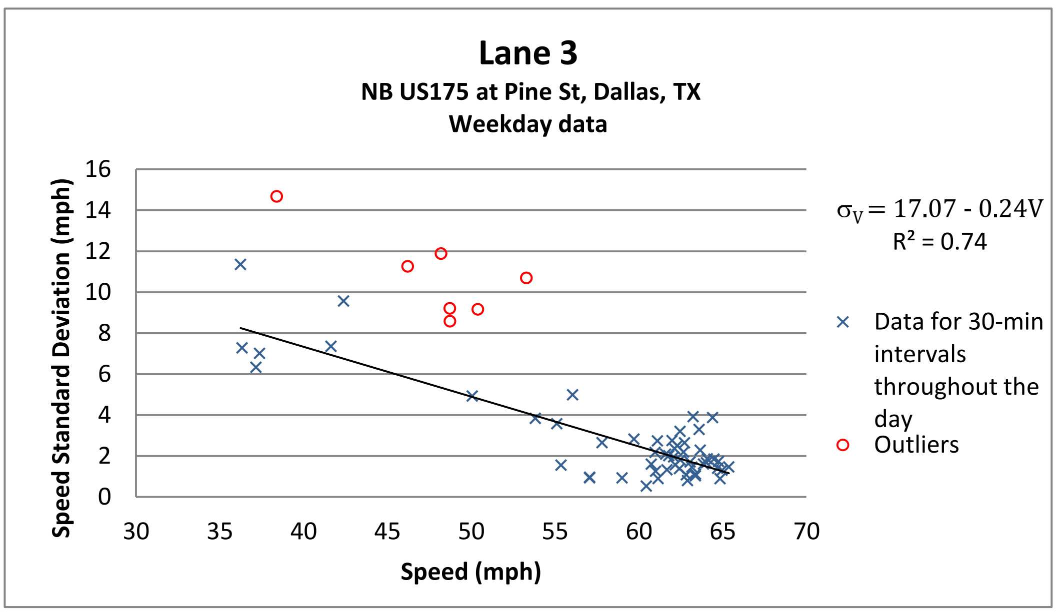

Figure 3-5 Speed Variation and Speed Relation for a Three-lane per direction Highway

(Lane 3)

The speed varies between 35 (mph) and 70 (mph) in this segment of the highway. The linear relation is strong in all of the lanes. The middle lane shows a slightly stronger linear relation.

The third highway is the four-lane per direction highway of Southbound US75 at Mockingbird. This point at US75 includes four lanes in each direction and is located in Dallas County, Texas.

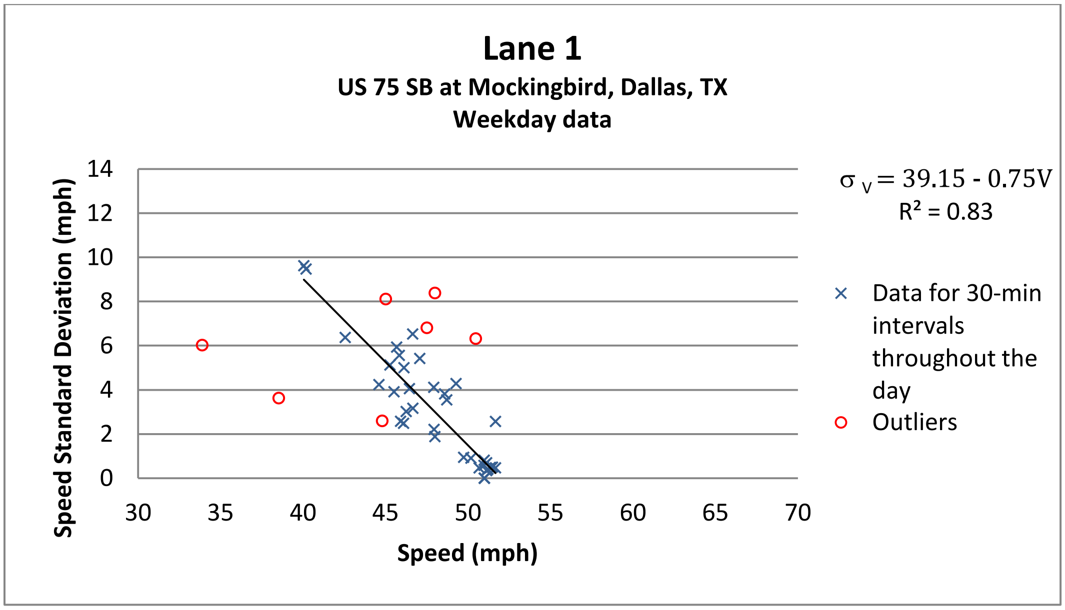

Figure 3-6 Speed Variation and Speed Relation for a Four-Lane per Direction Highway (Lane 1)

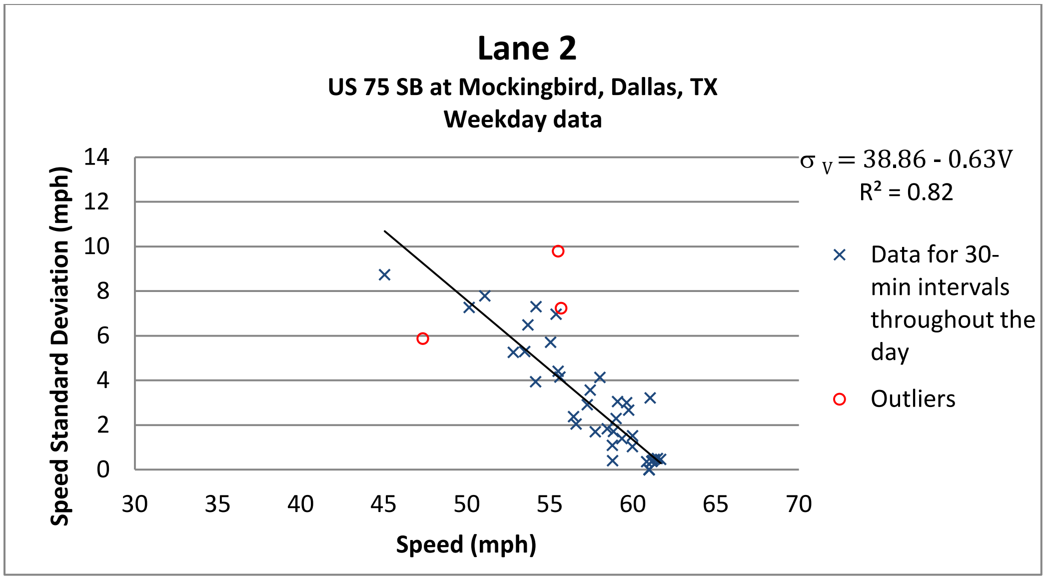

Figure 3-7 Speed Variation and Speed Relation for a Four-Lane per Direction Highway

