A COMPARISON OF VEHICLE SPEED AT DAY AND NIGHT AT RURAL HORIZONTAL CURVES

A Thesis

by

RIDWAN B. A. QUAIUM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2010

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Gene Hawkins
Committee Members,	Paul Carlson
	Tim Lomax
	Yunlong Zhang
Head of Department,	John Niedzwecki

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ABSTRACT

A Comparison of Vehicle Speed at Day and Night at Rural Horizontal Curves.

(May 2010)

Ridwan B. A. Quaium, B.S., Virginia Polytechnic Institute and State University

Chair of Advisory Committee: Dr. Gene Hawkins

This thesis documents the linear mixed model developed for vehicle speed along two-lane two-way rural horizontal curves in the outside lane. Speed data at each curve was collected at four points along the curve including the midpoint of the curve for a minimum of 48 hours during weekdays. Vehicle speed was analyzed separately for day and night conditions. The horizontal curves were categorized into different groups using different methods using side friction demand, radius and pavement edgeline marking retroreflectivity.

In the speed prediction model, radius, superelevation at the midpoint of the curve, deflection angle, posted speed limit and pavement edgeline marking retroreflectivity were used to predict the vehicle speed at the midpoint of the horizontal curve. The regression analysis indicates that all of these variables are statistically significant in predicting the vehicle speed at the midpoint of horizontal curves with a 95 percent confidence interval. The linear model determined that the vehicle speed has a positive relation with the radius of the curve, superelevation and posted speed limit but has a negative relation with the deflection angle and pavement edgeline marking retroreflectivity.

Curves were categorized based on side friction demand or radius and retroreflectivity of pavement edgeline marking. ANOVA was used to compare the day and night time speed. The comparisons reveal that vehicle speed at the horizontal curves decreases as the side friction demand value of the curves increases. Another finding of this research was that even though the posted speed limit is incorporated into the calculation of side friction demand, it may be necessary to analyze the impact of posted speed limit on vehicle speed for both daytime and nighttime. Previous literature determined that drivers may drive at an unsafe speed during nighttime at high levels of retroreflectivity. The results of this study could not confirm this statement as data from this study suggests that for curves with pavement edgeline marking retroreflectivity greater than 90 $mcd/m^2/lx$, the effects of retroreflectivity on speed was determined to be minimal. This is based on the finding that the daytime and nighttime speeda were basically the same as the daytime and nighttime speed difference was both statistically and practically insignificant.

DEDICATION

This thesis is dedicated to my parents and my younger brother. Without their support and encouragement, I would have never been able to come this far in my academic career.

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The author would like to thank Dr. Gene Hawkins and Mr. Jeff Miles for their support and guidance throughout this thesis. They have helped the author develop skills as a researcher. In addition, they have helped the author to improve communication skills.

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1. INTRODUCTION

Accidents on horizontal curves have been a safety challenge for many years. Studies have shown that the accident rate for curves is at least 1.5 to 4 times higher compared to the tangent sections of the roadway *(1)*. Crashes occur on two lane rural highways every year due to changes in road geometry and also due to driver's inattention and speeding. Thus, transportation engineers are trying to address this concern to make the roads safer.

A study by the Federal Highway Administration (FHWA) states that driver's err more on roads that have inconsistent design *(2)*. An inconsistent design consists of geometric features that require high driver workload that my result in drivers driving in an unsafe manner. In the past not as much attention was given towards safety when designing roadways. "A consistent roadway geometry allows a driver to accurately predict the correct path while using little visual information processing capacity, thus allowing attention or capacity to be dedicated to obstacle avoidance and navigation *(2)*."

At horizontal curves, 76 percent of the fatal crashes involve single vehicles leaving the roadway and driving into trees, utility poles, rocks, or other fixed objects and overturning. Another 11 percent are head on crashes *(3)*. As stated in the first paragraph, this may happen because of tight horizontal curves, lack of pavement markings and signing, or drivers not slowing down at the curve or trying to over correct after running onto the shoulder.

This thesis follows the style of *Transportation Research Record*.

The probability of a fatality while driving is 4 times higher during the night than during the day *(4)*. Three factors that make nighttime driving more challenging are: lack of visibility, fatigue and alcohol *(5)*.The presence of sunlight enhances visibility during daytime. At night, especially on rural roads where there is usually no street lighting, a driver has to depend solely on their vehicle headlights, thus reducing their visibility. Glare from opposing vehicles can reduce the vision of a driver even further. Visibility is an important aspect of driving, which is why there are specific sight distance requirements in the *A Policy on Geometric Design of Highways and Streets* by the American Association of State Highway and Transportation Officials (AASHTO) *(6)*.

To enhance driver visibility of the roadway and to promote safe driving at night, retroreflective pavement markings are used. According to FHWA, “Retroreflectivity is the scientific term that describes the ability of a surface to return light back to its source. Retroreflective signs and pavement markings reflect light from vehicle headlights back toward the vehicle and the driver's eyes, making signs and pavement markings visible to the driver” *(7)*. This research will focus on creating a model to predict vehicle speed at the midpoint of horizontal curves and comparing vehicle speed at day and night on rural horizontal curves with different curve geometry characteristics and edgeline pavement marking retroreflectivity levels.

PROBLEM STATEMENT

Roadway characteristics such as radius of curve, superelevation, grade and deflection have been identified as variables that have an effect on the vehicle speed at horizontal curves. At nighttime vehicle speed also depends on how clearly the driver is able to view the road. To improve roadway visibility, retroreflective pavement markings are generally used. In some cases raised retroreflective pavement markers (RRPM), chevron signs and other types of techniques are used to guide the driver through the roadway. Much research has been conducted to identify the minimum pavement marking retroreflectivity level that is required for nighttime driving *(8, 9, 10, 11)*. The current challenge is not only to identify the minimum required retroreflectivity level but also to identify the maximum required retroreflectivity level to ensure safe driving. This is because a low pavement marking retroreflectivity level (i.e. retroreflectivity level less than 100 $mcd/m^2/lx$) may not be safe for drivers, as drivers may not be able to see the road properly; hence they tend to drive much slower than the speed they would have chosen during the daytime. On the other hand, a high retroreflectivity level may also not be as safe because then drivers may feel too comfortable driving, leading them to speed and over run their headlights (*8*). At horizontal curves this may be a safety concern. To find out whether this is true, vehicle speed during the day and during the night should be compared at horizontal curves with different curve geometry and retroreflectivity levels.

RESEARCH OBJECTIVES

Even though only 40 percent of vehicle miles traveled occur in rural areas, about 75 percent of all fatal crashes occur on rural roads and 70 percent of them happen on two-lane two-way undivided roads (*3*, *12*). On these two-lane two-way undivided rural roads, most of the accidents occur on horizontal curves with radii less than 1968 ft (*1*).

In terms of distance traveled, driving at night is more risky than during the day. This statement is consistent for all age groups (*4*). Fatigue and alcohol are the two main factors behind nighttime crashes *(4, 12)*. Another factor for nighttime crashes is visibility (*13*). To compensate for the visibility issue, drivers need to slow down which often time they fail to do. This failure to slow adjust the speed by drivers during nighttime sometimes leads to crashes. At night, the visibility of the roadway at rural horizontal curves depends on the characteristics of the curve as well as the retroreflectivity levels of the pavement markings. The current concern is that a low retroreflectivity level may result in drivers choosing a speed significantly less than the speed they would travel at daytime and a high retroreflectivity level may result in drivers driving at a speed at night significantly faster than their daytime speed.

In this research, the goal is to develop a vehicle speed prediction model and to statistically compare vehicle day and nighttime speed at the midpoint of horizontal curves on two-lane two-way rural highways with different curve geometry and retroreflectivity levels. The specific objectives of this research are as follows:

- Determine the side friction demand of the horizontal curves using the Texas Curve Advisory Speed (TCAS) Software.
- Group the horizontal curves according to the side friction demand and retroreflectivity level and according to the radius and retroreflectivity level.
- Develop a linear mixed model for vehicle speed at the midpoint of horizontal curves at day and night.

- Determine if a statistically significant difference exists between the daytime and nighttime vehicle speed within each group using an ANOVA.
- Determine if a statistically significant difference exists in the daytime and nighttime vehicle speed among each group for the six methods using an ANOVA.
- Compare the day and nighttime speed difference using side friction demand and retroreflectivity level and using radius and retroreflectivity level.

SCOPE

Data for this research was collected at 18 horizontal curves on two-lane two-way rural highways in Tennessee. Vehicular speed data at each curve was collected for a minimum of 48 hours. In addition to speed data, roadway characteristic data and curve characteristic data were also collected at each of the curves such as speed limit, radius, curve length, deflection, lane width, shoulder width, retroreflectivity level, grade and superelevation.

This research focuses on developing a linear mixed model that will predict vehicle speed at the midpoint of two-lane two-way rural highways using side friction and retroreflectivity as the independent variables. This research does not intend to test the significance of other independent variables in predicting vehicle speed at horizontal curves.

In addition, the author compares day and night speed of different groups of horizontal curves. These curves are grouped based upon the side friction demand and retroreflectivity level. The grouping is done in different methods to determine if grouping the curves differently impacts the difference of day and nighttime speed.

2. LITERATURE REVIEW

A variety of research studies were reviewed to help the author better identify the issues related with vehicle speed at horizontal curves and the available methods and factors that should be considered when analyzing speeds in horizontal curves. The literature review was not limited to, but did include an emphasis on vehicle speed models associated with horizontal curves, nighttime driving, retroreflectivity, free flowing vehicles, Texas Curve Advisory Speed Software, vehicle speed data collection methods and linear mixed model.

VARIABLES THAT INFLUENCE VEHICLE SPEED

AASHTO has developed a vehicle speed model based on variables that they have determined to impact speed (*6*). This model is used by highway designers while designing curves and also many researchers use this model when they develop their vehicle speed model. The AASHTO model is as follows:

$$R = \frac{V^2}{15(e+f)} \tag{1}$$

In the above model,

R = radius (feet)

V = speed (mph)

e = superelevation (percent)

f = side friction factor

Researchers at Texas Transportation Institute (TTI) in their *Development of Guidelines for Establishing Effective Curve Advisory Speed* study developed vehicle speed models for rural horizontal curves *(14)*. They started developing their model from the traditional vehicle speed model, which is given below.

$$v_c = \sqrt{gR\left(f_D + \frac{e}{100}\right)} \tag{2}$$

In the above equation, v_c is vehicle speed (ft/s), g is gravitational acceleration (32.2 ft/s^2), R is the radius (ft), f_D is the side friction demand factor and e is the superelevation rate (percent).

After calibrating the above model, the variables that these researchers were able to identify that appeared to influence vehicle speed in rural horizontal curves were: tangent speed, vehicle type, curve deflection angle, tangent length, curve length, available stopping sight distance, grade and vertical curvature. The final speed model developed for rural horizontal curves was based on the parabolic relationship between tangent speed, radius and superelevation is:

$$V_c = \left(\frac{15.0R(b_0 - b_1V_t + b_2V_t^2 + e/100)}{1 + 32.3Rb_2}\right)^{0.5} \leq V_t \tag{3}$$

In the above equation, V_t is the tangent speed, R is the radius, e is the superelevation and b_o, b_1 and b_2 are coefficients. For passenger cars the values of the coefficients that best estimate the 85th percentile curve speed are: 0.256, 0.00245 and 0.0146 respectively for b_o, b_1 and b_2.

Medina and Tarko developed vehicle speed model at curves, tangents and transition sections for rural two-lane roads *(15)*. Curves with radius less than 1700 feet were used in this research. The speed model that was developed is:

$$V_C = 51.973 + 0.003SD - 2.639RES - 2.296DC + 7.748SE - 0.624SE^2 \quad (4)$$

Only variables with a 95percent confidence level were used to develop this model. The variables that were used are: sight distance (SD), residential development indicator variable (RES), where 1 mean there are 10 or more driveways and 0 otherwise, degree of curvature (DC) and superelevation rate (SE). This report also suggests that for flatter curves, the vehicle speeds are more dependent on the cross sectional elements and other road elements (i.e. grade, total gravel shoulder width, traveled way width, total untreated shoulder width etc.) than the curve design elements such as radius, curve length and deflection angle.

Anderson et. al. researched to construct speed prediction models on two-lane rural highways at both horizontal and vertical curves *(16)*. The horizontal curves were divided into four groups in terms of their grades, which are upgrades (0 to 4 percent), steep upgrades (greater than 4 percent), downgrades (-4 to 0 percent) and steep down grades (less than -4 percent). Regression models were developed to predict the 85th percentile speed at the horizontal curves. Data suggests that, for radii up to 400 meter (1312 feet), the speed increases notably but for radii greater than 400 meter (1312 feet) the speed increase is not that apparent. In the final model the inverse of the radius, 1/R, was used to predict the speed in the horizontal curve.

Gong and Stamatiadis developed multiple linear regression vehicular speed models at middle of horizontal curves on rural undivided four-lane highways *(17)*. Only isolated curves were analyzed. Isolated curves in this case were identified as curves away from intersections or driveways. Their research has shown that the speed at the inside and the outside lane are significantly different. Even variables that predict the vehicular speed in the inside lane and the outside lane turned out to be different. The inside lane and outside lane vehicular speed models are as follows:

$$V_{85} \text{ (inside lane)} = 51.520+1.567ST - 2.795MT - 4.001PT - 2.50AG+2.221\ln(LC) \quad (5)$$

$$V_{85} \text{ (outside lane)} = 60.779+1.804ST - 2.521MT - 1.071AG - 1.519FC+ 0.00047R+ 2.408\left[\frac{(LC)}{R}\right] \quad (6)$$

In the above two equations, ST is shoulder type index (paved or unpaved), MT is median type index (if barrier is positive or not), PT is pavement type index (bituminous or concrete), AG is approaching section grade index, LC is length of curve, FC is front curve index and R is the radius.

AASHTO, states that vehicles entering a curve to the right already has some superelevation from the normal cross slope *(6)*. Vehicles entering a curve to the left have negative superelevation resulting from the normal cross slope. To sustain the vehicle lateral acceleration at sharper curves, a positive slope is desired across the entire roadway. Thus, this means that in horizontal curves, the rate of superelevation has an impact on vehicle speed and vehicle lateral placement. Exhibit 3-15, in AASHTO provides minimum radius for five different types of superelevation, which are 4, 6, 8, 10 and 12 percent. The two things that this exhibit suggests are that the design speed decreases as the radius of the curve decreases and the design speed increases as the superelevation of the curve increases. AASHTO also mentions that vehicle speeds are affected when grades are above 5 percent (*6*).

A research study conducted by FHWA researchers investigated operating speed for horizontal curves, vertical curves and tangent sections. For passenger cars in horizontal curves the independent variable in the regression equation was 1/radius of the curve. When the radius of a curve is 800 meter (2625 feet) or more vehicle speeds were very similar to speeds on the tangent sections and in this situation the grade controls the speed of the vehicle rather than the radius *(2)*. Operating speeds decreases sharply when the radius is 250 meter (820 feet) or less. Thus, this study also showed horizontal curve speed was dependent on radius.

Research was done in northern Iraq to construct linear regression models at rural horizontal curves *(18)*. Speed data was collected at 48 curves under free flow conditions. Speed data was collected under daylight, off-peak and dry weather conditions. The range of radius used was from 164 feet (50 meter) to 1640 feet (500 meter), lane width from 9.8 feet (3.0 meter) to 12.1 feet (3.7 meter), shoulder width from 4.9 feet (1.5 meter) to 9.8 feet (3.0 meter), superelevation from 2-6 percent and grades from -9.3 percent to 9.3 percent. In the speed versus radius curve it was observed that speed of a vehicle along the curve increases as the radius increases. To analyze the combined effect of curve radius and grades on the curve speed, the grades were separated into four groups. Results suggest that for radius smaller than 656 feet (200 meter), the vehicle speed is more influenced by the radius but when the radius is more than 656 feet (200 meter), the speed of vehicle at the curve is more influenced by the grade. The linear regression speed model that was developed is:

$$V_{85} \text{ Curve} = 17.749 + 0.5\, V_{85} \text{ Approach} + 0.05203R - 0.161\, \Delta + 1.416e \qquad (7)$$

The variables used in the above equation are, 85th percentile approach speed (V_{85}), radius (R) in meters; deflection angle (Δ) in degrees and superelevation (e) in percentage. The vehicle speed in the above equation is given in kilometer per hour.

Dietz et al. reviewed eleven vehicle speed prediction models for rural horizontal curves developed by Engineers from different countries in their *Road Geometry, Driving Behaviour and Road Safety* study *(19)*. Most of these models only used radius in their prediction model. In addition with the radius, Biedermann (1984) and Lippold (1997) used road width in their model while Krammes et al. (1993) included curve length and the degree of curvature with the radius. It was observed that for radii greater than 476 feet (145 meter) the variability in the eleven speed models is less than the variability for radii less than 476 feet (145 meter).

Kupke (1977) found that vehicle speed decreases in small curves with increasing degree of curvature. This research mentions that due to advancements in vehicle engines, the influence of grade is unimportant in determining vehicle speed. In previous times, grades in excess of 2 percent had an impact but nowadays grades above 6 percent influence vehicle speed. The impact of curvature change rate (CCR) on vehicle speed at curves has mixed results. Biedermann (1984) was able to find a small influence of CCR on speed while models developed by Koppel/Bock (1979) and Lippold (1995) demonstrated that as the curve change rate increases, the velocity decreases.

A study in Australia finds that speeding is one of the leading factors for vehicle accidents *(20)*. This study also reports that the usage of advisory speed limit before curves and police enforcement has been found to be successful in reducing the number and severity of accidents. In addition, it states that vehicles travel slower on narrower roads but on the other hand, crash rate increases as the lane width decreases. Here, the method that was sought to decrease the vehicle speed was to perceptually narrow the width of the roadway. This can be done by widening the center line and the edgeline or by widening the center line and moving the edgeline closer to the centerline. Findings from this research states that on narrower roads the driver mental work loads increases. This is because on narrower roads the driver's steering effort increases. The study states, "Steering deviations were larger, and lateral deviations were smaller" *(20)*. This resulted in the vehicle to reduce their speed.

Another study was conducted in Australia to investigate vehicle speed at horizontal curves *(21)*. The regression analysis concluded that vehicle speed is influenced significantly by the desired speed related to the road section and curve. Based on the regression analysis a family of speed prediction relations was then developed. The prediction model used radius as the sole variable to predict the vehicle speed.