(Lane 2)

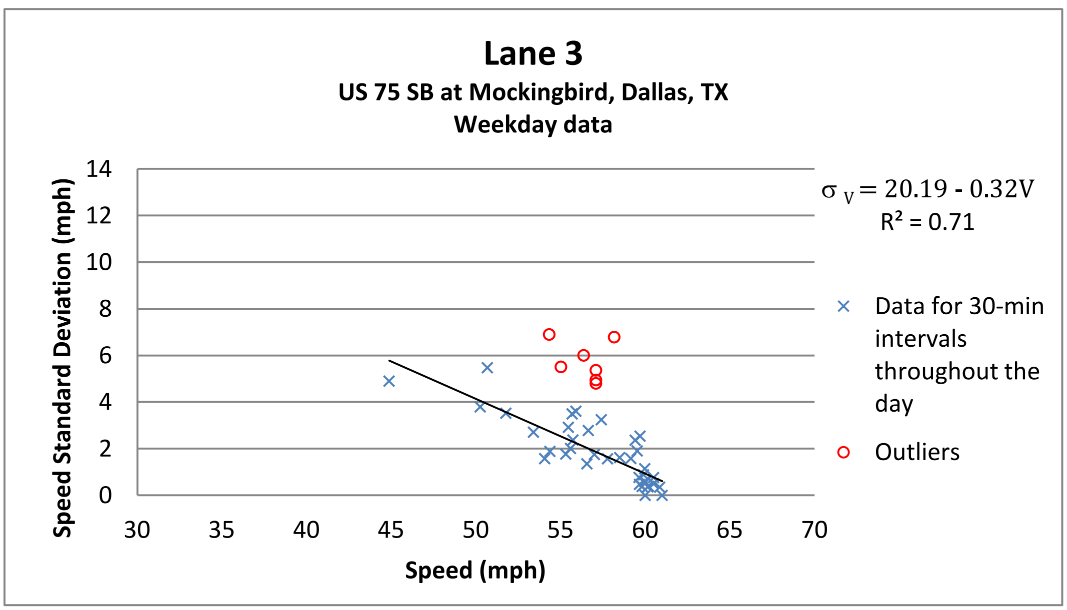

Figure 3-8 Speed Variation and Speed Relation for a Four-Lane per Direction Highway

(Lane 3)

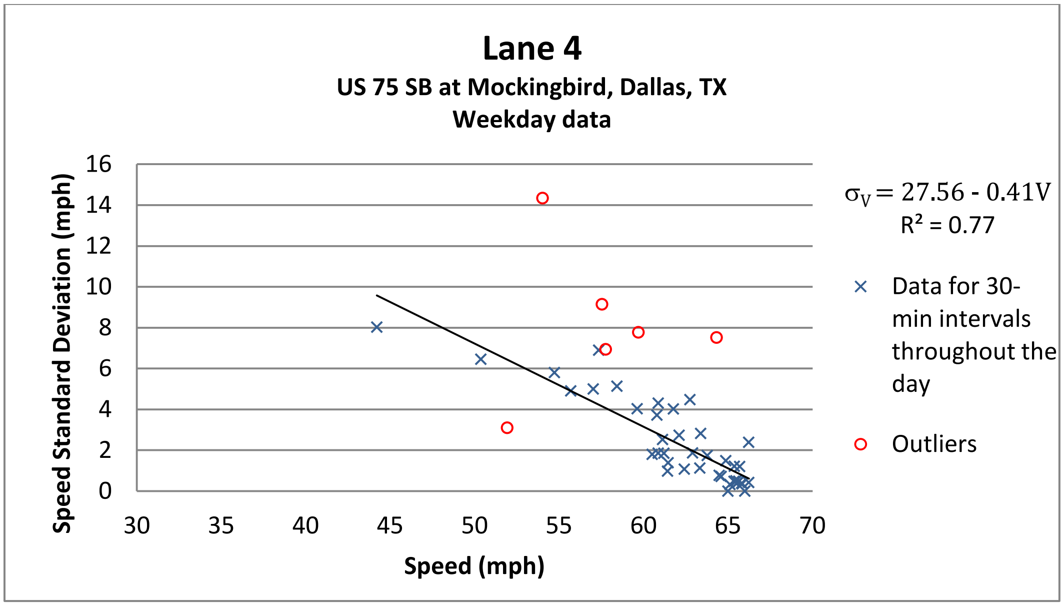

Figure 3-9 Speed Variation and Speed Relation for a Four-Lane per Direction Highway (Lane 4)

The speed varies between 35 (mph) and 70 (mph) in this segment of the highway. The linear relation is strong in all of the lanes. The middle lanes and the right lane show slightly stronger linear relation.

The last highway considered is five-lane per direction highway of Eastbound IH 20 at Cedar Ridge. This point at highway IH20 includes five lanes in each direction and is located in Dallas County, Texas. It should be noted that there is a steep uphill grade at this site.

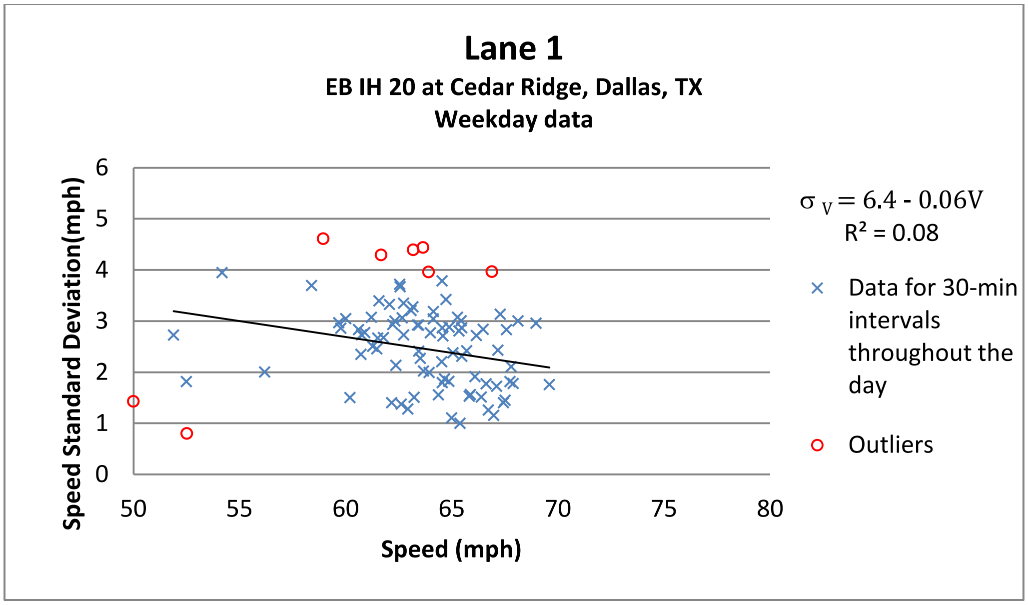

Figure 3-10 Speed Variation and Speed Relation for a Five-Lane per Direction Highway