The 'Meta-Analysis' conducted by Driel et. al. focused on the effect of edgeline, shoulder width and road environment on vehicle speed and lateral placement. Data for this study was collected in the Netherlands and in America. It was found that for both the countries edgeline with shoulders and with or without centerline has an impact on the vehicle speed *(22)*. An increase in speed is found when an edgeline is added to a road without centerline. The researchers in this study also proposed that ambient lighting conditions (day/night), traffic volume or presence or absence of opposing traffic or traffic on the same lane does not pose any impact on the vehicle lateral speed but due to limited data this cannot be verified.

NIGHTTIME DRIVING

Driving on a road during the daytime and nighttime can be very different. The absence of the sunlight makes driving very different at night than during the day. Three things that make driving at nighttime dangerous are visibility, fatigue and alcohol *(4)*. In addition, 90 percent of a driver's reaction depends on vision which is limited at nighttime, making it harder to drive at nighttime compared to daytime *(23)*. Some of the reference points that people use during the day to guide them through the road are no longer visible at night. A person's peripheral vision, color recognition and depth of vision at night are reduced, making it hard to focus on an object *(9, 22)*. Ward and Wilde, in their research states that, "Visual acuity, stimulus identification and distance estimation, area of eye scanning and viewing distance, as well as colour and contrast sensitivity are degraded in darkness" *(24)*. On rural roads, where there are usually no street lights, a driver solely depends on his/her vehicle headlights. Thus, it is very important to check if the headlights are working properly and clean. Vision of a person declines with age this makes it harder for older drivers to drive in the dark *(4)*. The visibility of a driver at night is also degraded from glares from oncoming vehicles *(5, 9, 13, 23, 24)*.

Fatality rates based on speed at nighttime were about three to four times higher at night than during the day *(5, 23)*. A study done in New Zealand states that the chance of getting involved in a crash in terms of distance traveled is higher at night than day *(5)*. This study also found that, besides visibility, fatigue and alcohol, another factor that is related to crashes at night is that drivers do not adjust their speed to compensate for the limited visibility at night. Drivers often overdrive their headlights at night, which means that they drive so fast that they cannot stop within the area that is illuminated by their headlights.

Bonneson et al. in their study showed that average nighttime speed tends to be slower for both passenger car and truck drivers compared to average daytime speed *(14)*. For passenger cars the nighttime speed was 2mph slower than daytime passenger car speeds and for trucks the nighttime speed was 1mph slower than the daytime truck speed.

In many states, speed limit is based on the 85th percentile speed measured at optimal conditions for free flowing vehicles during the day. Thus, it can be seen that usually speed limit is based on daytime traffic only. Nighttime is considered as a hazardous condition. Thus, vehicles should be driving 5-10 miles below the posted speed limit at night *(9)*. This is why Texas lowered their nighttime posted speed limit by 5 mph on rural highways and farm-to-market or ranch-to-market road if the day time posted speed limit was 60 mph or above *(25)*. This allowed drivers to have more reaction time if they needed to slow down for some reason.

RETROREFLECTIVITY

As stated earlier, retroreflectivity is the ability of a surface to reflect light back to its source. Wider pavement markings are helpful during the daytime. At nighttime both the width of the pavement marking as well as the amount of retroreflectivity of the pavement marking are important. A driver will probably drive differently at night on an 8 inch wide pavement marking with low retroreflectivity compared to a 4 inch wide pavement marking with high retroreflectivity. The *Manual on Uniform Traffic Control Devices* (MUTCD), "Markings that must be visible at night shall be retroreflective unless ambient illumination assures that the markings are adequately visible" *(26)*. Since rural highways are usually not illuminated, retroreflective pavement markings are used.

Retroreflectivity is measured in units of $mcd/m^2/lx$. The MUTCD states that a pavement marking that must be visible at night has to be retroreflective but it does not specify the level of reflectivity. Various research studies have been conducted to determine the minimum retroreflectivity level that is needed for drivers to view the road at night with ease. The minimum retroreflectivity level for pavement markings that were determined by the American Traffic Safety Services Association (ATSSA) in 2004 was 100 $mcd/m^2/lx$ for speed limit less than or equal to 50 mph and 125 $mcd/m^2/lx$ for speed limit greater than or equal to 55 mph *(10)*. The minimum retroreflectivity levels specified by FHWA for different speeds are given in the following table. FHWA requires the level to be 100 mcd/m^2/lx for high speed, 85 mcd/m^2/lx for moderate speed and 70 mcd/m^2/lx for low speed roadways *(10)*.

Research was conducted to investigate the retroreflectivity level that drivers preferred for nighttime driving (*11*). This research found that, 98 percent of the drivers felt that a level of 94 mcd/m^2/lx was adequate or more than adequate. The subjects of this research were mostly young and research was done in ideal field conditions *(11)*. Thus, it is highly probable that for older drivers and non ideal conditions such as rain or snow, the retroreflectivity level would need to be higher.

A research was designed by Aktan et. al. to determine the minimum retroreflectivity of pavement markings for roadways with and without RRPMs *(9)*. For fully marked roadways (with centerline, lane lines and edgelines) without RRPMs, different retroreflectivity levels have been recommended for different speeds. For speeds equal to and less than 50 mph, a retroreflectivity level of 40 mcd/m^2/lx, for speeds between 55-65 mph a level of 60 mcd/m^2/lx and for speeds equal to and greater than 70 mph a retroreflectivity level of 90 mcd/m^2/lx has been recommended. It has also been suggested that drivers older than 62 years may require greater retroreflectivity level than the minimum levels determined.

Driving is influenced on a lot of factors such as roadway geometry, light condition, weather, traffic conditions and driver's personal characteristics. During the day several visual clues exists that helps the driver guide their way on the road but at night driver's have to heavily rely on the pavement markings, markers and traffic signs. A research was performed in a rural section of Pennsylvania were a group of drivers of different age and gender were asked to drive along horizontal curves with different radii and different retroreflectivity of the pavement markings. One of the treatments had no pavement marking at all and the others had edgelines and centerlines with different levels of retroreflectivity and some of the edgelines were raised retroreflective pavement markings. After driving through the curve the drivers had to rate the curve on how well they were able to drive through it. Results indicate that driver's rated the curve with any treatment better than the curve without any treatment at all. One of the findings was that the retroreflectivity of sharp curves has more impact on drivers than on flatter curves *(10)*.

A low retroreflectivity level may increase the number of crashes as drivers are not able to visualize the roadway clearly. However, a too high retroreflectivity level may not be safe too as drivers may feel too comfortable during nighttime and drive at an unsafe speed *(8)*. This study on Permanent Raised Pavement Markings (PRPM) concludes that PRPMs are less effective on two lane rural highways with low volume traffic because drivers tend to increase their speed. In addition, this study found that sharp curves with a degree of curvature great than 3.5 may cause an increase in nighttime crash rate on rural, two-lane roadways.

FREE FLOWING VEHICLES

Platoon vehicles can be defined as those vehicles whose speed are influenced by the vehicles in front of them while free flowing vehicles are those vehicles where the drivers can choose their own travel speed or are vehicles that are free from interactions in the traffic stream *(27)*.

A study was done by Brewer and Pesti on different vehicle headway. Speed and headway data were collected at three different points on a construction zone on I-20 in Texas. The construction work required closing one of the two lanes. The first point was located 1 mile upstream of the construction zone where the speed limit was 70 mph. The second point was at the lane closure taper and the third point was at approximately at the middle of the work zone. This single lane section was 8 mile long, with no passing zones and the vehicle speed limit was 60 mph. After collecting the headway and speed data for three days, researchers have found that for location 1, the headway for free flowing vehicles was four seconds, while for location 2 and 3 the headway for free flowing vehicles are 10 seconds and 14 seconds respectively.

In the above study it can be observed that for special conditions such as in work zone conditions vehicles tend to keep a larger headway to stay uninfluenced from the vehicle ahead of them while at normal conditions vehicles can pick their own speed even at smaller headways. The above study mentions that, “A common rule of thumb is to set a time headway threshold and consider only those vehicles that have headways greater than or equal to the preset threshold” *(28)*.

Research was also conducted at Montana State University to determine the free flowing vehicles on rural highways. Data were collected on rural two-lane and four–lane highways. To determine the free flow or car following interactions, the relationship between speed and time headway were established. After the time headway exceeded a certain threshold, the number of vehicles following diminished. These vehicles were considered as free flowing vehicles. Data from this research concludes that free flowing vehicles on two lane rural highways are defined as vehicles having headway of six seconds or greater *(27)*.

When developing vehicle speed model, researchers tend to include only free flow vehicles. The threshold that researchers use to define free flow vehicles varies from four to six seconds. Gong and Stamatiadis used five seconds as the threshold for free flow vehicles *(*17). Medina and Tarko also used five seconds to classify between free flow and platoon vehicles *(15)*.

TEXAS CURVE ADVISORY SPEED SOFTWARE

TTI researchers, Bonneson et al., developed software called, Texas Curve Advisory Speed Software (TCAS) to automate the procedure and guidelines to determine the advisory speed for horizontal curves *(29)*. In addition to determining the advisory speed, this software provided the side friction demand for the curves which were then used to set the severity levels. Based on the severity levels, guidelines were provided on what type of warning signs and other delineation treatments should be used for that particular curve.

Using vehicle speed models for horizontal curves, Bonneson et al. developed this software. The first model that was developed was as follows:

$$V_c = \left(\frac{15.0R_p \left[b_0 - b_1(1.47V_t) + 0.001b_2(1.47V_t)^2 + b_3 I_{tk} + b_4 I_x + e/100 \right]}{1 + 0.0322R_p b_2} \right)^{0.5} \leq V_t \tag{8}$$

With,

$$R_p = R + \frac{3.0}{1 - Cos(0.5I_c)}$$

In the above equation,

V_c = curve speed, mph

V_t = tangent speed, mph

R_p = travel radius path, feet

b_3 = calibration coefficient for trucks

I_{tk} = indicator variable for trucks (=1.0 if model is used to predict truck speed, 0.0 otherwise)

b_4 = calibration coefficient for other factors

I_x = indicator variable (=1.0 if factor is present, 0.0 otherwise)

e = superelevation rate, percent, and

I_c = curve deflection angle, degrees *(14)*

After performing regression analysis, calibration coefficients were developed yielding the following model to predict the 85th percentile vehicle speed at curves for the TCAS software *(14)*:

$$V_{c,85} = \left(\frac{15.0R_p(0.196 - 0.00106V_{t,85} + 0.000073V_{t,85}^2 - 0.0150I_{tk} + e/100}{1 + 0.00109R_p} \right)^{0.5} \leq V_{t,85}$$

(9)

Here,

$V_{c,85}$ = 85th percentile curve speed, mph and

$V_{t,85}$ = 85th percentile tangent speed, mph

The side friction demand increase also known as the frictional differential was used to determine the severity level because the increase in side friction that a driver accepts is proportional to the energy required to slow the vehicle to the curve speed. Frictional differential is the difference between the side friction factor incurred by the vehicle and the upper limit of comfortable friction. Using the calibration coefficients from the above equation, the frictional differential equation that was developed for the TCAS software is:

$$\Delta f = 0.000073(V_{t,85}^2 - V_{c,85}^2)I_v = SideFrictionDemand \qquad (10)$$

In the above equation,

Δf=friction differential and

I_v=indicator variable (=1.0 if $V_{t,85}>V_{c,85}$; 0.0 otherwise)

This software was implemented as a excel spreadsheet. The advisory speed could be determined by two different processes. One is by, “Known Curve Geometry” and the other is the “Survey of Curve”. “Known Curve Geometry” is used when geometric data information about the roadway is known from the actual design of the roadway while

"Survey of Curve" is used when geometric data information is obtained by surveying the roadway. The top one-third cells in this software contain the 'input data' cells. The calculation cells are located in the bottom two-thirds of the worksheet. The radius is calculated from the deflection angle and the curve length while the ball bank reading is used to calculate the superelevation. The bottom third of the spreadsheet provides the traffic control device guidance based on the advisory speed that is calculated. The third row in this section provides the curve severity category which is based on the side friction demand increase thresholds. This software divides the severity of a curve into five levels.

VEHICLE SPEED DATA COLLECTION METHODS

Sun, Park, Tekell and Ludington evaluated edgeline pavement markings on narrow roads in Louisiana using vehicle speed and lateral placement data. Road Tubes also known as airswitch devices were used to collect the vehicle speed and lateral placement data. The researchers stated that this method was more reliable, less intrusive and easier to set up while compared to other vehicle speed and lateral placement data collection methods *(30)*. Using three sensors with eight tubes, the data that were collected for this study are: (a) number of right tires touching the 1-feet section of roadway next to the pavement edge, (b) number of right tires touching the roadway section between 1 and 2 feet from the edgeline, (c) number of vehicles crossing the centerline, (d) hourly traffic volume by direction, and (e) operation speed.

Traffic engineers have also used Global Positioning Systems (GPS) as an alternative method to collect traffic data (*31*). The purpose of this study was to collect a vehicle speed profile, vehicle acceleration and deceleration, vehicle queue length and vehicle's positions at highway work zones in Indiana. GPS was used on a test vehicle to collect these data at a work zone. The vehicle speed and position data is recognized by satellite signals and recorded this device. At each data point it records the vehicles position, speed time and the distance between the current and last time points. As the test vehicle is traveling with other traffic on the road, the GPS not only gives a speed profile of the test vehicle but also of the traffic flow *(31)*.

LINEAR MIXED MODELS

While making a model one has to characterize the dependence of a response variable on one or more covariates. These variables can be fixed or random. A statistical model that contains both fixed and random variable is known as mixed-effects model *(32)*. When the parameters in a mixed-effects model are chosen to be linear, the model then is known as linear mixed model. Statistical software packages such as CRAN-R and SPSS are capable of modeling linear mixed models. Generalized linear models do not address correlated errors. "The Linear Mixed Models procedure expands the general linear model so that the error terms and random effects are permitted to exhibit correlated and non-constant variability. The linear mixed model, therefore, provides the flexibility to model not only the mean of a response variable, but its covariance structure as well" *(33)*. In the CRAN-R manual, Fox, in his *Linear Mixed Model* chapter gives the Laird-Ware form of the linear mixed model, which is:

$$y_{ij} = \beta_1 x_{1ij} + \ldots + \beta_p x_{pij} + b_{i1} z_{1ij} + \ldots + b_{iq} z_{qij} + \varepsilon_{ij} \qquad (11)$$

Here,

- y_{ij}: the response variable.
- β_1……. β_p: the fixed – effect coefficients.
- x_{1ij}…….x_{pij}: the fixed – effect regressors.
- b_{i1}…….. b_{ip}: the random – effect coefficients.
- z_{1ij}………z_{qij}: the random – effect regressors.
- ε_{ij}: the error for observation j in group i.

SUMMARY

While developing vehicle speed models for the midpoint of horizontal curves, researchers have used many different variables. Some of the most common used variables are tangent speed, approach speed, radius, deflection angle, curve length and lane width. One observation that all researchers made was that vehicle speed increases with the increase in the curve radius. Another important observation is that for sharper curves vehicle speed is influenced more by the curve characteristics while for flatter curves the vehicle speed is impacted more by the cross sectional characteristics of the roadway such as lane width and shoulder width. Another important aspect of developing a vehicle speed model is to use free flowing vehicles. Researchers use between 4-6 seconds to distinguish between free flowing and platoon vehicles.

Nighttime driving is very different from daytime driving due to the absence of the sun at night. Visibility of the roadway is significantly reduced at nighttime especially if there is no street lighting. The fatality rate per mileage driven at night is higher compared to day. Visibility, fatigue and alcohol are three reasons for the high fatality rate at night. Visibility is an important factor while driving at night but unfortunately many drivers do not adjust their speed accordingly due to the limitations caused by visibility at night. Due to the high crash rate during nighttime, the state of Texas has a lower speed limit at night for high speed roadways. Thus, vehicle speed at day time and nighttime does vary.

Retroreflective materials are easier to see at night as they bounce of light to the light source. This is why MUTCD requires all pavement markings that are to be used at night to be retroreflective. Even though, MUTCD requires pavement markings to be retroreflective it does not provide any minimum level of retroreflectivity that should be used. Different studies have shown that the minimum retroreflectivity level that is needed for drivers to feel comfortable is around 100 $mcd/m^2/lx$. As too low retroreflectivity is not safe because drivers are not able to view the road properly, too high of a retroreflectivity may not be safe too as drivers may feel too comfortable leading them to speed and even over run their headlights.

By inputting the data for radius, curve length, superelevation, deflection angle and tangent speed the TCAS software is able to determine the advisory speed and also the severity level of the curve. Multiple linear regression speed model was used to develop this model. Other researchers also use multiple linear regression models to develop vehicle speed models.

Vehicle speed at day and night is different at tangent sections and also curve sections of roadways. As retroreflectivity of the pavement markings determines how clearly a driver is able to view the road, retroreflectivity is an important factor in driving at night because the driver may choose their speed depending on how clearly they can view the road. Thus, it is important to see how speed changes at day and night for curves with different geometric characteristics and retroreflectivity levels.

3. BACKGROUND INFORMATION ON DATA

Vehicle speed and vehicle lateral placement data on 18 two-lane two-way horizontal curves near Nashville, Tennessee were collected in the outside lane by the Texas Transportation Institute (TTI) during summer of 2007. This dataset was used for the analysis. The dataset is described below:

- Data were collected along 18 rural two-lane, two-way horizontal curves which differ from each other in terms of its geometric characteristics such as shoulder width, lane width, edgeline retroreflectivity, superelevation, grade, radius of the curve, curve length, deflection angle, speed limit and advisory speed.
- Data were collected at each curve for at least a 48 hour period during weekdays.
- To measure the vehicle speed and lateral placement, speed traps were placed at four locations in the outside lane of each curve as illustrated in Figure 1 and described below:
  - Upstream Location (U) – This point was located far enough upstream so that the vehicle speeds were be affected by the curve or even the warning signs. It was approximately 1000 feet upstream of the curve warning sign.
  - Advance Curve Warning Sign Location (W) – This was the location of the advance curve warning sign or the location where the sign would have been located if there was no sign present.
  - Point-of-Curve Location (PC) – This point was located at the point-of-curvature (PC) of the horizontal curve.

- Midpoint-of-Curve Location (MC) – This point was located at the midpoint of the horizontal curve (MC).

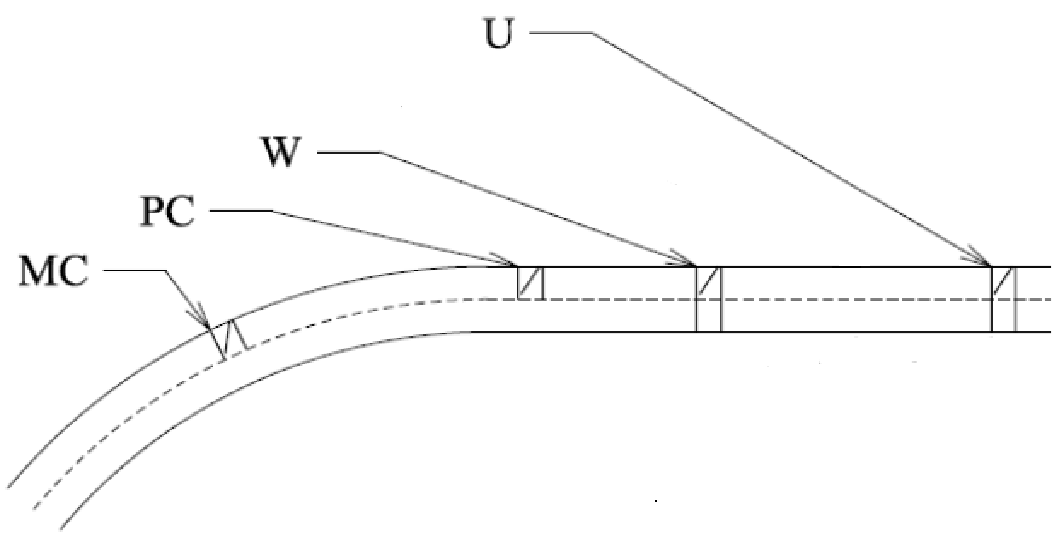

Figure 1 Location of the Traffic Classifier

- Each vehicle was tracked through all four points so the author could relate the speed at the MC to any other points if needed during the analysis.

- JAMAR traffic classifiers in conjunction with piezoelectric road sensors were placed in a Z configuration as shown in Figure 1 to collect the vehicle speed and lateral placement data. Figure 2 on the next page illustrates the Z configuration that was placed on one of the locations.

Figure 2 Illustration of a Z Configuration

4. DATA ANALYSIS

In this section, the author focuses on the procedure used to reduce the dataset prior to the analysis. The author describes the variables that were used as an input in the TCAS software to determine the side friction demand of the horizontal curves and how the curves were categorized. The author also outlines his statistical methodology used to create the linear mixed model and the statistical methodology used to compare the daytime and nighttime speed data.

REDUCE THE DATASET

The steps that were taken to reduce the dataset area as follows:

Step 1

The first step in reducing this dataset was to exclude erroneous and missing data.

Step 2

The second step in this reduction process was to eliminate extraneous data. As stated above, the original dataset has vehicle speed information at four points along the curve. However, for this study only the speed at the midpoint of the curve or speed at MC was used because it is assumed that this is the point where drivers reach their minimum speed along the curve. In addition, when developing vehicle speed models on horizontal curves, generally the models are based on operating speeds at the midpoint of the curves (*14, 15, 16, 17, 18, 21*). Thus, the speeds at PC, W and U were excluded from the dataset.

The curve geometry data has information on shoulder width, lane width, edgeline retroreflectivity, superelevation, grade, radius of the curve, deflection angle, speed limit lane width and advisory speed for each of the curves. From this dataset, data for only the radius of the curve, deflection angle, curve length, speed limit and retroreflectivity level were kept for the analysis. A description of these variables is given in the *Review the Dataset* section on page 32.

Step 3

The third step in reducing this dataset was to exclude vehicles that traveled through the curve half an hour before and after the sunset and sunrise. In addition, in this step, rain data was eliminated too.

Step 4

Only isolated free flowing vehicles were included in the analysis. Isolated and free flow vehicle is defined as those vehicles whose speed will not be influenced by the vehicle in front of the vehicle of interest. Speed profile was plotted for different headways starting from 1 second and increasing the increment by 1 second. This was done for the curves with high volumes because it is easier to observe the noise in the data with high volume traffic compared to low volume traffic. This speed profile is a graph of vehicle n against vehicle n+1 at the midpoint of the graph. Here n is the vehicle of interest. If the data from the graph shows that, the slope of the regression line is equal to y = x or close to that then the vehicles are defined as platoon vehicles but if the graph demonstrates that the data is scattered, this will suggest that the vehicles are isolated. In other words, if the slope is one then it will mean that the vehicle of interest is maintaining the speed of the vehicle that is in front of it. However, if the slope is not close to the y = x line then the vehicles are choosing their own speed. The first headway that shows a graph with scattered data was considered as the minimum headway required for isolated vehicles. Vehicles that have headway less than this minimum headway were excluded from the analysis. After plotting the speed of vehicles at some of the curves that were used in this analysis, it was determined that free flowing vehicles had an approximate headway of 6 seconds.

Curve 15 was one of the high volume curves. Appendix A has the speed profile plots for curve 15 for headways 1 through 6. These plots include a linear trend line with an R squared value of the trend line. An R squared value close to 1 will determine that the vehicles are in platoon. Smaller R squared values will determine that the vehicles are in free flowing condition. The linear trend line has been plotted by fixing the intercept to 0 so that it mimics a y = x graph. From these plots it was observed that free flowing vehicles in this curve occur for headways 5 second and larger.

To be conservative, the author defined free flowing vehicles as having headway of 7 seconds or more for this analysis. In this step vehicle that has headways less than 7 seconds were excluded.

Step 5

Here the plan was to remove vehicles that that have the presence of opposing traffic while going through the curve. This is why the time that a vehicle was present at the opposite direction was measured but due to the uneven time drifts in the sensors it was difficult to determine the exact time an opposing vehicle was present. Thus, unfortunately for this analysis, vehicle with and without the influence of opposing traffic were included in the analysis.

Step 6

The data were collected in such a way so that the number of axles of each vehicle passing through the curve could be calculated. This step consisted of determining the percentage of each type of vehicle and determining whether speeds differ among different types of vehicles (car vs. truck). However, when tracking the vehicles along the curve at the four locations (U, W, PC and MC) the data revealed that a same vehicle would have different number of axles at different locations. Due to this technical difficulty, the idea of determining the types of vehicles was abandoned.

REVIEW THE DATASET

In this section, the procedures that were used to collect the data for the variables that were used as input data in the TCAS software for the analysis is reviewed. Furthermore, how these variables were used in the analysis is discussed as well.

Vehicle Speed at Points MC

A speed trap was placed using JAMAR traffic classifiers in conjunction with piezoelectric road sensors to measure the speed at MC. The traffic classifier provides the time stamps when a vehicle crosses over the sensors. With these time stamp data and simple geometry the vehicle speed and lateral placement was calculated. Even though this is not one of the methods that has been identified in the Identify Methods to Collect Vehicle Speed and Vehicle Lateral Placement Data section, this data is reliable, as many of the researchers at TTI use this method to collect vehicle speed and lateral placement data.

Prior to performing the analysis, erroneous data, and rain data were excluded from the dataset.

Edgeline Retroreflectivity at MC

Retroreflectivity level was measured with a handheld pavement marking retro reflectometer. The average of four readings of retroreflectivity level was used to determine the retroreflectivity level at MC.

Superelevation at MC

Superelevation was measured using a ball-bank reading indicator. This was used as input data for the TCAS software.

Radius of the Curve

Radii of the horizontal curves were measured by a radiusmeter. This value was checked by measuring the radius on an aerial map.

Deflection Angle

Deflection angle was measured in the direction of travel by calculating the difference in the approach tangent heading and the exiting tangent heading. This was used as an input for the TCAS software.

Curve Length

As the measurement of radius and deflection was more accurate than the measurement of the curve length; the measured curve length value was not used. The curve length will be calculated from the radius and the deflection angle using the following equation:

$$L = \frac{\Delta \times \pi \times R}{180}$$

In the above equation,

L= length of curve

Δ= deflection angle

R= radius of curve

Table 1 below provides the curve geometry data that was used for the TCAS software for each of the curves.

Table 1 Input Data for TCAS Software

Curve ID	Radius (feet)	Deflection (deg)	Curve Length	Speed Limit (mph)	MC superelevation (degree)
1	406	63	446	35	0.3
2	511	46	410	35	3.0
4	1650	21	605	35	2.0
7	860	26	390	45	2.0
8	460	39	313	45	4.0
10	1161	68	1378	45	4.0
15	613	65	695	55	7.0
29	881	21	323	55	6.0
30	318	92	511	55	7.5
31	649	50	566	55	4.0
32	663	36	417	55	7.0
33	1857	32	1037	55	2.0
35	539	28	263	55	5.5
37	672	21	246	50	7.0
38	1193	52	1083	50	3.5
39	1425	37	920	55	6.0
40	1171	40	818	55	6.0
53	1250	32	698	55	7.5

CATEGORIZE THE HORIZONTAL CURVES USING SIDE FRICTION DEMAND AND RETROREFLECTIVITY

One of the objectives of this study was to compare the daytime and nighttime speed of vehicles at the midpoint of the curve. To perform this analysis, the curves were categorized using different methods. In each method, the curves were categorized according to its respective side friction demand and retroreflectivity level. Side friction demand was used because, "The increase in side friction demand that a driver accepts is proportional to the energy required to slow the vehicle to the curve speed" (*14*). As stated earlier, the TCAS software was used to determine the side friction demand. From the overview of the TCAS software in the *Literature Review* section, it was observed that one other advantage of using side friction demand is that the side friction demand equation includes the radius, curve deflection angle and superelevation of the curve. Thus, there will be no need to categorize the curves separately in terms of the radius, curve deflection angle and superelevation.

As stated in the *Literature Review* section, in addition, to providing the side friction demand value, the TCAS software also categorizes the curves into five groups according to the side friction demand value. The author did not use the same threshold values used in the TCAS software to categorize the curves but used those thresholds as guidelines when he categorized the curves for this analysis.

The first reason was because for this analysis, the curves were not grouped based only on the side friction demand value but also according to the retroreflectivity value. Dividing the curves into five groups based just on side friction demand would increase the total number of groups being analyzed. As this analysis has only 18 curves, making too many groups could become an issue as some groups may not have any curves while others may have too few curves to analyze and to come up with a conclusion. The second reason was that the threshold values used in the TCAS software is used as a guideline to determine the type of warning treatment needed for a curve. However, that is not the scope of this study. Thus, it is not necessary to use the threshold values used in the TCAS software.

Retroreflectivity level was used as the other factor in categorizing the curves as one of the objectives was to determine at what retroreflectivity levels the daytime speed and nighttime speeds significantly differ.

The author decided to categorize side friction demand and retroreflectivity into 2-3 separate groups. However, it was determined that some curves could fall into more than one group if the threshold between each group is changed. This led the author to categorize the curves in six different methods. Categorizing the curves into six different methods would determine the sensitivity of the curves. In other words, by changing the threshold points between the groups, the author replaced curves from one group to another group to examine how this replacement of curves changed the daytime and nighttime speed within a group and how the speeds are changing among different groups. The matrix in Table 2 Curve Categorization Matrix demonstrates in what group the curves belong to for the six methods. In addition, the matrix also provides the side friction demand obtained from the TCAS software and, the retroreflectivity level for each curve. Definitions of the groups and explanations on how the curves were grouped for the six methods are given below:

Table 2 Curve Categorization Matrix Using Side Friction Demand and Retroreflectivity

Curve ID	Side Friction Demand Increase	Marking Retroreflectivity (mcd/m^2/lx)	Method					
			1	2	3	4	5	6
1	0.07	157	C	C	B	C		E
2	0.04	286	B	B	A	B	B	C
4	0.00	384	A	A	A	B	B	C
7	0.03	90	B	B	A	A	A	A
8	0.07	117	C	C	B	C	C	D
10	0.00	285	A	A	A	B	B	C
15	0.07	175	C	C	B	C		E
29	0.02	201	B	B	A	B		B
30	0.12	222	C					
31	0.08	117	C	C	B	C	C	D
32	0.06	160	C	C	B	C		E
33	0.00	153	A	A	A	A		B
35	0.08	129	C	C	B	C	C	D
37	0.02	203	B	B	A	B		B
38	0.01	479	B	B	A	B	B	C
39	0.00	101	A	A	A	A	A	A
40	0.00	119	A	A	A	A	A	A
53	0.00	300	A	A	A	B	B	C

Method 1

In this method the curves was categorized into groups based on its side friction demand value only; the effects of retroreflectivity level was not analyzed in this method. As can be seen from the above table, in this method there are three groups, which are as follows:

- Group A: Curves with side friction demand value of 0
- Group B: Curves with side friction demand greater than 0 and less than 0.05
- Group C: Curves with side friction demand greater than 0.05

From the *Literature Review* section of *Development of Guidelines for Establishing Effective Curve Advisory Speeds*, it was found that curve warning signs are not needed when the friction differential is 0.00. This means that a vehicle may not need a slower speed than the tangent section speed as they go through a curve when the frictional differential is 0.00. Thus, it is assumed that visibility of the roadway will not be an issue at these curves especially at night. As a result, the day and night time speed may not be significantly different in this group. To test this assumption, Group A was created.

The author chose 0.05 as the side friction threshold value between Group B and Group C because after observing the side friction values of the 18 curves the author identified that there was one curve with side friction value of 0.04 and one curve with side friction value of 0.06 but there was no curve with a value of 0.05. Hence, 0.05 was used as the threshold between Group B and Group C as no curve has a side friction value of 0.05

If Group C is observed, then one will find that there are seven curves in this group. Out of these seven curves, six of them have side friction values between 0.06 and 0.08 while the other one, Curve 30, has a side friction demand value of 0.12. This is the largest side friction value in this dataset. The difference between this largest side friction demand value and the second largest side friction demand value is (0.12 – 0.08) = 0.04.

Since there are no side friction demand values between 0.12 and 0.08; having Curve 30 in Group C may provide inconclusive results. To eliminate this problem, Curve 30 could have been put into another group which would have curves having side friction demand value greater than 0.10. However, in that case that group would contain only Curve 30 and it maybe biased to obtain any conclusions from a group that has only one curve. Hence, Group D was not created.

To eliminate the issue of having inconclusive results in Group C because of the big difference between the side friction demand value of the largest side demand value and the second largest side friction demand value, in Method 2, these same groups was retained except that Curve 30 was eliminated from the analysis. In fact, Curve 30 was not used in any of the other methods.

Method 2

As mentioned above, this method is exactly the same as Method 1, except that curve 30, which has a side friction level of 0.12, was excluded here.

Method 3

This method was used as the primary step for categorizing the curves for the latter three methods. In this method the curves were also categorized based only on the side friction demand values. The difference between the previous two methods and this method is that here the curves were categorized in two groups rather than three groups. Here, Group A and Group B of Method 1 and 2 were combined into one group, which is named as Group A and Group C of Method 1 and 2 is renamed as Group B.

The reason for combining Group A and Group B of the previous two methods into one group in this method is that, in the next methods the curves were categorized based on both the side friction demand value and retroreflectivity level. Creating three separate groups for side friction demand and retroreflectivity level would create a 3 × 3 matrix, which means that there would be nine different combinations of side friction demand and retroreflectivity. However, categorizing the curves into nine different combinations of side friction demand and retroreflectivity level may lead to inconclusive results because there may not be enough data in each group to analyze as altogether there are only 17 curves available to analyze. Hence, to reduce the size of the matrix, in the latter three methods, side friction demand was divided into two groups.

One can question why to make two groups, Group A and B were combined instead of combining Group B and C of Methods 1 and 2. The reason for combining Group A and Group B of the previous two methods is that, there are curves with side friction demand value of 0.00 and 0.01 and 0.00 is the threshold between Group A and Group B. On the other hand as stated previously, there are no curves with side friction demand value of 0.05, which is why 0.05 was chosen as the threshold between Group B and Group C. As a result, one can see that it is easier to combine Group A and B rather than to combine Group B and C.

In the next three methods after categorizing the curves in terms of side friction demand value using the technique used in this method, the curves were categorized further using retroreflectivity level.

Method 4

As stated previously, in this method, after categorizing the curves based on the side friction demand using the technique in Method 3, the curves were further categorized using retroreflectivity level.

In the *Literature Review* section, it was mentioned that a low retroreflectivity level may make drivers drive significantly slower than their daytime speed because they are unable to visualize the road properly whereas a high retroreflectivity level may make the drivers feel too comfortable and hence drive at a speed higher than daytime (*8*). In this method, it was assumed that a retroreflectivity level of 200 mcd/m^2/lx or more is more than what a driver needs to maintain the posted speed limit. Hence, this created two groups of retroreflectivity, one group with retroreflectivity less than 200 mcd/m^2/lx and the other with retroreflectivity more than 200 mcd/m^2/lx.

As a result, dividing the side friction demand and retroreflectivity level in two separate groups has created four combinations or groups of side friction demand and retroreflectivity level in this method. The four groups are as follows:

- Group A: Curves with side friction demand less than 0.05 and retroreflectivity level less than 200 mcd/m^2/lx
- Group B: Curves with side friction demand less than 0.05 and retroreflectivity level more than 200 mcd/m^2/lx
- Group C: Curves with side friction demand greater than 0.05 and retroreflectivity level less than 200 mcd/m^2/lx
- Group D: Curves with side friction demand greater than 0.05 and retroreflectivity level greater than 200 mcd/m^2/lx

After categorizing the curves in its respective group the author determined that there were no curves that met the requirements of Group D. Hence, there is going to be only three groups for this method.

Method 5

This method was a modification of Method 4. Similar to method 4, after categorizing the curves based on the side friction demand using the technique in Method 3, the curves here were further categorized using retroreflectivity level.

In the previous method, 200 mcd/m^2/lx was used as the threshold to create the two groups of retroreflectivity level. Here too, there were two groups of retroreflectivity but the threshold was defined differently than in the previous method. The issue in the previous method was that, the author realized that there are some curves such as curves 29 and 37 that have retroreflectivity value close to 200 mcd/m^2/lx (201 mcd/m^2/lx and 203 mcd/m^2/lx respectively). Previously, it was mentioned that the retroreflectivity values that are used here are an average of four retroreflectivity values that were measured close to the MC location. The retroreflectivity value of curves 29 and 37 may become less than 200 mcd/m^2/lx if another reading was taken. In that case these two curves would have been placed in Group A instead of Group B.