(Lane 1)

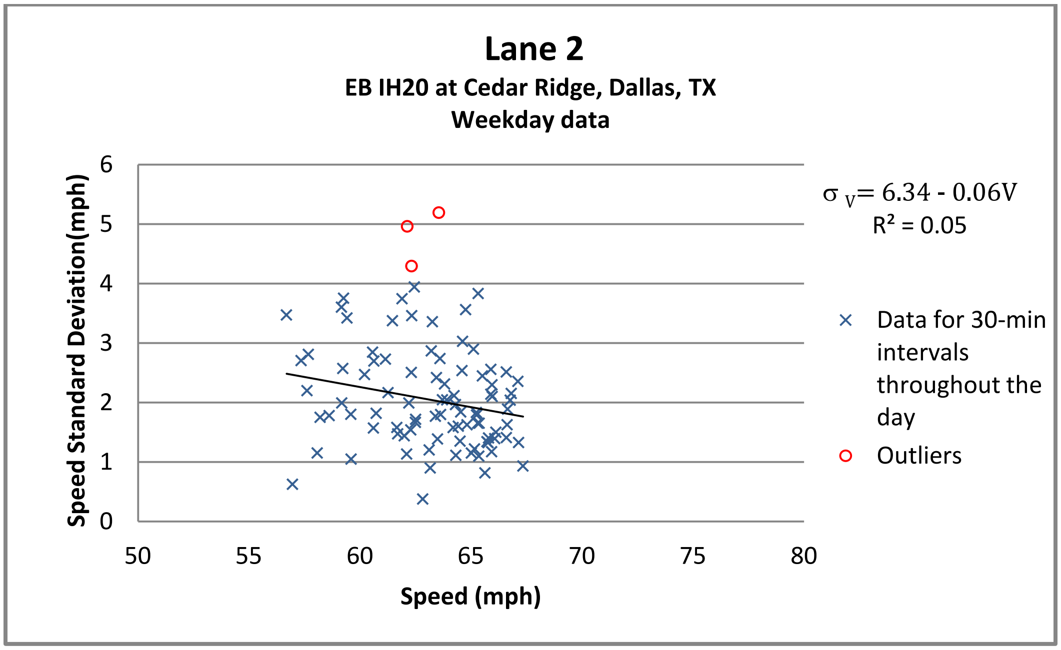

Figure 3-11 Speed Variation and Speed Relation for a Five-Lane per Direction Highway

(Lane 2)

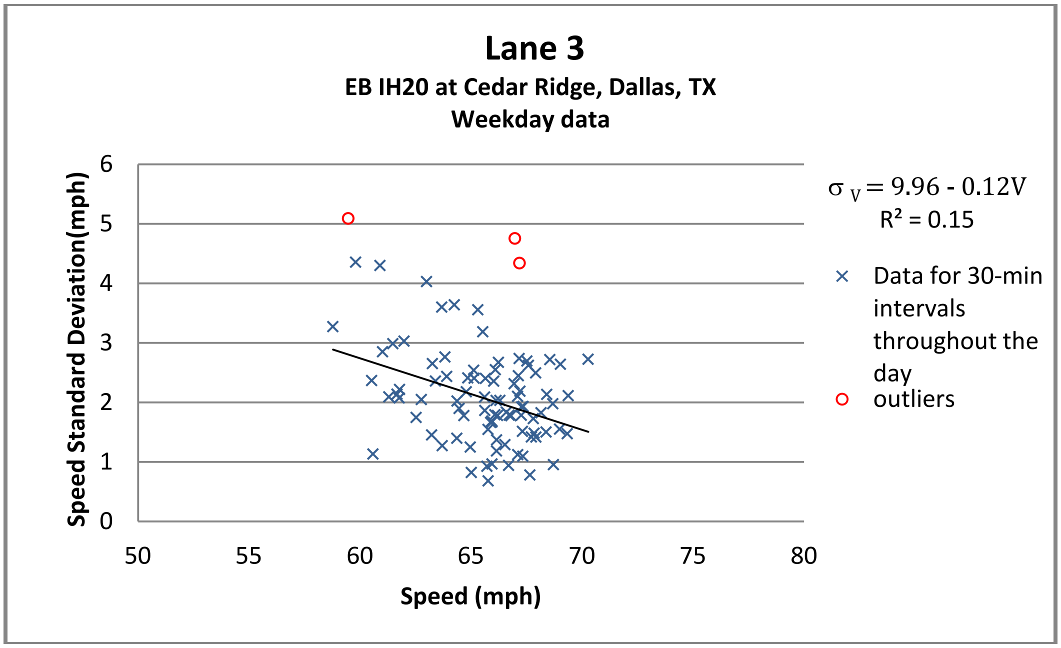

Figure 3-12 Speed Variation and Speed Relation for a Five-Lane per Direction Highway

(Lane 3)

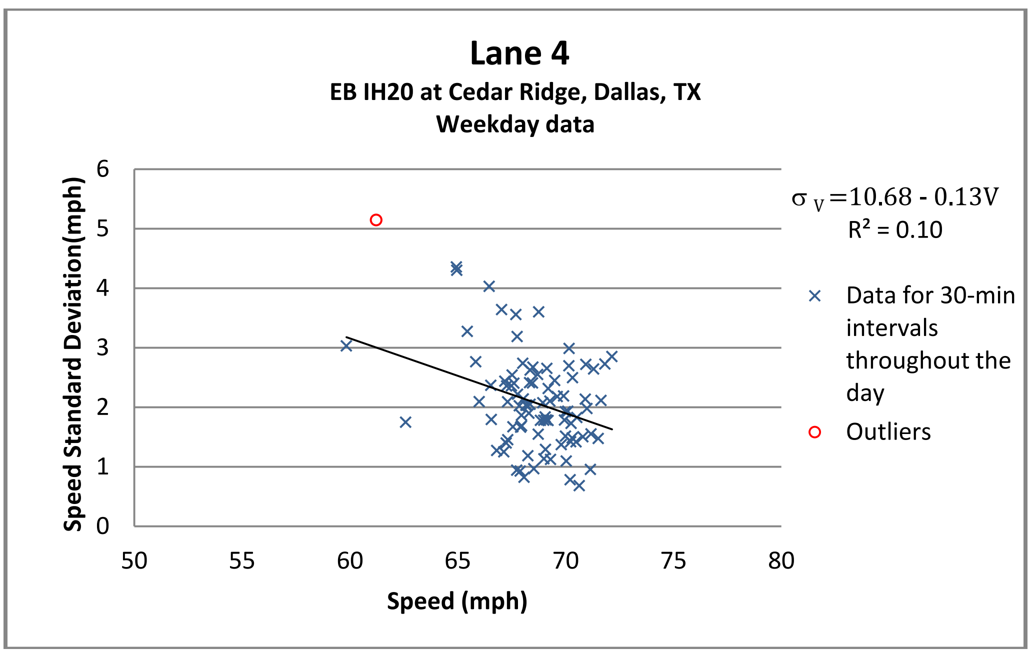

Figure 3-13 Speed Variation and Speed Relation for a Five-Lane per Direction Highway

(Lane 4)

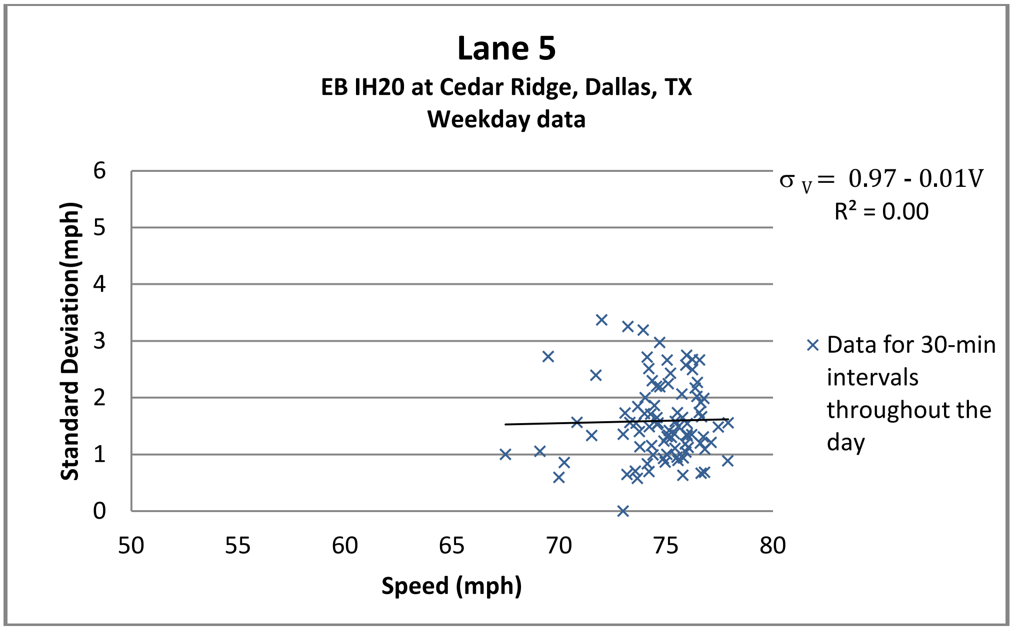

Figure 3-14 Speed Variation and Speed Relation for a Five-Lane per Direction Highway (Lane 5)

The outcome indicates that there is no relation between speed standard deviation and speed in this five-lane highway. The reason could be attributed to the fact that this highway does not reach its capacity at this site and there could be any speed standard deviation associated with any speed.

The other point to consider is that, there is a steep uphill grade at this site. Also, the doctor's operating condition shows the detector is operating well, but still detector's condition on this site could be questioned because of the site's characteristics.

Finally, all of the highways' data excluding 5-lane highway are combined to come up with an average formula for the relation between speed standard deviation and speed. The result shows that there is a strong negative relation between speed standard deviation and speed. The outcome is shown in Figure 3-15. The equation between standard deviation of speed and speed shows there is a negative relation between standard deviation of speed and speed. In addition, this equation indicates the correlation between speed standard deviation and speed. The correlation coefficient as shown in Figure 3-15 and Table 3-1 is -0.18, meaning that at speeds above 20 mph, and keeping all the other conditions unchanged, an increase in average speed by one mph causes the standard deviation of speed to decrease by 0.18 mph.