To resolve this issue, curves that were within ± 50 mcd/m^2/lx of 200 mcd/m^2/lx were excluded from the analysis in this method. The author could have chosen a smaller margin (i.e. ± 20 mcd/m^2/lx), which would have excluded fewer curves from the analysis. However, just to be conservative, the author chose ± 50 mcd/m^2/lx as the margin because after all the retroreflective values used in the analysis are an average value and another reading may well change that average quite a bit if the next reading location was in a spot were the retroreflectivity might have worn out significantly compared to the other locations due to reasons such as weather, vehicle tire etc.

Hence, in this method one group has curves with retroreflectivity value less than 150 mcd/m^2/lx and the other group has curves with retroreflectivity more than 250 mcd/m^2/lx. Thus, due to a 2 × 2 matrix, this method too has four groups, which are as follows:

- Group A: Curves with side friction demand less than 0.05 and retroreflectivity level less than 150 mcd/m^2/lx
- Group B: Curves with side friction demand less than 0.05 and retroreflectivity level more than 250 mcd/m^2/lx
- Group C: Curves with side friction demand greater than 0.05 and retroreflectivity level less than 150 mcd/m^2/lx
- Group D: Curves with side friction demand greater than 0.05 and retroreflectivity level greater than 250 mcd/m^2/lx

It was determined that there was no curve that met the requirement of Group D. Thus, similar to Method 4, in this method too there will be three groups.

Method 6

This method is very similar to Method 5. In the previous method, curves that were within ± 50 mcd/m^2/lx of 200 mcd/m^2/lx were excluded from the analysis. In this method, the curves that were excluded in Method 5 were included in the analysis by creating a separate group for those curves. Thus, here, there are two groups for side friction demand and three groups for retroreflectivity level which has created six combinations or six groups of side friction demand and retroreflectivity level by creating a 2 × 3 matrix. The six groups developed for this method are as follows:

- Group A: Curves with side friction demand less than 0.05 and retroreflectivity level less than 150 mcd/m^2/lx
- Group B: Curves with side friction demand less than 0.05 and retroreflectivity level greater than 150 mcd/m^2/lx and less than 250 mcd/m^2/lx
- Group C: Curves with side friction demand less than 0.05 and retroreflectivity level greater than 250 mcd/m^2/lx
- Group D: Curves with side friction demand greater than 0.05 and retroreflectivity level less than 150 mcd/m^2/lx
- Group E: Curves with side friction demand greater than 0.05 and retroreflectivity level greater than 150 mcd/m^2/lx and less than 250 mcd/m^2/lx
- Group F: Curves with side friction demand greater than 0.05 and retroreflectivity level greater than 250 mcd/m^2/lx

Group F of this method and Group D of the previous method are the same. It was mentioned in the previous method that no curves met the requirements of Group D which is why Group D was omitted from the analysis. Here too, Group F was excluded from the analysis. Thus, there are give groups of curves in this method.

By including the curves that were excluded from the analysis in Method 5, in this method, the author intends to determine whether this new group of curves have speeds similar to curves with retroreflectivity less than 150 mcd/m^2/lx or similar to curves with retroreflectivity more than 250 mcd/m^2/lx or whether this new group of curves has speed which are significantly different from curves less than 150 mcd/m^2/lx and more than 250 mcd/m^2/lx.

CATEGORIZE THE HORIZONTAL CURVES USING RADIUS AND PAVEMENT EDGELINE MARKING RETROREFLECTIVITY

As mentioned in the previous section, one of the objectives of this study was to compare the daytime and nighttime speed of vehicles at the midpoint of the curve. In the previous section, the curves were categorized into different groups using the side friction demand and the pavement edgeline marking retroreflectivity. All the researchers who developed vehicle speed model in the past has used radius as an independent variable to predict the vehicle speed at curves. This demonstrates that radius has the biggest impact on vehicle speed.

As using side friction demand to categorize curves is not commonly used, in this section the author grouped the curves based on the radius to determine whether the result of the day and nighttime speed difference found using radius to classify curves into different groups is the same as grouping the curves according to the side friction demand value. If classifying the curves based on the radius yields similar day and nighttime speed difference as classifying the curves based on the side friction demand then it would mean that it is justified to group curves based on the side friction demand too. Similar to the previous section the author would also use retroreflectivity as the other factor to classify the curves.

To determine whether classifying the curves based on radius yields similar or different result as classifying the side friction demand, the author repeated Method 4 and Method 5 of the previous section but instead of using side friction demand and pavement edgeline marking retroreflectivity, the author used radius and pavement edgeline marking retroreflectivity. The matrix in Table 3 demonstrates in what group the curves belong to for the two methods and provides the radius and pavement edgeline marking retroreflectivity for each curve. Definitions of the groups and explanations on how the curves were grouped for the two methods are given below:

Table 3 Curve Categorization Matrix Using Radius and Retroreflectivity

Curve ID	Radius (feet)	Marking Retroreflectivity (mcd/m²/lx)	Method	
			1	2
1	406	157	A	
2	511	286	B	B
4	1650	384	D	D
7	860	90	C	C
8	460	117	A	A
10	1161	285	D	D
15	613	175	A	
29	881	201	D	
30	318	222	B	
31	649	117	A	A
32	663	160	A	
33	1857	153	C	
35	539	129	A	A
37	672	203	B	
38	1193	479	D	D
39	1425	101	C	C
40	1171	119	C	C
53	1250	300	D	D

Method 7

This method was very similar to Method 4 of the previous section. As mentioned earlier, instead of grouping the curves on the basis of side friction demand and retroreflectivity level, the curves were divided based on radius and retroreflectivity. A study sponsored by FHWA states that vehicle speed decreases sharply for radius less than 250 meter (820 feet) (*2*). On the basis of this, two curve groups were created, one group with curves less than 820 feet and the other group with curves less than 820 feet. Using the logic presented in Method 4 and to keep consistency with Method 4 of the previous section, the retroreflectivity level threshold was kept at 200 $mcd/m^2/lx$. Hence, the four groups in this method are:

- Group A: Curves with radius less than 820 feet and retroreflectivity level less than 200 $mcd/m^2/lx$
- Group B: Curves with radius less than 820 feet and retroreflectivity level more than 200 $mcd/m^2/lx$
- Group C: Curves with radius greater than 820 feet and retroreflectivity level less than 200 $mcd/m^2/lx$
- Group D: Curves with radius greater than 820 feet and retroreflectivity level greater than 200 $mcd/m^2/lx$

Method 8

This method was very similar to Method 5 of the previous section. Once again, instead of using side friction demand the author used radius of the curve. Method 4 and Method 5 of the previous section used the same side friction demand threshold value. To keep consistency with the technique of Method 4 and Method 5 of the previous section, the radius threshold value for this method was kept the same as Method 7 above, which was 820 feet. In Method 5 of the previous section, curves with edgeline marking retroreflectivity level between 150 $mcd/m^2/lx$ and 250 were excluded from the analysis. The same thing was done here too. The four groups in this method are:

- Group A: Curves with radius less than 820 feet and retroreflectivity level less than 150 $mcd/m^2/lx$
- Group B: Curves with radius less than 820 feet and retroreflectivity level more than 250 $mcd/m^2/lx$
- Group C: Curves with radius greater than 820 feet and retroreflectivity level less than 150 $mcd/m^2/lx$

- Group D: Curves with radius greater than 820 feet and retroreflectivity level greater than 250 mcd/m^2/lx

DEVELOP A LINEAR MIXED MODEL

After categorizing the data, the first step in analyzing the data consisted of developing a linear mixed model. Statistical models were developed in the past to find out how certain independent variables influences a dependent variable. Several models can be developed in this regard such as a linear model, non-linear model, mixed effects model, generalized linear model, linear mixed model etc. Depending on the type of research and the type of data, researchers use different models. For this analysis, a linear mixed model was developed. The reasons for this are (1) a linear mixed model can contain both fixed and random variables (2) it is an expansion of the generalized linear model where the error terms and random effects can produce correlated and non-constant variability. To simplify the statistical procedure, a linear model was chosen over a non-linear model.

A stepwise linear regression was also conducted to develop the linear mixed model. The advantage of creating such kind of model is that, it identifies the significant variables and creates a model with the significant variables only. Hence, one does not have to create multiple models with different combinations of the independent variables to determine which variables are significant in predicting the dependent variable. The statistical software package, SPSS was used to develop the linear mixed model as it has the capability to conduct a stepwise linear regression. In the ‘Analyze’ menu of SPSS, the 'Stepwise' option in 'Linear Regression' was used to conduct the stepwise regression analysis.

To develop the model, the author used the independent variables (curve length, superelevation, posted speed limit, deflection angle) that were used to calculate the increase in side friction demand also known as the frictional differential in the TCAS software. One reason for using those variables was because the frictional differential in the TCAS software was calculated from a vehicle speed model and the vehicle speed model included variables that influence vehicle speed at the midpoint of a curve. Another reason was because the vehicle speed model that was developed for the TCAS software is actually a modification of the traditional vehicle speed model given in Equation 1 in the *Literature Review* section. Furthermore, from the *Literature Review* section it can also be observed that most researcher used those variables when they developed their vehicle speed model.

In addition to the variables that were used in the vehicle speed model in the TCAS software, the author used another variable in the vehicle speed model which was retroreflectivity level of the pavement edgeline markings. Retroreflectivity level was used as another variable in the model because one of the objectives of this research was to determine the impacts of retroreflectivity level on vehicle speed at the midpoint of horizontal curve. As pavement markings are made retroreflective to improve nighttime driving, retroreflectivity was used for the nighttime speed data only by creating an interaction term between the retroreflectivity level and the light condition (*26*). To do that, a column was created in the data sheet labeled as 'Day/Night Code', where 0 was used to code for day data and 1 was used to code for night data. After that another column was created labeled as 'Retroreflectivity × Day/Night Code'. As the column heading suggests, in this column the retroreflectivity column was multiplied by the day/night code. As a result, in this column, all the day data became 0 and all the night data revealed the retroreflectivity value of the pavement edgeline marking.

As mentioned, the variables that were included in the vehicle speed model were radius of the curve, deflection angle, superelevation, posed speed limit and retroreflectivity of the pavement edgeline marking with nighttime speed data. To calculate, the side friction demand, the TCAS software used curve length and deflection angle but the author chose to use radius and deflection angle. This is because although, for the TCAS software, curve length was used, Dr. Bonneson actually used radius in the vehicle speed model. Instead of using radius as an input for the TCAS software, he used curve length and deflection angle as inputs and then calculated the radius from the curve length and deflection angle. Moreover, the traditional vehicle speed model uses radius and also most researcher uses radius instead of curve length. Instead of using radius and superelevation, the author used the square root of the radius and the square root of the superelevation to predict the vehicle speed because this is how the radius and superelevation were used in the traditional vehicle speed model and also in the vehicle speed model developed by Dr. Bonneson for the TCAS software.

Depending on the output two or three vehicle speed models was to be created. The first model (Model 1) would have all the five independent variables and the second model (Model 2) included only the variables that were significant in determining the vehicle speed at the midpoint of the curve identified by a stepwise regression analysis. If the stepwise regression analysis excludes the retroreflectivity of edgeline markings factor from the model, then the author would develop another model (Model 3) using the variables that were identified as significant in the stepwise analysis and the retroreflectivity of pavement edgeline marking factor. This is because observing the effects of retroreflectivity of edgeline markings on nighttime vehicle speed was one of the main objectives of this study. Hence, the author wants that to be a part of the model. If the stepwise method does not exclude the retroreflectivity variable then only two models would be created.

Statistical analysis of the model was conducted to determine the fit of the prediction model. A significance level or p-value of 0.05 was used to determine if the variables are able to predict the vehicle speed or not. The p-value in SPSS could be found in the 'Sig.' column of the 'Coefficients' table in the analysis section. If the p-value of a certain variable is greater than 0.05, it would indicate that the certain variable is not able to predict the vehicle speed at the midpoint of the curve with a 95 percent confidence level.

Previous researchers used a minimum of 100 vehicles while developing vehicle speed models (*14, 16, 18*). For this research, a minimum of 100 vehicles will be used for daytime and nighttime when developing the model.

COMPARE DAYTIME AND NIGHTTIME SPEED

The last objective of this research is to compare the average daytime and nighttime speed of vehicles at the midpoint of the curves for the groups that were created in each of the methods in the *Categorize the Horizontal Curves* section. Two hypotheses were tested in this study. They are as follows:

Hypothesis 1

The null hypothesis (H_0) states that, within a group there is a statistical significant speed difference between the daytime and nighttime at the midpoint of the curve, the alternative hypothesis (H_A) states that within a group there is no statistical significant speed difference between the daytime and nighttime speed at the midpoint of the curve.

Hypothesis 2

The null hypothesis (H_0) states that, there for the same light condition, (i.e. day) there is a statistical significant speed difference between two consecutive groups. The alternate hypothesis (H_A) states for the same light condition, that there is no statistical significant speed difference between two consecutive groups.

T-test and Analysis of Variance (ANOVA) are commonly used methods to compare mean speeds. T-test is usually used to compare means of two groups while ANOVA is used to compare speeds of more than two groups (*34*). A multiple T-test can be used to compare means of more than two groups. However, the number of tests to be performed increases geometrically as a function of the number of groups being compared. As a result, it becomes cumbersome, time consuming and it increases the chance of committing at least one Type I error. ANOVA has the capability of performing fewer hypothesis tests to compare the means of more than two groups.

In this research, a One-Way ANOVA was used instead of T-test. SPSS was used for this comparison. A multiple comparison Tukey test was also conducted. This test puts all the groups in the first column and then compares each group to every other group to determine if they are significantly different at the specified level of significance. In addition, it lists the mean difference between each group. Thus, this test enables the author to not only compare the mean day and night speed for each group but it lets the author to observe the differences or similarities that exist in speed among the different groups. The goal will be to have atleast 100 vehicles at daytime and nighttime for each group when comparing the speed at the midpoint of the curve.

5. RESULTS

The results have been divided into two sections. The first section contains the linear mixed model while the second section documents the comparison of the daytime and nighttime speeds.

LINEAR MIXED MODEL

The number of vehicles that was used for the day and night to create the linear mixed model are shown in Table 4.

Table 4 Vehicle Sample Size

Light Condition	Vehicles
Day	21795
Night	2061

The minimum requirement was to use 100 vehicles during the day and 100 vehicles during the night when creating the model. Hence, the sample size used in this analysis met the sample size requirement.

Before developing the linear models the author first observed the scatter plots of the dependent variable (vehicle speed) against the independent variables separately which are given in Figure 9 through Figure 13 of Appendix B. This was done to determine if the independent variables had a linear relationship with vehicle speed or whether the relationship is quadratic or cubic or other higher order relationships. Figure 9 through Figure 13 suggest that all the independent variables have a linear relationship with vehicle speed at the midpoint of horizontal curves. Hence, this justifies developing a linear mixed model instead of a non-linear model.

Two linear mixed models were created. A third model was not needed as the stepwise analysis included the retroreflectivity level with nighttime data. In Appendix B, Model 1 is the model that included all the variables and Model 2 is the model that was created with the stepwise regression analysis. The results of Model 1 indicated that all the five variables were significant in determining the vehicle speed at the midpoint of the curve. As a result, Model 2 is identical to Model 1, because it did not need to exclude any of the independent variables. The results of Model 1 and Model 2 are discussed below.

Model 1

The regression result of Model 1 is located in Table 17, Table 18 and Table 19. The variables used in this model were the square root of radius, square root of superelevation, deflection angle, posted speed limit and an interaction term between pavement edgeline marking retroreflectivity level and the light condition which was, 'Retroreflectivity × Day/Night Code', where 0 was used for daytime data and 1 was used for nighttime data. The interaction term between retroreflectivity and the light condition was done to ensure that retroreflectivity was used to predict the nighttime vehicle speed only. As retroreflectivity does not impact daytime speed it was unnecessary to use retroreflectivity as a variable to predict the daytime speed.

Before observing the regression analysis result, the author first observed the residual plot given in Figure 14. This figure suggests that there is no certain pattern in the data; the data is distributed equally above and below the y axis. The author also tested the normality of the data by observing the histogram in Figure 15. This figure also suggests that there is normality in the data. Table 17 provides the r-square and the adjusted r-square of the regression analysis, which was 0.412 for both of them. The author believes that this value is moderate and also believes that one should not judge the model solely based on this value because there are other indicators that provides the effectiveness of this model such as the p-value for the model and the p-value for the independent variables.

Table 18 provides the p-value for the linear mixed model while Table 19 provides the p-value for the independent variables that were used in the linear mixed model. In Table 18 a p-value 0.05 or less would imply that all or some of the variables are able to predict the vehicle speed at the midpoint of the curve with a 95 percent confidence level. The last column in Table 18 indicates that the p-value for this model was 0.00, which meant that all or some of the independent variables were able to predict the vehicle speed at the midpoint of two-lane two-way rural horizontal curves with 95 percent confidence.

To identify which independent variables were significant in predicting the vehicle speed, the p-values in column 6 labeled as ‘Sig’ in Table 19 was observed. Values from this table suggest that all five variables used in the prediction model were significant in predicting the model. This table also provides the coefficient of the variables which is the relation between the independent variable and the dependent variable or the rate at which the dependent variable increases or decreases as the independent variable changes one unit. A positive coefficient would imply that when the independent variable increases the dependent variable also increases, which is a direct relationship. A negative coefficient would imply that when the independent variable increases the dependent variable decreases, which is an indirect relationship. This is given in the second column of this table labeled as 'Unstandardized Coefficients B'.

The 'Standardized Coefficient' column provides information on how many standard deviations the dependent variable increases when the independent variable standard deviation increases by one unit. Using the coefficients give in Table 19, the equation form of the linear mixed model for the speed at the midpoint of two-lane two-way rural horizontal curves is as follows:

$$\text{Speed (MC)} = 22.376 + 0.614\sqrt{\text{Radius}} + 1.837\sqrt{\text{MC Superelevation}} - 0.065\,(\text{Deflection Angle}) + 0.105\,(\text{Posted Speed Limit}) - 0.003\,(\text{Retroreflectivity} \times \text{Day/Night Code}) \quad (12)$$

In the above model, speed at MC is in units of miles per hour, radius in feet, superelevation in percentage, deflection angle in degrees, posted speed limit in miles per hour and retroreflectivity level in units of $mcd/m^2/lx$.

Equation 12 suggests that while the square root of radius, square root of superelevation and posted speed limit has a positive relation with the vehicle speed, deflection angle and retroreflectivity level has a negative relation with the vehicle speed.