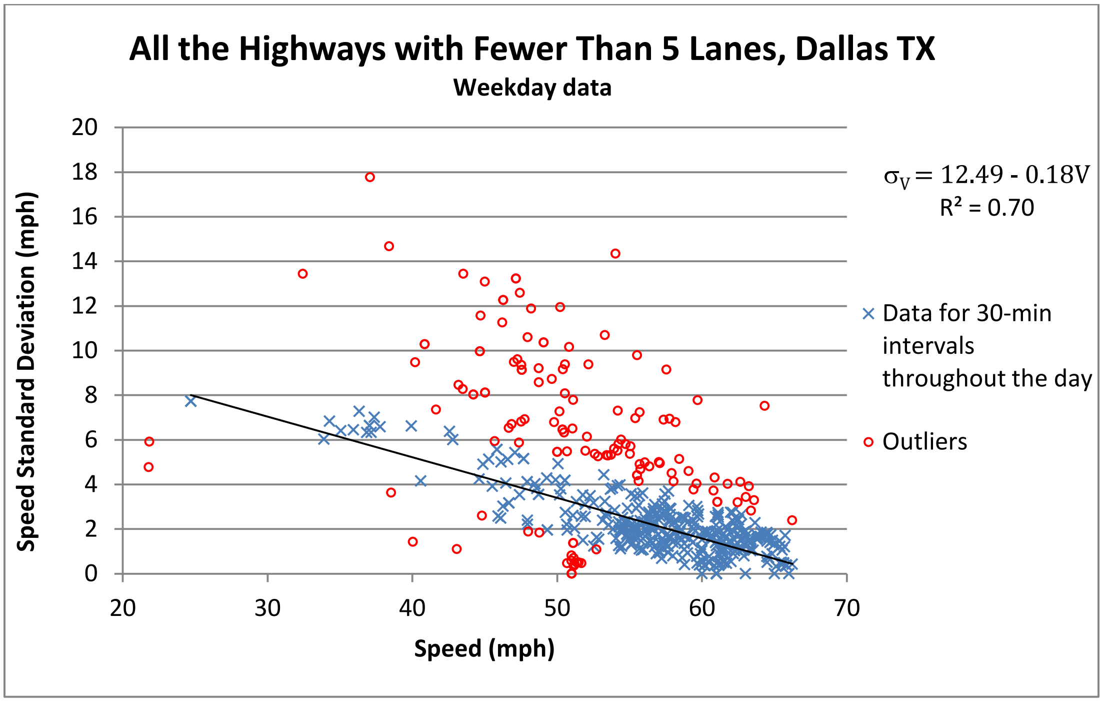

Figure 3-15 Speed Variation and Speed Relation for All the Highways

The result indicates that there is a strong relation between speed standard deviation and speed. The coefficient of determination in all the four models is above 0.70, which shows a large amount of variability in speed noise could be explained by the variability in speed. This relation seems to be stronger in right lanes rather than left lanes, and that could be attributed to the wider range of speed variation in the right lanes.

The results of the regression analysis along with the regression model for each lane and for all the highways are demonstrated in Table 3-1.

Table 3-1 Speed Variation Models for Various Highway Sections in Dallas, TX

`HWY Section	Lane #	Data W/O Outliers ($R_c > 2$)	
		R^2	Regression Model
EB IH20 at Cedar Ridge Dr. (Tue, Jan 22, 2013) (Sa, Jan 19, 2013)	5 (Left)	0.00	$\sigma_V = 0.97 - 0.008V$
	4	0.10	$\sigma_V = 10.68 - 0.13V$
	3	0.15	$\sigma_V = 9.96 - 0.12V$
	2	0.05	$\sigma_V = 6.34 - 0.07V$
	1 (Right)	0.08	$\sigma_V = 6.42 - 0.06V$
SB US75at Mockingbird (Tue, Jan 22, 2013)	4 (Left)	0.77	$\sigma_V = 27.60 - 0.41V$
	3	0.70	$\sigma_V = 20.18 - 0.32V$
	2	0.82	$\sigma_V = 38.86 - 0.63V$
	1 (Right)	0.83	$\sigma_V = 39.15 - 0.75V$
NB US175 at Pine St (Tue, Jan 22, 2013) (We, Jan 30, 2013) (Thu, Jan 31, 2013) (We, Feb 06, 2013)	3 (Left)	0.74	$\sigma_V = 17.70 - 0.24V$
	2	0.78	$\sigma_V = 21.09 - 0.31V$
	1 (Right)	0.76	$\sigma_V = 22.10 - 0.36V$
EB SH114 at O'Connor (Tue, Jan 22, 2013) (We, Jan 30, 2013) (We, Feb 06, 2013)	2 (Left)	0.69	$\sigma_V = 29.67 - 0.47V$
	1 (Right)	0.73	$\sigma_V = 29.55 - 0.49\ V$
All the Highways with Fewer Than five Lanes per Direction (Tue, Jan 22, 2013) (We, Jan 30, 2013) (Thu, Jan 31, 2013) (We, Feb 06, 2013)	All	0.70	$\sigma_V = 12.49 - 0.18\ V$

An overview of all the regression analyses and plots reveals there is a high correlation between the speed and the speed standard deviation. Based on the results, it could be concluded that at higher speeds, the speed variation is lower. This relation is stronger in the right lanes compared to the left lanes. Almost all the R-squared values are above 0.70, which indicates a large amount of variability in speed noise could be explained by variability in speed. The only exception is the five-lane per direction highway of Eastbound IH20 at Cedar Ridge Dr., where none of the lanes' regression models and analyses are significant. The reason could be attributed to the fact that in a five-lane highway, contrary to highways with fewer lanes, any speed pattern could be seen in any lane, so there are roughly the same variations in low speed condition as high speed condition. Also, the steep upgrade at this site could be another explanation for this observation.

The final model

The final model derived from a combination of all the data is shown below.

$$\sigma_V = 12.49 - 0.18V \tag{3.2}$$

Where,

σ_V : Speed standard deviation in mph

V: Average speed in mph

As noted before, the speed variance in the above model denotes the variance over time of the aggregate speeds and the speed variable represents the 5-minute aggregate speeds. The model is derived from the data gathered from the two-lane, three-lane, and four-lane per direction highways in Dallas area. The same model could also be used in other areas; but may need re-calibration due to potential regional differences in driver behavior.

3.5 Summary of Chapter 3

This chapter discusses the TxDOT data and the mathematical model that indicates the relation between the speed standard deviation and the speed. A regression model is developed to predict the speed standard deviation based on the speed. The result of the regression on different highways with different number of lanes shows there is a strong relation between speed standard deviation and speed for all the highways with fewer than five lanes per direction. The speed coefficient is negative, indicating a lower speed standard deviation at higher speeds. The indicated relation between the speed standard deviation and speed is not statistically different for each of the lanes of one specific highway. The last part of the chapter introduces the final model between speed standard deviation and speed which could be used for all the highways with different numbers of lanes.

The next chapter shows how the findings in Chapter 3 could be used to modify an existing steady-state fuel consumption model to reflect the impact of the variation in speed in the model and reflect more precisely the actual fuel consumption rates.

Chapter 4

Sample Model Application

4.1 Introduction

In the previous chapter, a model was developed to show the relation between the speed standard deviation and the speed. In this chapter, one of the applications of this finding is introduced. This derived model is implemented in an existing well-known fuel consumption model to improve it by taking the speed noise into consideration. In other words, the modified model reflects the influence of the speed noise in fuel consumption models.

4.2 Correlation between Fuel Consumption and Speed Standard Deviation

There are a few studies that postulate a positive relation between the speed variation and fuel consumption, but there is no study that presents an analytical model to capture this influence. Therefore, in this section, an analysis is performed to formulate this correlation.

The data used to determine the correlation coefficient between fuel consumption rate and the standard deviation of speed is derived from the research by Ardekani and Sumitsawan (Ardekani & Sumitsawan, 2010). In this study, the fuel consumption rate is measured once for the steady-state speed of 30 (mph) and once for the increasing speed from 0 (mph) to 30 (mph). The value of change in fuel consumption over speed standard deviation is considered to be the correlation coefficient between fuel consumption and the speed standard deviation.