From Equation 2 and Equation 8 and 9, one can see that the square root of radius and the square root of superelevation have a positive relation with the vehicle speed. Hence, the relations that the model provides for the radius and the superelevation is consistent with the traditional vehicle speed model and the vehicle speed model that was developed for the TCAS software. If it is assumed that most drivers follow the posted speed limit then the posted speed limit should also have a positive relation with the vehicle speed which is verified by this model. A curve generally gets tighter as the deflection angle increases. Hence, the vehicle speed decreases as the deflection angle increases. The result of this model is consistent with the previous statement too.

Edgeline pavement markings are made retroreflective to ensure that drivers could properly visualize the travel way at nighttime (*26*). Many literatures have identified that an edgeline marking retroreflectivity level of at least 100 mcd/m^2/lx is necessary for drivers to comfortably drive during nighttime (*9, 10, 11*). In addition, one research study has identified that at high levels of retroreflectivity drivers may feel too comfortable and may drive at unsafe speeds during the nighttime (*8*).

The previous three statements imply that the retroreflectivity of edgeline markings have a direct relationship with the vehicle speed at nighttime because all three imply that nighttime vehicle speed increases as the retroreflectivity level increases. Thus, the coefficient for the variable 'Retroreflectivity × Day/Night Code' in the model should be positive. However, Equation 12 demonstrates that the coefficient for the variable 'Retroreflectivity × Day/Night Code' in this model is negative. This means that the vehicle slows down the least when the edgeline marking is close to 0 mcd/m^2/lx. This definitely not true because if this was true then there would not have been any need to use retroreflective pavement marking.

What this is implying is that, the relationship between retroreflectivity probably does not have a one directional linear relationship with nighttime vehicle speed. In other words up to a certain level of retroreflectivity, as the retroreflectivity increases the vehicle speed increases and after that level, as retroreflectivity increases, the vehicle speed decreases. The author believes that the relationship between retroreflectivity level and vehicle speed is a two directional linear relationship, which means that the plot of speed and retroreflectivity level should resemble an upside down 'V'.

Most literature recommends that a retroreflectivity level of 100 mcd/m^2/lx is needed to drive comfortably at nighttime. The lowest retroreflectivity level that this dataset contained was 90 mcd/m^2/lx. Hence, 17 out of the 18 curves in this dataset had curves that had pavement marking retroreflectivity more than the level that literature recommends. To see the upside down 'V', this dataset needed to have more curves that had retroreflectivity below 100 mcd/m^2/lx. The author believes that if this dataset had more curves which had retroreflectivity level below 100 mcd/m^2/lx, then from the minimum retroreflectivity level to the curve that had retroreflectivity level close to 100 mcd/m^2/lx, an increase in speed would have been observed.

By observing the coefficients for the independent variables in the above equation, one might think that the superelevation has greater impact on speed compared to the other variables that has been used in the model because it has the largest coefficient value among the five variables. However, that is not the case.

In the above equation, the radius of the curve actually has the biggest impact on speed even though it has a smaller coefficient value than the superelevation. This is because the numerical value of a radius is much larger than the numerical value of a superelevation. For example, in this dataset the curve with the smallest radius had a radius of 318 ft. Hence, according to this model, for this radius the vehicle speed would increase by 17.8 mph ($0.614\sqrt{318}$). On the other hand, the curve with the largest superelevation in the dataset had a superelevation of 13.2 percent. According to the model created here, this superelevation would increase the vehicle speed by 6.5 mph ($1.837\sqrt{13.2}$). Thus, even though superelevation has a higher coefficient than the radius, the smallest radius in the dataset impacts the vehicle speed more than the largest superelevation because of the magnitude of a radius is much larger than superelevation.

The curve with the highest posted speed limit in this dataset had a speed limit of 55 mph. This speed limit would increase the vehicle speed by 5.8 mph (0.105×55). The highest deflection angle in this dataset was 92, which would decrease the speed by 6 mph (0.065×92). The largest retroreflectivity level was 479 which would decrease the speed by only 1.4 mph (0.003×479). Hence, one can see that according to the model that was developed in Equation 12, radius has the largest impact on vehicle speed. This is definitely why all the vehicle speed models that were developed in the past had radius as one of the independent variables.

Model 2 (Stepwise Regression Analysis)

Column 2 and column 3 of Table 20 located in Appendix B demonstrates which variables were entered and which variables were excluded in each step to develop the model. Model 1 suggested that all the variables were significant in predicting the vehicle speed. As a result the stepwise regression did not remove any of the independent variables. In each step, it just added another variable. The R-square column in Table 21 of Appendix B indicates that the R-square of the models in each step improved. This means that the inclusion of each variable improved the R-square of the model and thus, the final model should include all of these five variables which are radius, superelevation, posted speed limit, deflection angle and retroreflectivity of pavement edgeline marking with nighttime speed data. The author did not examine the residual plot or the histogram plot for this model as this model as mentioned before was identical to Model 1. The author is also not going to provide the equation for this model as it is identical to Model 1 too.

COMPARISON OF DAYTIME AND NIGHTTIME SPEED USING SIDE FRICTION DEMAND AND RETROREFLECTIVITY

The following paragraphs discussed the ANOVA test that compared the daytime and nighttime speed at the midpoint of the curve for the six different methods. Prior to that, the author provides the average daytime and nighttime speed for each curve in the Table 5 below.

Table 5 Average Daytime and Nighttime Speed for Each Curve

Curve ID	Average Daytime Speed (mph)	Average Nighttime Speed (mph)
1	37.5	37.4
2	41.3	41.5
4	46.8	47
7	47.7	47.2
8	43.9	43.5
10	50.3	50.3
15	42.9	39.7
29	46.4	46.4
30	38.1	38.2
31	44.3	44.3
32	49.6	49.5
33	56.1	56.3
35	51.1	51.2
37	49.6	49.8
38	50.1	50.1
39	57.8	57.9
40	55.2	55.5
53	55.8	55.7

Method 1

Before comparing the daytime and nighttime speed, the first step consisted of verifying whether each group met the minimum sample size requirement. Table 6 on the next page provides some of the basic statistics for each group in this method obtained from SPSS.

Table 6 Method 1 Descriptive Statistics

Group	N	Mean	Std. Deviation	Std. Error
A_D	6108	52.71	6.81	.08
A_N	615	51.64	6.82	.27
B_D	4897	45.74	6.58	.09
B_N	351	46.35	7.32	.39
C_D	7526	42.93	6.33	.07
C_N	639	42.46	6.89	.27

In the group column, the first letter corresponds to the group and the second letter denotes the light condition (D for day and N for night). In the *Data Analysis* section, it was mentioned that a minimum of 100 vehicles was to be used for each group. From the above table it can be observed that all of the groups for both daytime and nighttime had more than 100 vehicles. Thus, each group met the minimum sample size requirement that was set for this analysis.

The first null hypothesis (H_0) stated that within a group there was statistical significant speed difference between the daytime and nighttime at the midpoint of the curve while the first alternative hypothesis (H_A) stated that within a group there was no statistical significant speed difference between the daytime and nighttime speed at the midpoint of the curve.

As Group C had curves with higher side friction demand value compared to the other two groups, it was assumed that for this group, the daytime and nighttime speed difference would be significant and this difference would be higher than the daytime and nighttime speed difference of Group A and B. As Group A contained flatter curves or curves with a side friction demand value of 0; the daytime and nighttime speed may not be significantly different for Group A. Since Group B contained curves that had a side friction demand value more than 0 but not as high as curves in Group C, it was hard to make any assumption about the speed difference.

As mentioned in the *Data Analysis* section, Tukey test was conducted for each method which is part of the One-way ANOVA test. Only the result of the Tukey test was discussed because it is easier to compare the speeds for each group in the Tukey test result. The Tukey test results table labeled as ‘Multiple Comparisons’, for this method is given in Table 22 of Appendix C. In this table, column 3 provides the mean speed difference between two groups and column 5 labeled as ‘Sig.’ contains the p-values, which indicates whether the difference in column 3 is statistically significant or not. A p-value of 0.05 or less corresponds to the two groups being statistically significantly different at a 95 percent confidence level. To make the p-values easier to visualize when it is 0.05 or less, SPSS puts an asterisk beside the mean difference value in column 3. A positive value in column 3 suggests that the mean speed decreased from column 1 to column 2.

The results of Table 22 suggest that for Group A the daytime and nighttime speeds were significantly different statistically while for Group B and Group C the daytime and nighttime speeds were not significantly different statistically. Thus, while the null hypothesis was true for Group A, for Group B and C the alternative hypothesis was true.

Unfortunately, the results of the analysis contradict the assumptions made by the author. However, there is a reason for that. The assumptions that were made by the author may have been correct if side friction demand was the only dependent variable and other variables such as retroreflectivity were kept constant. However, that was not the case for this method. For example, even though Group A had flatter curves, it contained curves with pavement markings with a wide range of retroreflectivity value. Thus, at curves with low retroreflectivity levels, vehicles may have been slowing down significantly at night compared to daytime. In addition to that the overall speed data in Group A may have been dominated by curves with lower retroreflectivity levels rather than curves with higher retroreflectivity levels. As a result, the daytime speed was significantly higher than the nighttime speed.

After observing the daytime and nighttime speed differences of Group B and C, the author concluded that the daytime and nighttime speed for these groups are the same because the difference between the speed for the two light conditions for these two groups are less than 1 mph, which the author considers to be negligible.

The second null hypothesis (H_0) stated that, for the same light condition, there was a statistical significant speed difference between two consecutive groups. The alternate hypothesis (H_A) stated that for the same light condition, there was no statistical significant speed difference between two consecutive groups.

In the *Data Analysis* section it was mentioned that in this method side friction demand value increases from Group A to Group C or curves become sharper from Group A to Group C. Hence, the vehicle mean speed should decrease from Group A to Group C. The average speed values in 'Mean' column of Table 6 are consistent with this assumption. Group A has the highest mean speed while Group C has the lowest mean speed.

The null hypothesis which stated that there was a statistical significant speed difference between two groups of the same light condition was true for all the three groups. For the daytime groups, Group A_D had significantly higher speed than Group B_D and Group B_D had significantly higher speeds than Group C_D. For the nighttime groups, Group A_N had significantly higher speed than Group B_N and Group B_N had significantly higher speeds than Group C_N. This verified that vehicle speed does decrease as the side friction of the curve increases. In addition, it proved that the categorizing of the curves in terms of side friction demand had been done properly. If the curves were not categorized properly then this significant difference in speed would not have been observed.

The author could not conclude anything from the difference between the daytime and nighttime speeds for the three groups that were analyzed but this method verified that as the side friction demand increases, the vehicle speed decreases at the midpoint of the curve on two-lane two-way rural horizontal curves.

Method 2

The *Data Analysis section* stated that this method was exactly the same as the previous method except that Curve 30, which was in Group C in Method 1, was removed from the analysis here. Thus, the results for Group A and Group B of this method and Method 1 are identical as they have been kept unchanged. Table 7 below which provides the descriptive statistics for this method demonstrates that all of the groups met the minimum sample size requirement.

Table 7 Method 2 Descriptive Statistics

Group	N	Mean	Std. Deviation	Std. Error
A_D	6108	52.71	6.81	.08
A_N	615	51.64	6.82	.27
B_D	4897	45.74	6.58	.09
B_N	351	46.35	7.32	.39
C_D	6677	43.56	6.29	.07
C_N	553	43.07	7.10	.30

Only the results of Group C were analyzed here. To avoid redundancy the results of Group A and Group B were not analyzed since Group A and Group B of this method are the same Group A and Group B of Method 1.

The first hypothesis focused on the daytime and nighttime speed difference. In the previous method, it was assumed that for Group C, the speed difference between the daytime and nighttime vehicles would be significant because it contained curves with higher side friction demand compared to the other two groups. Group C of this method was exactly the same as Group C of method 1 except that curve 30 which had the highest side friction demand (0.12) among all the curves being analyzed was excluded from the analysis. Since even after having the curve with the highest side friction demand value the daytime and nighttime speed difference of Group C in the previous method was not statistically significant, the author predicted that, in this group too the difference would not be significant.

Tukey test result in Table 23 of Appendix C is consistent with this assumption that the speed differences between the daytime and nighttime vehicles were not significant in Group C. This meant that the alternative hypothesis was true that there was no significant difference in daytime and nighttime speed. Infact, since the difference was less than one mile per hour, the author believes that the daytime and nighttime speeds were the same.

The second hypothesis focused on the speed difference between two consecutive groups. As Group C has sharper curves than Group B, it was assumed that the vehicle speed in Group C was significantly lower than the vehicle speed in Group B for both daytime and nighttime vehicles. The Tukey test results of this method given in Table 23 Appendix C demonstrate that Group B_D had significantly higher speed than Group C_D and Group B_N has significantly higher speed than Group C_N. Hence, this proved the null hypothesis that there was a significant speed difference between the vehicle speeds of two groups with the same light condition.

Similar to Method 1, the results of this method suggested that as the side friction demand increases, vehicle speed decreases at the midpoint of the curve on two-lane two-way rural horizontal curves.

Method 3

In the previous two methods, side friction was divided into three groups. In this method, side friction was categorized in to two groups. Here, Group A was the combination of Group and Group B of Method 2 and Group B was the Group C of Method 2. To avoid repetition, Group C was not discussed here anymore. Data from

Table 8 below suggest that for both day and night conditions Group A and B met the minimum sample size requirement.

Table 8 Method 3 Descriptive Statistics

Group	N	Mean	Std. Deviation	Std. Error
A_D	11005	49.61	7.55	.07
A_N	966	49.72	7.45	.23
B_D	6677	43.56	6.29	.07
B_N	553	43.07	7.10	.30

The first hypothesis was concerned with the speed difference between the daytime and nighttime speeds within a group. Results from Table 24 in Appendix C suggest that for both the groups there was no significant speed difference between the daytime and nighttime speed. In the previous method, for Group A, the daytime speed was higher than the nighttime speed but in Group B the nighttime speed was higher than the daytime speed, although none of these speed differences were statistically significantly different.

Results for Group A of this method, which was the combination of Group A and B of the previous method, demonstrated that the nighttime speed was higher than the daytime speed. As in the previous method, the nighttime speed of Group B was not statistically significantly higher than the daytime speed, combining it with the vehicle speeds of Group A, which had the opposite results (daytime speed higher than nighttime speed) certainly would not make nighttime speed significantly higher than the daytime speed. Data from Table 24 was consistent with this statement. Hence, the alternative hypothesis, which stated that there was no significant speed difference between the daytime and nighttime vehicles, was true for both of these groups. The author concluded that the daytime and nighttime speeds for these two groups were actually the same as the speed difference was within 1 mph.

The second hypothesis was concerned with the speed difference between two consecutive groups. From Table 24 it can be observed for the daytime groups, Group A_D has a significantly higher speed than Group B_D and for the nighttime groups, Group A_N has a significantly higher speed than Group B_N. This proved the null hypothesis which stated that there was a significant difference in speed between consecutive two groups with the same light condition. Once again, this proves that vehicle speed decreases as the side friction of the curve increases and that the categorizing of the curves in terms of side friction demand had been done properly. This is why the significant difference in speed was observed. It was very important to categorize the curves properly in this method because the technique used in this method to categorize the curves in terms of side friction was used in the following three methods too.

Similar to the previous two methods, from this method too the author was not able to conclude anything from the difference between the daytime and nighttime speed but was able to verify that vehicle speed decreases at the midpoint of the curve on two-lane two-way rural horizontal curves.

Method 4

This was one of the three methods where the curves were categorized based on both the side friction demand and the pavement edgeline marking retroreflectivity level. A 2 × 2 matrix was used to categorize the curves. According to the size of the matrix, there was supposed to be four groups in this method but since no curve met the criteria for Group D which was to have curves with side friction demand more than 0.05 and pavement edgeline marking retroreflectivity more than 200 mcd/m^2/lx, this method finally had three groups. Table 9 below contains some of the basic statistics for the groups created here.

Table 9 Method 4 Descriptive Statistics

Group	N	Mean	Std. Deviation	Std. Error
A_D	2857	54.61	6.37	.11
A_N	219	55.30	5.95	.40
B_D	8148	47.85	7.14	.07
B_N	747	48.08	7.04	.25
C_D	6677	43.56	6.29	.07
C_N	553	43.07	7.10	.30

Data from the above table suggest that all of the groups met the minimum sample size requirement. The first null hypothesis (H_0) stated that within a group there was a significant speed difference between the daytime and nighttime at the midpoint of the curve while the first alternative hypothesis (H_A) stated that within a there was no significant speed difference between the daytime and nighttime speed at the midpoint of the curve.

From Table 2, located in the Data Analysis section it can be assumed that Group B would have the least difference between the daytime and nighttime speed as this group had curves with lower side friction demand and higher retroreflectivity level and the nighttime speed maybe higher than the daytime speed since it had curves with higher range of retroreflectivity levels. In addition, Group C would have the largest difference between the daytime and nighttime speed among the three groups because curves in this group high side friction demand value and low retroreflectivity level which are assumed to effect vehicle speed negatively.

To test the above hypotheses, Table 25 of Appendix C, which contains the speed comparisons of these groups, was observed. The speed comparisons suggest that the largest difference between daytime and nighttime speed occurred in Group A followed by Group C and B respectively. Not only for Group B but also for Group A the nighttime speed was higher than the daytime speed. Group B_N had curves with retroreflectivity more than 200 mcd/m^2/lx. Thus, from the results of Group B_D and Group B_N the author could conclude that at curves with edgeline markings having retroreflectivity level of 200 mcd/m^2/lx or more, vehicle speed during the nighttime is higher than the vehicle speed during the daytime.

However, as the difference in the daytime and nighttime speed was only 0.2 mph which was neither a statistically significant difference nor a practically significant difference, the author would not conclude this. A statistical significant difference would occur when the p-value 0.05 or less but a practical significant difference would occur when the speed difference is more than 1 mph. As the speed difference is neither statistically significantly different nor practically different, the author states that the daytime and nighttime speed for Group B was the same.

The author assumed that Group A had curve or curves that had retroreflectivity level close to 200 mcd/m^2/lx (i.e. 190 mcd/m^2/lx) and at these curve or curves the nighttime speed was higher than the daytime speed. In addition, these curves had more data, which was why results of these curves were dominating the overall result. From Table 2 the author determined that no curves in Group A had retroreflectivity close to 200 mcd/m^2/lx. The curve with the highest retroreflectivity level in this group had a retroreflectivity level of 150 mcd/m^2/lx. Hence, the author believes there was something else other than the retroreflectivity level which was made the nighttime speed higher than the daytime speed in Group A.