The below formula is used to calculate the coefficient:

$$b = \frac{\text{Avg. } \Delta \text{ Fuel Consumption}}{\text{Speed SD}} \quad (4.1)$$

In this study there are two main scenarios, one with constant speed of 30 (mph) and the other one with speed varying from 0 (mph) to 30 (mph). Since we have the data for two points, the speed standard deviation is calculated as below.

$$\text{Speed SD} = \sqrt{\frac{(X_2 - \overline{X})^2 + (X_1 - \overline{X})^2}{n - 1}} = \sqrt{\frac{(0 - 15)^2 + (30 - 15)^2}{2 - 1}} = 21.21 \text{ mph}$$

Knowing the speed standard deviation and average change in fuel consumption, the coefficient between fuel consumption and the speed standard deviation could be calculated. Table 4-1 shows the average change in fuel condition for different road condition and calculated associated coefficient.

Table 4-1 Correlation Coefficient between Fuel Consumption and Speed Standard Deviation

Road Condition	Avg. Fuel Consumption (ml, Constant Speed)	Avg. Fuel Consumption (ml, Varying Speed)	Avg. Δ in Fuel Consumption (ml)	b (ml-hr/mi)
PCC/Dry	12.046	61.499	49.453	2.333
AC/Dry	13.077	65.251	52.174	2.461
PCC/Wet	14.292	68.843	54.552	2.573
AC/Wet	14.767	71.142	56.374	2.659
PCC/Dry	11.148	63.454	52.306	2.467
AC/Dry	13.552	68.077	54.525	2.572
PCC/Wet	12.046	59.729	47.683	2.249
AC/Wet	14.609	68.658	54.050	2.550
Average	13.192	65.832	52.640	2.483

The final correlation coefficient is calculated as below:

$$\text{Avg.}\,\Delta\ \text{Fuel Consumption} = 52.64\ \text{ml}$$

$$Speed\ SD = 21.21\ mi/hr$$

$$\text{b} = \frac{52.64\ \text{ml}}{21.21\ \text{mph}} = 2.483\ \text{ml} - \text{hr/mi}$$

Figure 4-1 also demonstrates the final correlation coefficient between fuel consumption and the standard deviation.

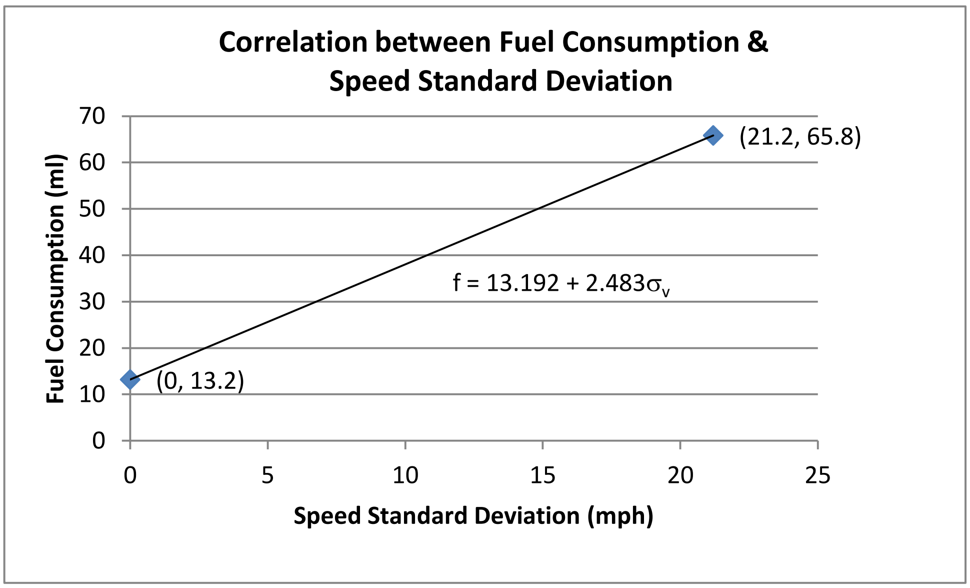

Figure 4-1 Correlation between Fuel Consumption and the Speed Standard Deviation

So, the correlation coefficient is 2.483 ml-hr/mi

4.3 Vincent Steady-State Speed Model

As noted in Chapter 2, one of the well-known average speed models (steady-state speed models) is the Vincent model (Vincent et al., 1980). This model is valid at any speed range, so if the relatively constant speed can be maintained, this model could be used (Ardekani et al., 1992). Also, The Vincent model is used in several simulation packages such as TRANSYT.

The Vincent model for the highway traffic condition is as follows:

$$f_c = a + bV_c + cV_c^2 \tag{4.2}$$

Where,

f_c : Steady-state fuel consumption rate at cruising speed (ml/km)

V_c: Steady-state cruising speed (kph)

a = 170 ml/km,

b = - 4.55 ml-hr/km

c = 0.049 ml-hr /km (Ardekani et al., 1992)

The reason for choosing an steady-state speed model is its simplicity, generality, and applicability. The other advantage of this model is that just cruising speed of the vehicle needs to be available for calculations and the model will still be relatively accurate in predicting the fuel consumption rate. The greatest shortcoming of this type of model is that it does not account for speed variation, which in reality makes a difference in the fuel consumption rate. The reason for not including the impact of the speed variation in these models might be the difficulty of measuring speed variation for model calibration purpose.

4.4 Proposed Model

The proposed model is the Vincent model which is modified by adding another term. The added term reflects the impact of standard deviation of the speed on fuel consumption since the standard deviation of speed is found to be influential in fuel consumption rate (37).

The proposed model is as follows:

$$f = a + bV + cV^2 + d\,\sigma_V \tag{4.3}$$

Where,

f : Steady-state fuel consumption rate at steady-state speed (ml/mi)

V: Steady-state speed (mph)

σ_V: Standard deviation of speed in (mph)

a = 273.59 ml/mi,

b = - 7.32 ml /mi

c = 0.079 ml /mi

d = 2.483 ml /mi

The original Vincent model is in metric, the conversion from original formula done by applying the kilometer to mile conversion (1 km= 0.621371 mi)

Now that the relation between the speed standard deviation and speed has been formulated, the corresponding term can be substituted in the equation, as follows:

$$\sigma_V = a^* + b^* V = 12.49 - 0.18V$$

$$f = a + bV + cV^2 + d\,(a^* + b^* V)$$

$$f = a + bV + cV^2 + d \times a^* + d \times b^* V$$

$f = (a + d \times a^{*}) + (b + d \times b^{*})V + cV^{2}$

$f = (a + d \times a^{*}) + (b + d \times b^{*})V + cV^{2}$

$f = \acute{a} + \acute{b}V + \acute{c}V^{2}$

$\acute{a} = a + d \times a^{*} = 273.59 + 2.483 \times 12.49 = 301.67$ ml-hr/mi

$\acute{b} = \mathrm{b} + \mathrm{d} \times b^{*} = -7.32 + 2.483 \times (-0.18) = -7.72$ ml-hr/mi

$\acute{c}$ = 0.079 ml-hr /mi

So, putting all the variables and their coefficients together in the formula, the final formulation is obtained as below:

$$f = \acute{a} + \acute{b}V + \acute{c}V^{2} \tag{4.4}$$

Where,

f : Steady –state fuel consumption rate at steady-state speed (ml/mi)

V: Steady-state speed (mph)

$\acute{a}$ = 301.67 ml/mi,

$\acute{b}$ = - 7.72 ml /mi

$\acute{c}$ = 0.079 ml/mi

In the proposed model, the impact of speed variation is captured in the fuel consumption model.

It should be noted that the final fuel consumption model is valid for all highways with fewer the five lanes per direction since the obtained relation between the speed standard deviation and the speed is valid for highways with fewer than five lanes per direction.

4.5 Summary of Chapter 4

This chapter demonstrates an implementation of formulating a relation between speed standard deviation and speed. Finding this relation facilitates the consideration of speed variation's impact on fuel consumption rate. In the first part of this chapter, the correlation coefficient between fuel consumption rate and speed standard deviation is extracted from a previous study. Later, the standard deviation of speed term is entered into the Vincent fuel consumption model. The calculated correlation coefficient is used to complete the model. Finally, the standard deviation of speed is substituted by its equivalent speed term modeled in Chapter 3. The final model is believed to reflect the impact of speed variation in the fuel consumption rate.

The next chapter provides the conclusion and summary of the findings and discusses the limitations of the proposed model. In addition, it shows the possible future research on the topic.

Chapter 5

Conclusions

5.1 Summary of the Thesis

The primary aim of this research has been to use field data to formulate a relation between the speed standard deviation and speed. In doing so, the speed and count data are extracted from the TxDOT detector data website. This relation is investigated by applying a linear regression model to speed standard deviation against speed in different highways and for each lane separately. The results for all of the highways (except for a five-lane per direction highway) and lanes demonstrate a strong relation between speed standard deviation and speed. The final model is established using the entire data for all the highways with fewer than five lanes per direction. The final model also indicates a strong relation between speed standard deviation and speed.

The established model between speed standard deviation and speed could be used for different purposes. One of the applications is in fuel consumption models. The existing steady-state speed models for highways do not account for the impact of speed variation in estimating the fuel consumption, so the only needed speed profile is the cursing speed. This is mainly because measuring the speed standard deviation is a hard task. Based on the findings of this study, a new term could be added to the fuel consumption model to overcome that deficiency. Now that the relation between speed standard deviation and speed is established, the equivalent speed term could substitute the speed standard deviation term in the proposed model. The initial model that is considered is the Vincent model for highways. The final proposed model has the similar terms as the Vincent model; however, the coefficients are modified to reflect the variation in speed impact on predicting fuel consumption.

5.2 Model Limitations

Similar to any mathematical model, there are some limitations in applying the developed model. These limitations include the following:

- The first limitation results from the fact that any established model might not be useful beyond the scope of the tested area. The established model between speed standard deviation and speed might not be applicable in different regions with their specific characteristics and driver behavioral biases. So further studies might be needed to establish a generic model applicable to different regions.
- The second limitation results from the inherent limitation of any mathematical model. A mathematical model usually simplifies the reality to facilitate the prediction and implementation. The mathematical models might not exactly reflect the reality, but their results could still be accurate and reliable. Following this general rule, the considered model in this study has simplifications, so the accuracy of the proposed model and the associated fuel consumption prediction could only be evaluated by implementing the model in a case study research.
- The third limitation results from the lack of data to compute the correlation coefficient between fuel consumption and speed standard deviation. A More systematic field study could be conducted to get a more accurate correlation coefficient.
- Finally, the initial assumption for developing regression model between speed and speed standard deviation and identifying outliers is that the residuals are normally distributed and have a constant variance. If the

further analysis shows that the variance of residuals is not constant, the weighted regression should be used to model relation between speed and speed standard deviation.

5.3 Further Research

- The developed model between speed standard deviation and speed in this research was based on data from highways in one county (Dallas County, Texas). This model could be applied in different regions to see if it applies to other regions regardless of the region and the highway type.
- The primary model for modification in this research is the Vincent fuel consumption model, but the new term of speed standard deviation could be considered in any steady-state speed or average speed model to reflect the speed variation in measuring the fuel consumption.
- The correlation between speed variation and fuel consumption rate could further be examined using fuel consumption data directly from an instrumented vehicle.
- In this study, the aggregated data as an input is used to develop a macro model between speed and speed standard deviation. The non-aggregated data for individual vehicles could be used to find out how much characteristics in micro level is lost by using aggregated data.
- The final proposed model for fuel consumption with the new coefficient could be used for a case study with different scenarios in cruising speed and varying speeds to further validate the model.

References

Agency, J., Nam, E.K., Gierczak, C.A., & Butler, J.W. (2003). A Comparison Of Real-World and Modeled Emissions Under Conditions of Variable Driver Aggressiveness, in Annual TRB Meeting, T.A.M. CD-ROM, Editor: Washington DC.

Ahn, K. (1998). Microscopic Fuel Consumption and Emission Modeling, Master Thesis, Virginia Polytechnic Institute and State University, Virginia, USA.

Ahn, K., & Rakha, H. (2008). The Effects of Route Choice Decisions on Vehicle Energy Consumption and Emissions. Transportation Research, Part D, 13(3), 151–167.

Ahn, K., Rakha, H., Trani, A., & Van Aerde, M. (2002). Estimating Vehicle Fuel Consumption and Emissions Based on Instantaneous Speed and Acceleration Levels. Journal of Transportation Engineering, 128(2), 182–190.

Akcelik, R. (1981). Fuel Efficiency and Other Objectives in Traffic System Management. Traffic Engineering and Control, 22(2), 54–65.

Al-Momani, W., & Badran, O. (2007). Experimental investigation of factors affecting vehicle fuel consumption. Int. Jour. Mech. Mat. Eng. 2, 180–188.