One explanation of this is that since these curves were located in rural areas, the percentage of drivers who were familiar with these curves was more at nighttime than daytime. As they were used to driving on these curves, the low retroreflectivity level did not impact their speed. This was why the nighttime speed was higher than the daytime speed. The author also considered that the speed for the daytime and nighttime was the same as the difference in speed between the two light conditions was within 1 mph.

For Group C, the nighttime speed was lower than the daytime speed but not significantly. Furthermore, Group B had a lower difference between the vehicle speeds for the two light conditions than Group C which was assumed by the author. All three groups prove the alternative hypothesis that there was no significant difference in speed between the daytime and nighttime vehicles within a group and since these differences in speed for the two light conditions for all three groups are within 1 mph, the author believes that each of the three groups had the same day and night speed.

ANOVA test results from Table 25 suggest that the results for the second hypothesis test were consistent with the results of the second hypothesis test for the previous methods. Hence, the null hypothesis that there was a significant difference in speed in two consecutive groups for the same light condition was true for all three groups. For the daytime groups, Group A_D had statistically significantly higher speed than Group B_D and Group B_D had a statistically significantly higher speed than Group C_D. For the nighttime groups, Group A_N had statistically significantly higher speed than Group B_N and Group B_N had statistically significantly higher speed than Group C_N.

During daytime, it was assumed that vehicle speed is impacted by side friction demand only and not the retroreflectivity level. This was why in the mixed linear model for the daytime vehicles; only side friction demand was used as the independent variable. According to this assumption, there should not be any significant difference in speed between Group A_D and Group B_D because curves in this group had the same range of side friction demand (<0.05). This meant that besides side friction demand something else might have impacted the vehicle speed. The author predicted that the posted speed limit impacted the vehicle speed.

Even though the posted speed limit was one of the variables used in the calculation of side friction demand by the TCAS software, the author believed that there was a need to analyze the effect of posted speed limit separately because in the calculation of side friction demand by the TCAS software, five different inputs were used. This was one of the advantages of using side friction demand for the analysis that only one variable was used instead of five different variables because it simplified the analysis process but at the same time it was also a disadvantage because by inputting so many variables together it was diminishing the importance of each individual variable. Table 10 below provides the posted speed limit and the averages of the posted speed limit for the curves in Group A and B.

Table 10 Speed Limit for Curves in Group A and B in Method 4

Group	Curves	Posted Speed Limit (mph)	Average Posted Speed Limit (mph)
A	7	45	52.5
	33	55	
	39	55	
	40	55	
B	2	35	46.4
	4	35	
	10	45	
	29	55	
	37	50	
	38	50	
	53	55	

The average posted speed limit values for the two groups suggest that Group A had a higher average posted speed limit than Group B. Thus, even though these two groups had curves with the same range of side friction demand values, since Group A had a higher average posted speed limit than Group B, vehicles in Group A_D were traveling at a significantly higher speed than vehicles traveling in Group B_D. This suggested that it was important to analyze the impact of the posted speed limit separately even though it has been used to calculate side friction demand.

For the nighttime groups, Group A_N had a significantly higher speed than Group B_N even though the latter group had curves with higher retroreflectivity level. This meant that for these groups the posted speed limit impacted the vehicle speed more than the retroreflectivity level.

The reasoning for Group C having significantly lower vehicle speed than Group B for both light conditions was that Group C had higher side friction demand than Group B. In addition, Group C_N had curves with lower retroreflectivity level than Group B_N and it was assumed that lower retroreflectivity level impacted speed negatively during nighttime. The impact of retroreflectivity level on nighttime vehicles would have been understood better if Group D_N could be compared to Group C_N because in that case only retroreflectivity level would have been the variable. Unfortunately due to a lack of curves in Group D_N the author could not conduct that comparison.

From this method, the author determined that at curves with edgeline markings having retroreflectivity levels of 200 $mcd/m^2/lx$ or more, vehicles at nighttime may travel at a higher speed than vehicles traveling during the day. In addition, it may be necessary to analyze the impact of the posted speed limit separately on vehicle speed even though it has already been incorporated into the calculation of side friction demand

Method 5

In this method the curves were grouped in terms of side friction demand, using the same technique used in Method 3 and 4. In the previous method, the author arbitrarily chose 200 mcd/m^2/lx as the threshold to create the two retroreflectivity groups. The author believes that the actual threshold point maybe different than that. Thus, there maybe curves in the two groups that need to switch groups if the actual threshold point was used. Since the actual threshold point is unknown, the author as mentioned in the *Data Analysis* section, excluded curves having retroreflectivity between 150 mcd/m^2/lx and 250 mcd/m^2/lx to better extinguish the difference between the two retroreflectivity groups. After that the existing curves were grouped in two groups, one containing curves less than 150 mcd/m^2/lx and the other group containing curves more than 250 mcd/m^2/lx. Similar to Method 3, this created a 2 × 2 matrix, which was supposed to yield four groups, but once again no curves met the criteria for Group D (side friction demand >0.05 and retroreflectivity level >250 mcd/m^2/lx), which is why at the end there were three groups.

Table 11 Method 5 Descriptive Statistics

Group	N	Mean	Std. Deviation	Std. Error
A_D	2449	54.33	6.40	.12
A_N	176	55.54	5.82	.43
B_D	5956	47.69	7.48	.09
B_N	548	47.87	7.01	.29
C_D	2523	45.08	5.59	.11
C_N	216	45.71	6.06	.41

Values from Table 11 above imply that all the three groups had more than 100 vehicles for both types of light conditions. The first hypothesis focused on the comparison of the daytime and nighttime vehicle speed within a group. To analyze the results of this daytime and nighttime speed comparison, values in Table 26 of Appendix C was observed.

The results of Method 4, determined that Group A and Group B had a higher vehicle speed at nighttime compared to daytime but for Group C the daytime speed was higher than the nighttime speed. The average retroreflectivity level of curves in Group B of this method was higher than the average retroreflectivity level of curves in Group B of the previous method. Since in Group B of the previous method, the nighttime speed was found to be higher than the daytime speed, the same result is expected in Group B of this method too. In addition, the author assumes that here the vehicle speed in Group B_N might be actually significantly higher than the vehicle speed in Group B_D.

For Group A and C the author predicted the daytime speed to be higher than the nighttime speed. Group B would have the least difference between the daytime and nighttime speed as this group had curves with lower side friction demand and higher retroreflectivity level. Furthermore, Group C would have the largest difference between the daytime and nighttime speed among the three groups because curves in this group had characteristics that are assumed to affect speed negatively which are high side friction demand value and low retroreflectivity level.

The results of the Tukey test which compared the daytime and nighttime vehicle speed for this method is given in Table 26 of Appendix C. The nighttime speeds for all three groups were higher than the daytime speed but none of these differences were statistically significant. For Group B, the author predicted that the nighttime speed may be significantly greater than the daytime speed but in reality the nighttime was only 0.2

miles higher than the daytime speed. Thus, the author could not conclude with certainty that at curves with edgeline markings having retroreflectivity level of 250 mcd/m^2/lx or more, vehicle speed during nighttime is higher than the daytime vehicle speed.

Group A of the previous method had Curves 7, 33, 39 and 40 while Group A of this method had Curves 7, 39 and 40. Group A of this method, excluded Curve 33 from the analysis to ensure sure that there was no curve with retroreflectivity level close to 200 mcd/m^2/lx, which was assumed to be the retroreflectivity level above which drivers at nighttime driver faster than the daytime. Thus, having curves with retroreflectivity level close to 200 mcd/m^2/lx was not the reason why Group A_N had a higher speed than Group A_D because curves within 50 mcd/m^2/lx of 200 mcd/m^2/lx were excluded in this method. The author believes that the reason why Group A in this method had a higher nighttime speed than daytime speed was because of the same reason why Group A had a higher nighttime speed than daytime speed in the previous method. Since the difference in daytime and nighttime speed for Group A was more than 1 mph, the author would not consider the daytime and nighttime speed to be the same though.

Group C of this method should not have the issue that was pointed out in Group A of the previous method, which was having curves with retroreflectivity close to 200 mcd/m^2/lx. This was because as mentioned in the previous paragraph, this method excluded curves within 50 mcd/m^2/lx of 200 mcd/m^2/lx. The author believes the reason why Group C_N had higher speed than Group C_D was because of the same reason why Group A_N of this method and the previous method had a higher speed than Group A_D of this method and the previous method. Due to a nonzero difference in speed between daytime and nighttime, the author gave the explanation as to why it might have happened but as this difference was less than 1 mph, the author considers the daytime and nighttime speed to be the same.

For Group C, the nighttime speed was lower than the daytime speed. In addition, Group B had a lower difference between the vehicle speeds for the two light conditions than Group C which was assumed by the author. All three groups prove the alternative hypothesis that there was no significant difference in speed between the daytime and nighttime vehicles within a group.

To determine whether the null hypothesis or the alternative hypothesis was true for the second hypothesis, the author observed the Tukey test results in Table 26 again. As found in the previous methods, in this method too for both daytime and nighttime each group had significantly higher speeds than the next group.

Similar to Method 4, in this method too both Group A and Group B had curves with the same range of side friction demand value. The author believed that Group A_D had a higher average posted speed limit than Group B_D, which is why vehicles in Group A_D were traveling at a significantly higher speed than Group B_D. Table 12 provides the posted speed limit of the curves in this two groups and the average speed limit for the two groups.

Table 12 Speed Limit for Curves in Group A and B in Method 5

Group	Curves	Posted Speed Limit (mph)	Average Posted Speed Limit (mph)
A	7	45	51.7
	39	55	
	40	55	
B	2	35	44
	4	35	
	10	45	
	38	50	
	53	55	

The above table demonstrates that group A had a significantly higher average posted speed limit than Group B. The author believes that this is the reason why Group A_D had a significantly higher speed than Group B_D.

Like in Method 4 in this method, even though, Group B_N had curves with higher retroreflectivity than Group A_N, the vehicle speed of Group A_N was significantly higher than Group B_N. The higher average posted speed limit of Group A than Group B was the reason for this. Hence, for these groups the posted speed limit impacted the vehicle speed more than the retroreflectivity level.

Having curves with higher side friction demand than Group B was the reason why the daytime vehicles in Group C had significantly lower speed than the daytime vehicles in Group B. Group C_N had significantly lower vehicle speed than Group B_N because Group C had curves with higher side friction demand and lower pavement edgeline marking retroreflectivity level compared to Group B. Once again, the effect of retroreflectivity on vehicle speed would have been understood better if Group D existed. This is because then Group D_N could have been compared to Group C_N where retroreflectivity would have been the only variable. Unfortunately, due to a lack curves in Group D, the author could not conduct the comparison.

The results of this method were identical to the results of the previous method. The author determined that at curves with edgeline markings having retroreflectivity level of 250 mcd/m^2/lx or more, vehicle at nighttime may travel at a higher speed than vehicles traveling at daytime. In addition, it might be necessary to analyze the impact of the posted speed limit separately even though it has already been used to calculate side friction demand.

Method 6

In this method both side friction demand and retroreflectivity were also used to categorize the data. This method was identical to the previous method, except that in this method, the curves that were excluded from the analysis in the previous method (curves with retroreflectivity between 150 mcd/m^2/lx and 250 mcd/m^2/lx) were included in the analysis by forming a different group for those curves. Hence, in this method there were two groups for side friction demand and three groups for retroreflectivity level that created a 2 × 3 matrix. Although, due to the size of the matrix there should have been six groups, this method had five groups as there were no curves that met the criteria for one of the groups. The purpose of including the curves that were excluded in Method 5 by forming a different group was to identify whether drivers traveling in these curves at nighttime travel at a speed similar to drivers traveling at nighttime at curves with retroreflectivity less than 150 mcd/m^2/lx or if they travel at a speed similar to drivers traveling at nighttime at curves with retroreflectivity more than 250 mcd/m^2/lx or whether their speed is significantly different from drivers traveling at curves with edgeline markings less than 150 mcd/m^2/lx and more than 250 mcd/m^2/lx . Table 13 below contains some of the basic statistics for the groups created here.

Table 13 Method 6 Descriptive Statistics

Group	N	Mean	Std. Deviation	Std. Error
A_D	2449	54.33	6.40	.12
A_N	176	55.54	5.82	.43
B_D	2600	49.56	6.72	.13
B_N	242	49.66	7.31	.47
C_D	5956	47.69	7.48	.09
C_N	548	47.87	7.01	.29
D_D	2523	45.08	5.59	.11
D_N	216	45.71	6.06	.41
E_D	4154	42.64	6.50	.10
E_N	337	41.37	7.21	.39

The above table demonstrates that each group met the minimum sample size requirement of 100 vehicles. The Tukey test results for this method are located in Table 27 of Appendix C. First the author focused on the results of the first hypothesis which was to examine the difference between the daytime and nighttime speed for each group.

Results of Group A, C and D were not discussed as they are the same as Group A, B and C of the previous method. In Group B, the nighttime speed was greater than the daytime speed but since the speed difference was not significant and was within 1 mph the author considers the daytime and nighttime speed of Group B to be the same.

For Group E the daytime speed was significantly greater than the nighttime speed. This result was contradictory to the results found in literature. Literature stated that at higher retroreflectivity levels, vehicle drive at unsafe speeds during nighttime (*8*). If retroreflectivity level between 150 mcd/m^2/lx and 250 mcd/m^2/lx is considered high retroreflectivity level then the result of Group E contradicts the previous statement. In that case the nighttime speed for Group E should have been higher than the daytime speed or should have been at least the same as the daytime speed. However, the opposite had happened.

From the result of this group, the author could conclude that despite the retroreflectivity level, at curves with side friction level more than 0.05, drivers drive significantly slower at night time compared to the daytime. The issue is that if this was true then, in Group D too, the nighttime speed would have been significantly slower than the daytime speed but that did not happen. The author finally concluded that, at curves with side friction demand more than 0.05 and with pavement edgeline marking retroreflectivity level between 150 mcd/m^2/lx and 250 mcd/m^2/lx, drivers drive significantly slower at nighttime than during the daytime. This was because, due to the high retroreflectivity level, drivers are better aware of the sharpness of the curve then they would have at lower levels of retroreflectivity level. This led them to slow down. At curves with side friction demand more than 0.05 and edgeline marking retroreflectivity level less than 150 mcd/m^2/lx drivers do not slow down because the author believes that they are not able to judge the sharpness of the curve and may even underestimate the sharpness of the curve.

In the *Linear Mixed Model* section, the author planned to determine the retroreflectivity level where the relationship between retroreflectivity and vehicle speed changes. From the result of this group, the author determines that for curves with side friction demand more than 0.05, retroreflectivity level of 150 mcd/m^2/lx is where the relationship between retroreflectivity level and vehicle speed at night changes.

However, to determine whether this relationship between retroreflectivity and nighttime vehicle speed stays the same (as retroreflectivity level is more than 250 mcd/m^2/lx, nighttime vehicle speed decreases), the author need to examine Group F, which was supposed to have curves with side friction demand greater than 0.05 and edgeline marking retroreflectivity more than 250 mcd/m^2/lx. Due to a lack of curves in Group F, the author could not be certain whether for curves with side friction demand greater than 0.05 and edgeline marking retroreflectivity level greater than 250 mcd/m^2/lx, daytime vehicle speed is significantly greater than the nighttime vehicle speed or whether for retroreflectivity level greater than 250 mcd/m^2/lx, the relationship switches again and the nighttime speed becomes greater than the daytime speed.

From the first hypothesis, the author determines that regardless of the retroreflectivity level, for curves with side friction demand less than 0.05, the daytime and nighttime speeds are similar. For curves with side friction demand greater than 0.05 and pavement edgeline marking retroreflectivity level between 150 mcd/m^2/lx and 250 mcd/m^2/lx, the daytime speed was significantly higher than the nighttime speed.

The purpose of the second hypothesis was to compare the speed differences between consecutive groups for the same light condition. One-way ANOVA test results provided for this method in Table 27 suggested that each group had a significantly higher speed for both daytime and nighttime than the next group's daytime and nighttime speed, proving the null hypothesis.

For the daytime groups the only statistical significant difference in speed should have been between Group C_D and Group D_D because these two consecutive groups had curves with different ranges of side friction demand. Groups A_D, B_D and C_D should have the same or similar speeds because these groups had curves with the same range of side friction demand while Group D_D and Group E_D should have the same or similar speeds because these two groups contained curves with the same range of side friction demand. The author predicted that the difference in the average posted speed limit between each consecutive group caused the significant difference in speed. The average posted limit for each group is presented below in Table 14.

Table 14 Speed Limit for Curves in Method 6

Group	Curves	Posted Speed Limit (mph)	Average Posted Speed Limit (mph)
A	7	45	51.7
	39	55	
	40	55	
B	29	55	53.3
	33	55	
	37	50	
C	2	35	44.0
	4	35	
	10	45	
	38	50	
	53	55	
D	8	45	51.7
	31	55	
	35	55	
E	1	35	48.3
	15	55	
	32	55	

Tukey test results demonstrated that Group A had significantly higher daytime speed than Group B. However, from the above table it can be observed that Group B had a higher average posted speed limit than Group A. This led the author to observe the average speeds of the curves in Group A and B given in Table 5. From Table 5 the author determined that even though Curve 29 which was in Group B, had a posted speed limit of 55 mph, the average daytime vehicle speed was only 46.4 mph. The author determined that the presence of a t-leg intersection upstream of the midpoint of the curve caused the average vehicle speed to be considerably lower than the posted speed limit at Curve 29. For this reason, Group A had a higher average daytime speed than Group B despite having a lower average posted speed limit than Group B.

For having a higher posted average posted speed limit, Group B had a higher average daytime speed than Group C and Group D had a higher average daytime speed than Group E. As mentioned previously, Group C_D had a higher daytime speed than Group D_D because vehicles in Group D_D were traveling on sharper curves compared to Group C_D.

For the nighttime groups too, the author believes that the speed difference between the consecutive groups had been caused mainly due to the posted speed limit and the side friction demand. The effect of retroreflectivity is very hard to determine. Among groups A, B and C and groups D and E, the effect of retroreflectivity could have been determined only if both the side friction demand and the posted speed limit were kept constant.