An, F., & Rosse, M. (1993). A Model of Fuel Economy with Application to Driving Patterns. SAE Technical Paper 930328. Society of Automotive Engineers.

Ardekani, S., Hauer, E., & Jamei, B. (1992). Traffic impact models. Chapter 7 in Traffic Flow Theory, Oak Ridge National Laboratory Report.

Ardekani, S.A., & Sumitsawan, P. (2010). Effect of Pavement Type on Fuel Consumption and Emissions in City Driving. Final Report to the Ready Mixed Concrete Research & Education Foundation.

Baker, M. (1994). Fuel Consumption and Emission Models for Evaluating Traffic Control and Route Guidance Strategies, Mater thesis, Queen's University, Kingston, Ontario, Canada.

Berry, I.M. (2010). The Effects of Driving Style and Vehicle Performance on the Real-World Fuel Consumption of U.S. Light-Duty Vehicles, in Department of Mechanical Engineering and the Engineering Systems Division. Massachusetts Institute of Technology.

Bigazzi, A., Clifton, K., & Gregor, B. (2012). Modeling the Effects of Congestion on Fuel Economy for Advanced Power train Vehicles. 91st Annual Meeting of the Transportation Research Board:Washington, D.C.

Blandin, S., Salam, A., & Bayen, A. (2011). Individual speed variance in traffic flow: analysis of Bay Area16 radar measurements. 91th Annual Meeting of the Transportation Research Board: Washington, D.C.

Bulteau, E., Leblanc, R., Blandin, S., & Bayen, A. (2013). Fconsumption ratlow estimation using higher-order speed statistics, Individual speed variance in traffic flow: analysis of Bay Area16 radar measurements. 93th Annual Meeting of the Transportation Research Board: Washington, D.C.

Chang, D. J., & Morlok, K. M. (2005). Vehicle Speed Profiles to Minimize Work and Fuel Consumption, Journal of Transportation Engineering © ASCE.

Consumption of Oil for Transportation, Retrieved July, 2013, from http://www.aps.org/policy/reports/popa-reports/energy/transportation.cfm

DFW Traffic Data, Retrieved January, 2013, from http://dfwtraffic.dot.state.tx.us/#showContent%28%27/DfwTrafficData/%27%29%3B

Eccleston, B.H., & Hurn, R.W. (1978). Ambient Temperature and trip Length-Influence on Automotive Fuel Economy and Emissions, SAE.

Ericsson, E. (2001). Independent driving pattern factors and their influence on fuel-use and exhaust emission factors. Transportation Research Part D: Transport and Environment, 6(5), 325-345.

Evans, L., Herman, R., & Lam, T. (1976). Multivariate Analysis of Traffic Factors Related to Fuel Consumption in Urban Driving. Transportation Science, 10(2), 205–215.

Herman, R., & Ardekani, S. (1985). The influence of Stops on Vehicle Fuel Consumption in Urban Traffic. Transportation Science, 19 (1), 1–12.

Hopkins, J. B., Hazel, M. E., & McGrath, T. (1978). Railroads and the environment—estimation of fuel consumption in rail transportation Volume III: Comparison of computer simulations with field measurements. Final Rep. No. FRA-OR&D-75-74.III to U.S. Federal Railroad Administration, Rep. No. PB-288866, National Technical Information Service, Springfield, Va.

Kenworthy, J.R., Rainford, H., Newman, P.W.G., & Lyons, T.J. (1986) Fuel consumption, time saving and freeway speed limits. Traffic Engineering & Control, 27 (9), 455-459.

Kim, E., & Choi, E. (2013). Estimates of Critical Values of Aggressive Acceleration from a Viewpoint of Fuel Consumption and Emission, in TRB 2013 Annual Meeting: Washington D.C.

Makberud, D. B. (1983). The 55 mph speed limit: costs, benefits and implied trade-offs. Transpn Res. 17A (1), 51-64.

Murrell, D. (1980). Passenger Car Fuel Economy: EPA and Road. U.S. Environmental Protection.

Organization for Economic Co-Operation and Development. (1982). Automobile Fuel Consumption in Actual Traffic Condition, Paris.

Rakha, H., & Ding, Y. (2003). Impact of Stops on Vehicle Fuel Consumption and Emissions. J. Transp. Eng., 129(1), 23–32. Technical Papers.

Schipper, L., Saengerand, C., & Sudardshan, A. (2010). Retrieved July 2013, from http://academia.edu/368027/Transport_and_Carbon_Emissions_in_the_United_States_The_Long_View.

Shankar, V., & Mannering, F. (1998). Modeling the Endogeneity of Lane-Mean Speeds and Lane-Mean Speed Deviations: A Structural Equations Approach. In Transportation Research - Part A, 32(5), 311-322.

Sivak, M., & Schoettle, B. (2012). Eco-driving: Strategic, tactical, and operational decisions of the driver that influence vehicle fuel economy. Transport Policy, 22(0), 96-99.

Song, G., & Yu, L. (2009). Estimation of Fuel Efficiency of Road Traffic by Characterization of Vehicle-Specific Power and Speed Based on Floating Car Data. Transportation Research Record: Journal of the Transportation Research Board, 2139 (1), 11-20.

Tenny, N., & Lam, M. (1985). Estimating Fuel Consumption From Engine Size 1985, journal of transportation Engineering, 111 (4).

Vincent, R. A., Mitchell, A., & Robertson, D. (1980). User Guide to TRANSYT Version 8. Transport and Road Research Lab Report No 8. LR888.

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Bahar Zarin, studied Master of Civil Engineering at University of Texas at Arlington from 2011 to 2013. She received her Certificate in Geographic Information Systems (GIS) from UT Arlington in 2013.

Her experience in UT Arlington is as follows: Worked as a graduate Research Assistant (GRA) on the project titled “The Relation between Freeway Average Speed and Speed Noise” under supervision of Dr. Ardekani; Worked as a GRA on the project titled "Linking Transportation Planning with Public Health: An Ecological-Based Paradigm for Institutional Collaboration" funded by U.S. DOT under supervision of Dr. Li; Worked as GRA on a project titled “A Planning Support System for Integrated Metropolitan Land Use-Transportation Forecasting” funded by The North Central Texas Council of Governments (NCTCOG) under supervision of Dr. Anjomani.

Her future goal is pursuing her Ph.D. in Transportation Engineering in the area of Intelligent Transportation Systems or Traffic Modeling. Her final goal is to find a research oriented occupation in transportation studies.