Out of the six methods, the author believes that the finding from this method was the most important. From the results of this method the author determined that at curves with side friction demand more than 0.05 and with pavement edgeline marking retroreflectivity between 150 mcd/m^2/lx and 250 mcd/m^2/lx drivers drive slower at nighttime than during the daytime because the enhanced retroreflectivity actually helps driver become more aware of the curvature of the road, which leads them to slow down. At curves with side friction demand greater than 0.05 and with pavement edgeline marking retroreflectivity up to 150 mcd/m^2/lx drivers underestimate the curvature and the road conditions and hence do not feel the need to slow down. Finally, the author believes that for curves with side friction demand greater than 0.05, a pavement edgeline marking retroreflectivity level of 150 mcd/m^2/lx is where the relationship between retroreflectivity and vehicle speed changes direction.

COMPARISON OF DAYTIME AND NIGHTTIME SPEED USING RADIUS AND RETROREFLECTIVITY

The following paragraphs discussed the ANOVA test that compared the daytime and nighttime speed at the midpoint of the curve for the two methods.

Method 7

The basic statistics for this method are provided in the table below and the ANOVA test results for this method is provided in Table 28 of Appendix C.

Table 15 Method 7 Descriptive Statistics

Group	N	Mean	Std. Deviation	Std. Error
A_D	6677	43.56	6.29	.07
A_N	553	43.07	7.10	.30
B_D	3972	43.33	7.00	.11
B_N	318	43.85	7.32	.41
C_D	2857	54.61	6.37	.11
C_N	219	55.30	5.95	.40
D_D	5025	49.77	6.57	.09
D_N	515	49.09	6.63	.29

Table 15 above suggests that all the groups in this method met the minimum sample size requirement. The purpose of conducting this method was to examine the difference between the daytime and nighttime speeds between each group. Then in the next section the results of the daytime and nighttime speed difference determined in this method was compared with the daytime and nighttime speed difference of Method 4 in the previous section. The results of the ANOVA analysis determine that in each group there was no significant daytime and nighttime difference. The daytime and nighttime speed difference for each group was less than 1 mph which is both statistically and practically insignificant.

Method 8

The basic statistics for this method are provided in the following table and the ANOVA test results for this method is provided in Table 29 of Appendix C.

Table 16 Method 8 Descriptive Statistics

Group	N	Mean	Std. Deviation	Std. Error
A_D	2523	45.08	5.59	.11
A_N	216	45.71	6.06	.41
B_D	1802	41.24	5.18	.12
B_N	116	41.57	5.27	.48
C_D	2449	54.33	6.40	.12
C_N	176	55.54	5.82	.43
D_D	4154	50.48	6.54	.10
D_N	432	49.56	6.44	.31

Table 16 above indicates that all groups met the minimum sample size requirement. Once again, the purpose of conducting this method was to compare the daytime and nighttime speed difference determined in this section to the daytime and nighttime speed difference of Method 5 of in the previous section. The ANOVA test results for this method suggests that for each group there was no significant speed difference between the daytime and nighttime speed. The maximum daytime and nighttime speed difference occurred in group C which was only 1.2 mph. For the other groups it was less than 1 mph. Hence, for each group the author states that the daytime and nighttime speeds are the same as the difference is both statistically and practically insignificant.

RESULTS OF COMPARISONS OF DAYTIME AND NIGHTTIME SPEED USING SIDE FRICTION DEMAND AND RETROREFLECTIVITY AND RADIUS AND RETROREFLECTIVITY

Method 4 and Method 5 of *Comparison of Daytime and Nighttime Speed Using Side Friction Demand and Retroreflectivity* section were very similar to Method 7 and Method 8 of *Comparison of Daytime and Nighttime Speed Using Radius and Retroreflectivity* section. The only difference is that the first two methods used side friction demand and retroreflectivity level to categorize the curves and the latter two methods used radius and retroreflectivity to categorize the curves. Method 4 used the same retroreflectivity threshold value as Method 7 while Method 5 used the same retroreflectivity threshold value as Method 8. The daytime and nighttime speed comparisons for each group in all these methods indicate that regardless of whether the curves are grouped based on side friction demand and retroreflectivity or radius and retroreflectivity, there is basically no speed difference in daytime and nighttime speed. From this, the author concludes that categorizing the curves in terms of side friction demand is justified as it yields the same result as categorizing the curves in terms of radius.

SUMMARY OF FINDINGS

The findings regarding the linear mixed model are:

- From the linear mixed model, it was found that radius, superelevation, posted speed limit, deflection angle and pavement edgeline marking retroreflectivity level at nighttime are significant in predicting vehicle speed at the midpoint of horizontal curves on two-lane two-way rural highways. As a result, the stepwise regression analysis did not exclude any of the above five variables.

- The linear mixed model suggests that vehicle speed increases as the radius, superelevation and posted speed increases but the vehicle speed decreases as the deflection angle increases.
- Out of the five independent variables in the model, the radius had the biggest impact on the vehicle speed.
- For nighttime vehicle speed, the model determined that nighttime vehicle speed decreases as retroreflectivity increases. Although the author believes that the relationship between nighttime vehicle speed and retroreflectivity level is not totally indirect. Up to a certain level of retroreflectivity, the relationship is direct, after that it becomes indirect. Due to a lack of sites with curve having retroreflectivity level less than 100 mcd/m^2/lx, the relationship between speed and retroreflectivity could not be evaluated for levels that represent minimum preferable retroreflectivity of edgelines.

The findings for the speed comparisons are as follows:

- Vehicle speed decreases as the side friction demand value of curves increases.

- Even though, posted speed limit is incorporated into the calculation of side friction demand, it may be necessary to analyze the impact of posted speed limit separately on vehicle speed.
- For curves with side friction demand in excess of 0.05 and pavement edgeline marking retroreflectivity level between 150 mcd/m^2/lx and 250 mcd/m^2/lx, vehicles at nighttime travel at a speed significantly less than the vehicles traveling during the daytime.
- When radius was used to categorize the curves no significant difference in daytime and nighttime speed was observed.
- The results of the daytime and nighttime speed difference by categorizing the curves in terms of side friction demand and retroreflectivity and categorizing the curves in terms of radius and retroreflectivity yielded the same result that there was no significant speed difference in daytime and nighttime speed difference in each group.

6. SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

The accident rates at curves are 1.5 to 4 times higher than on tangent sections of a roadway (*1*). Imperfect roadway geometry, driver's inattention, and driving over the speed limit are the main reasons for crashes on two lane rural highways. In addition to the financial cost, crashes may also lead to loss of human life. A majority of the crashes that occur on horizontal curves consist of single vehicle running off the roadway and hitting an object such as a tree, utility pole, rock, or other fixed objects. Some of the crashes involved vehicles driving into the opposing lane of travel resulting in head-on crashes (*3*). Driver inattention, tight horizontal curves and lack of warning signs are additional reasons for crashes on horizontal curves.

The nighttime crash rate is four times higher than the daytime crash rate (*4*). Factors such as lack of vision, fatigue and alcohol contribute to the higher crash rate at night (*5*). To make the travel way more visible to drivers at nighttime, retroreflective pavement markings are used. The literature recommends pavement markings have at least 100 mcd/m^2/lx level of retroreflectivity (*9, 10, 11*). One research study determined that at high levels of retroreflectivity during nighttime, drivers may feel too comfortable and may drive at higher speeds (*8*).

This study focused on developing a statistical model that would predict the vehicle speed at the midpoint of horizontal curves in daytime and nighttime conditions. In addition, the research determined if there was a statistically significant difference between the daytime and nighttime mean speed at the midpoint of horizontal curves for different groups of horizontal curves. The curves were grouped based on its side friction demand value or radius and retroreflectivity level.

SUMMARY

Vehicle speed data were collected in the outside lane of 18 rural two-lane two-way horizontal curves near Nashville, Tennessee for a minimum of 48 hours. Additional data unique to each curve, such as radius, curve length etc., were recorded and coded with the speed data.

Two linear mixed models were developed. One was a regular linear mixed model while the other was a stepwise regression model. The two models were identical because the stepwise model did not exclude any of the independent variables as all the five variables that were used to predict speed were able to predict the vehicle speed with 95 percent confidence interval. The five independent variables that were used in the model are radius of the curve, superelevation of the curve, posted speed limit, deflection angle and pavement edgeline marking retroreflectivity level with nighttime data.

The horizontal curves were grouped using eight different methods to determine if there was a statistical significant difference in speed between daytime and nighttime within a group and also if there was a significant speed difference among groups with the same light condition. Curves were grouped based on side friction demand or radius and pavement edgeline marking retroreflectivity. Using SPSS, ANOVA analysis was conducted to compare the speed data. The findings of this study are listed in the *Conclusions* sections.

CONCLUSIONS

Based on the findings of this research, the following conclusions have been drawn for vehicle speeds at the midpoint of two-lane two-way rural horizontal curves:

- The five independent variables together; which are radius, superelevation at the midpoint of the curve, posted speed limit, deflection angle, and pavement edgeline marking retroreflectivity level with nighttime data; are able to predict the vehicle speed at the midpoint of horizontal curves with a 95 percent confidence interval.
- Vehicle speed at the midpoint of the curve has a positive relation with radius, superelevation at the midpoint of the curve, and posted speed limit but has a negative relation with the deflection angle and retroreflectivity.
- The radius of the curve had the biggest impact on the vehicle speed among the five independent variables that were included in the linear mixed model.
- Even though the posted speed limit is incorporated into the calculation of side friction demand, it may be necessary to analyze the impact of the posted speed limit separately on vehicle speed while comparing vehicle speed.
- There was no significant speed difference in daytime and nighttime speed. This was determined by categorizing the curves in terms of side friction demand or radius and pavement edgeline marking retroreflectivity.

LIMITATIONS

The author offers the following limitations to this study, which might have impacted the overall study results:

- For simplicity, the author developed a simple linear mixed model to predict the vehicle speed at the midpoint of the curve using radius, superelevation, posted speed limit, deflection angle and retroreflectivity. The author believes that the relationship between speed and retroreflectivity may not have been a one directional linear. However, due to a lack of sites with curves having retroreflectivity below the recommended minimum by literature (100 mcd/m^2/lx), the model that was developed may have failed to capture the actual relationship with speed and retroreflectivity.
- The dataset did not have curves with high side friction demand and high retroreflectivity level such as curves with side friction demand more than 0.05 and edgeline marking retroreflectivity more than 250 mcd/m^2/lx. For this reason the author could not determine whether for curves with such characteristics, drivers drive significantly slower at nighttime compared to daytime or whether drivers drive significantly faster at nighttime compared to daytime.
- Presence of opposing vehicle is believed to impact vehicle speed at the curve, which is why the author wanted to analyze only isolated vehicles. Unfortunately, due to time drift issues in the traffic classifiers, the author

RECOMMENDATIONS

Using the same methodology, another research study could be conducted by analyzing the speed values of isolated vehicles only. Finally, in the future, GPS could be used to collect the vehicle speed data to improve the accuracy of the vehicle speed data. However, the issue with that is not much vehicle data could be collected.

For pavement edgeline marking retroreflectivity greater than 90 mcd/m^2/lx, daytime and nighttime speeds are practically the same. Hence, as recommended in previous studies, this study also recommends a pavement edgeline marking retroreflectivity of at least 100 mcd/m^2/lx for comfortable nighttime driving.

Curve radius has positive relation with vehicle speed. To ensure that the vehicle speed at the tangent section of the roadway and at the curve section of the roadway do not differentiate too much highway designers should try to design curves with larger radius as much as possible.

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APPENDIX A

FREE FLOW VEHICLES

The following are the speed profile plots of vehicle n against vehicle n+1 for Curve 15. From these plots, it can be noted that at this curve, free flowing vehicles can be considered to have headways 5 seconds and greater.

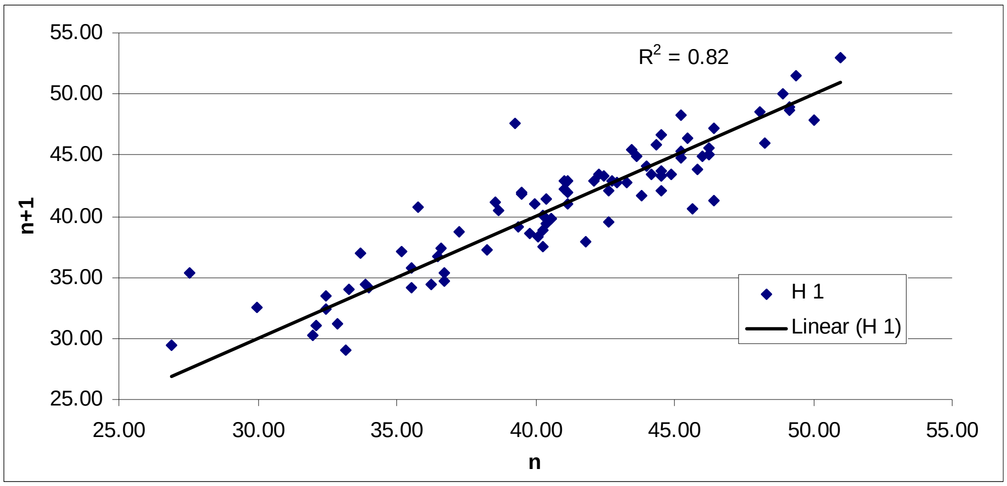

Figure 3 Headway 1

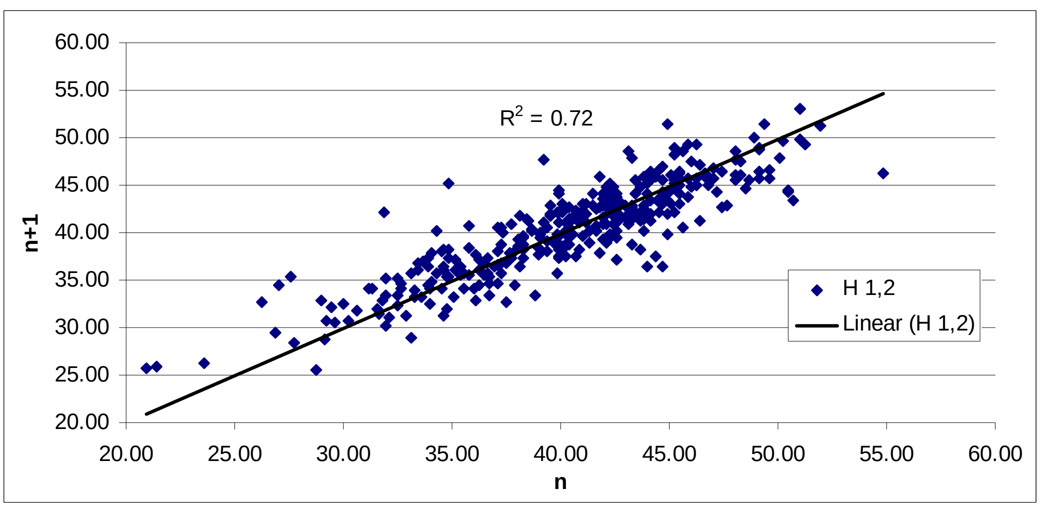

Figure 4 Headway 1, 2

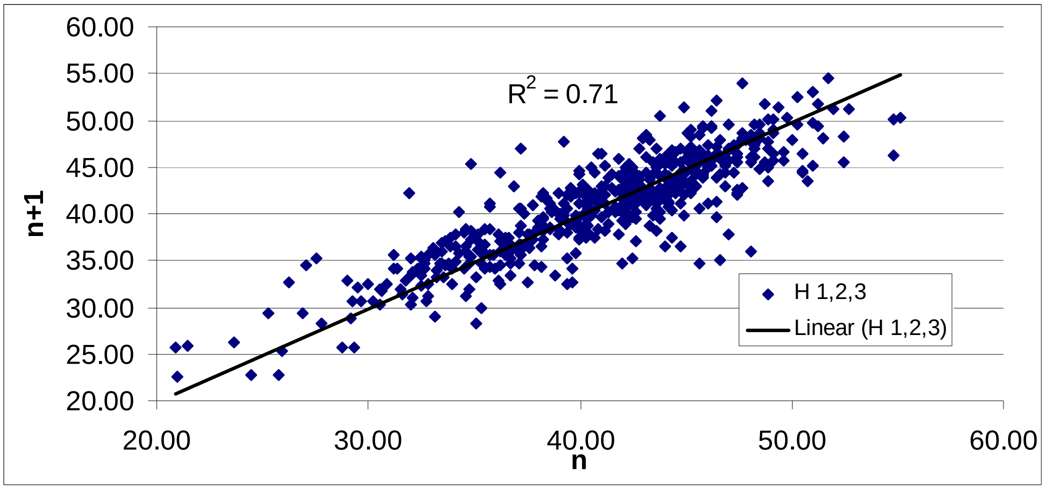

Figure 5 Headway 1, 2, 3

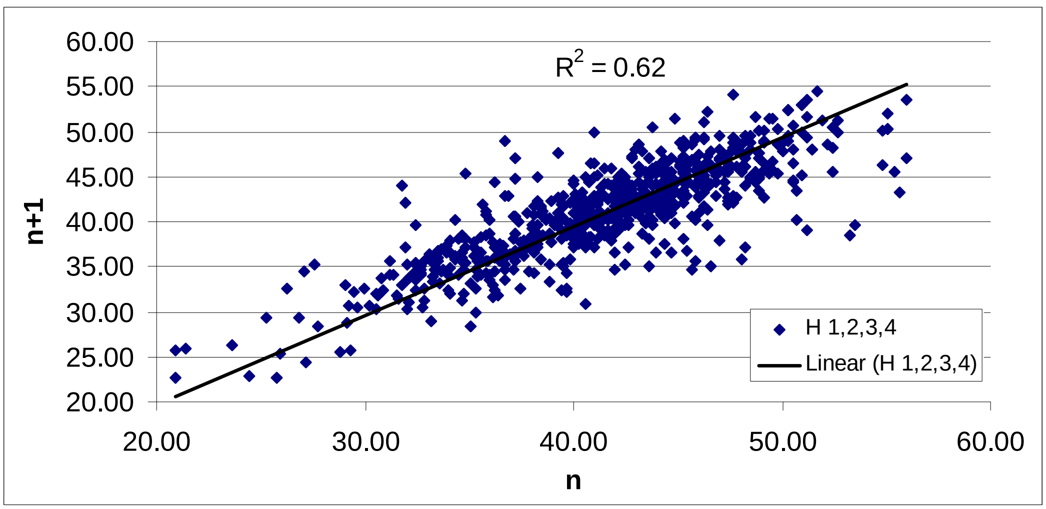

Figure 6 Headway 1, 2, 3, 4

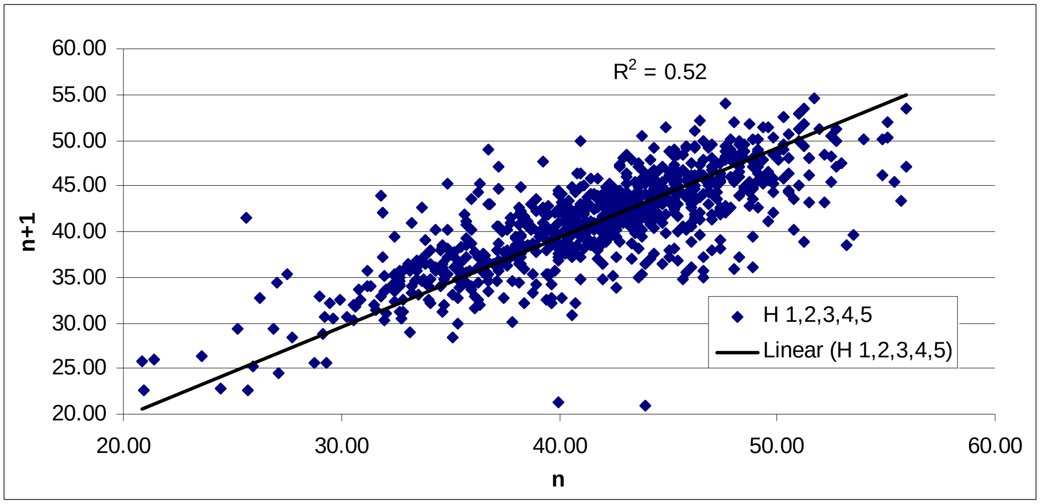

Figure 7 Headway 1, 2, 3, 4, 5

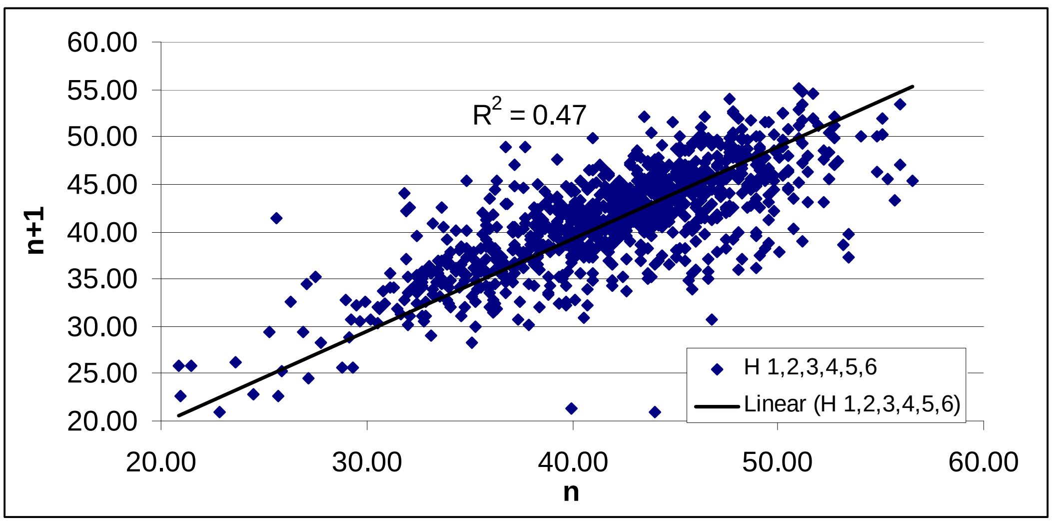

Figure 8 Headway 1, 2, 3, 4, 5 ,6

APPENDIX B

REGRESSION

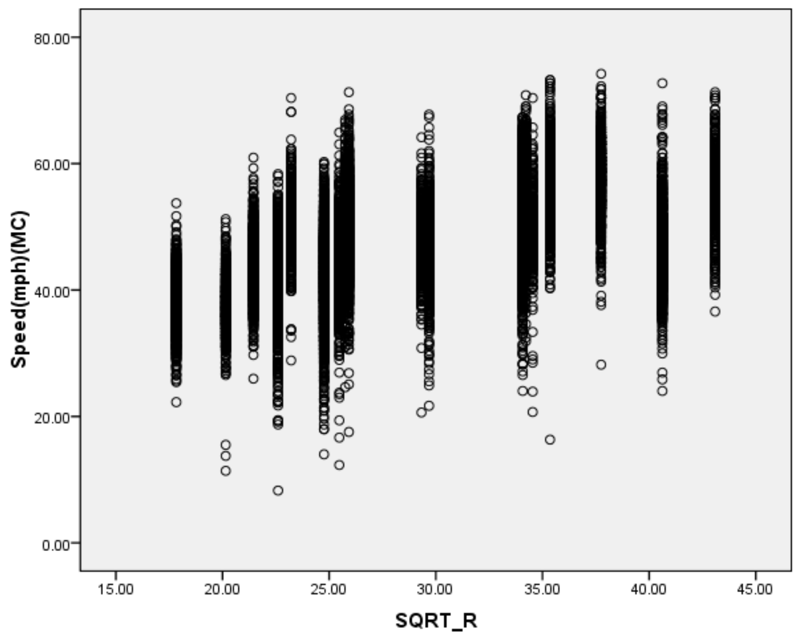

Figure 9 Scatter Plot of Speed vs. Square Root of Radius

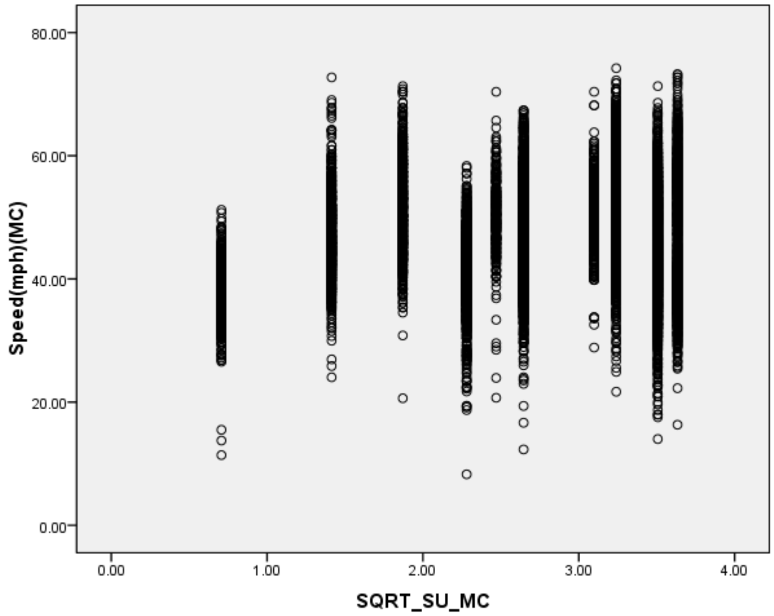

Figure 10 Scatter Plot of Speed vs. Square Root of Superelevation

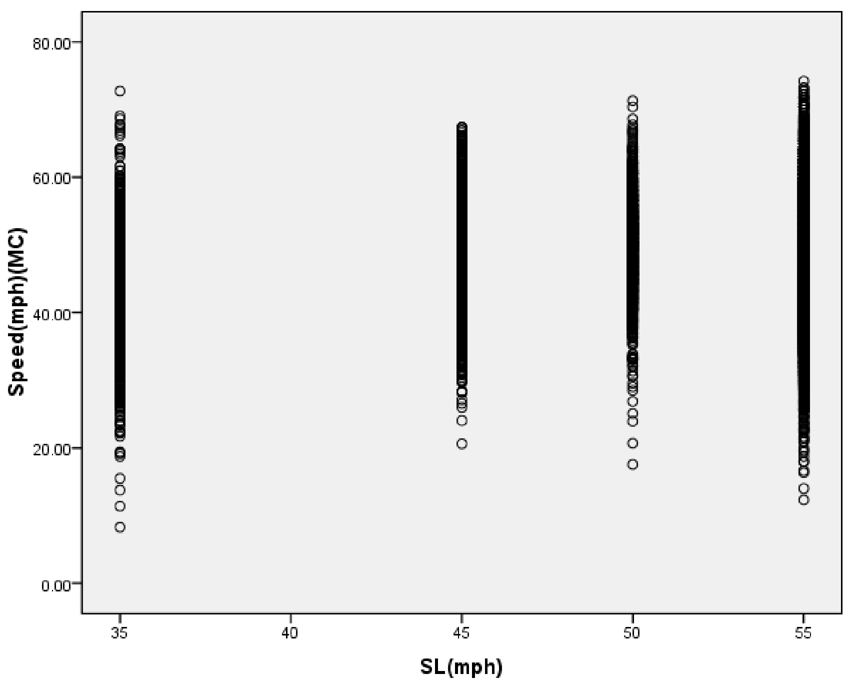

Figure 11 Scatter Plot of Speed vs. Posted Speed Limit

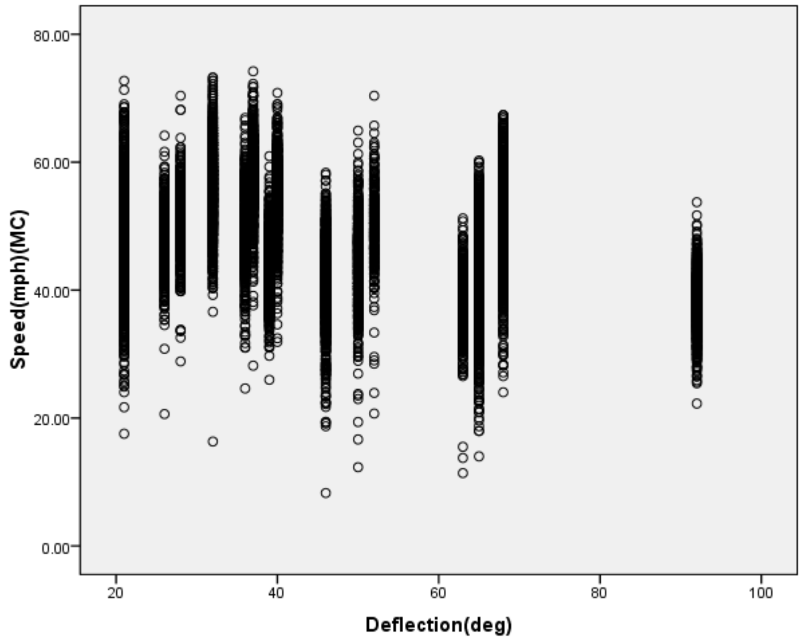

Figure 12 Scatter Plot of Speed vs. Deflection Angle

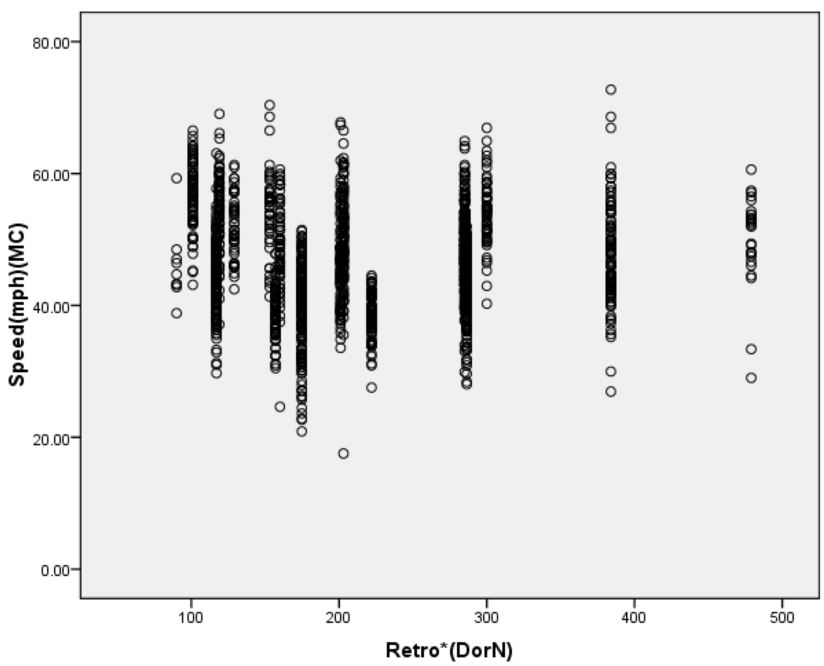

Figure 13 Scatter Plot of Speed vs. Retroreflectivity with Nighttime Speed Data

Model 1

Table 17 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.642[a]	.412	.412	6.00173
a. Predictors: (Constant), Retro*(DorN), Deflection(deg), SL(mph), SQRT_R, SQRT_SU_MC				
b. Dependent Variable: Speed(mph)(MC)				

Table 18 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	508468.044	5	101693.609	2823.197	.000[a]
	Residual	725097.159	20130	36.021		
	Total	1233565.203	20135			
a. Predictors: (Constant), Retro*(DorN), Deflection(deg), SL(mph), SQRT_R, SQRT_SU_MC						
b. Dependent Variable: Speed(mph)(MC)						

Table 19 Coefficients for Linear Mixed Model

	Unstandardized Coefficients		Standardized Coefficients			95% Confidence Interval for B	
Model	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
(Constant)	22.376	.355		63.042	.000	21.680	23.072
SQRT_R	.614	.007	.522	85.311	.000	.600	.629
SQRT_SU_MC	1.837	.096	.184	19.096	.000	1.649	2.026
SL(mph)	.105	.010	.104	10.822	.000	.086	.124
Deflection(deg)	-.065	.002	-.162	-27.568	.000	-.070	-.061
Retro*(DorN)	-.003	.001	-.024	-4.452	.000	-.004	-.002
a. Dependent Variable: Speed(mph)(MC)							

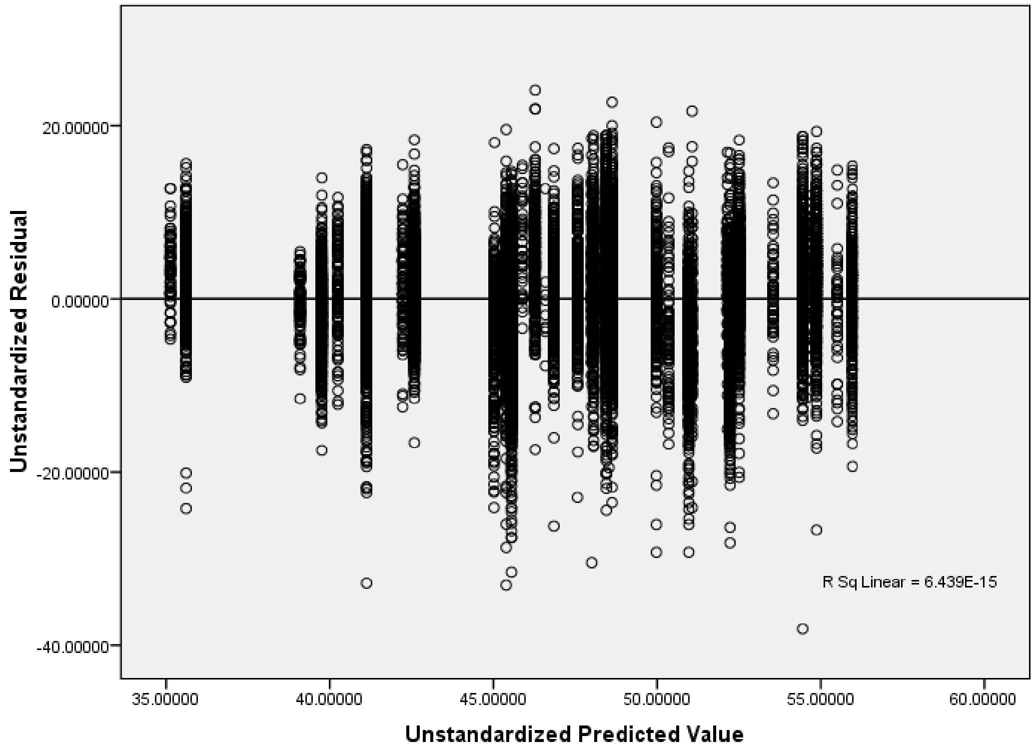

Figure 14 Residual Plot

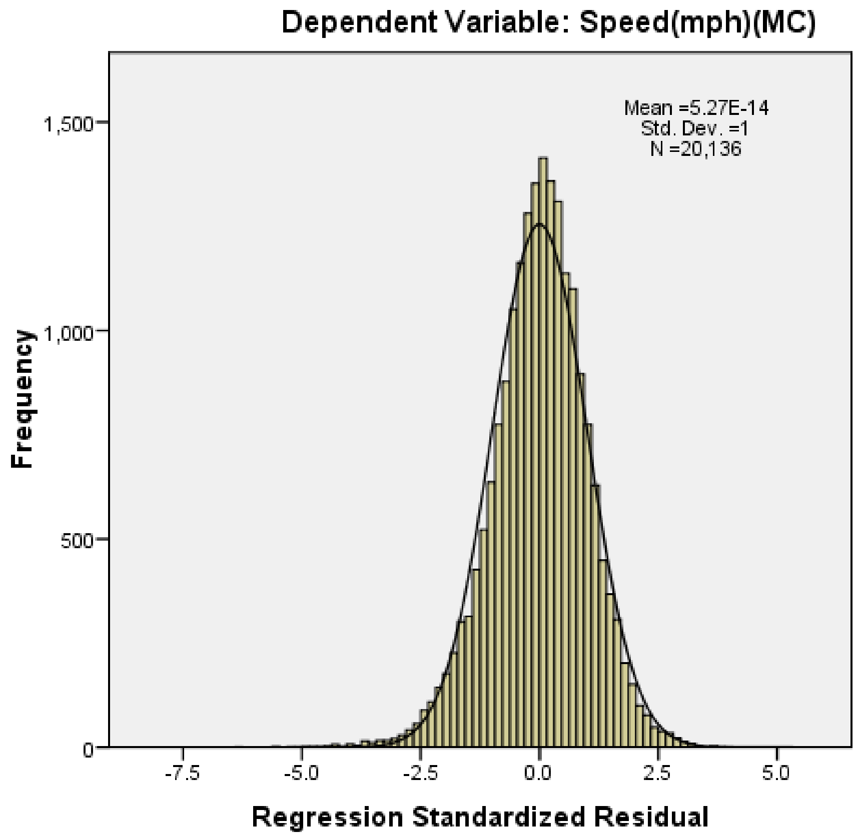

Figure 15 Histogram

Model 2 (Stepwise Regression Analysis)

Table 20 Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	SQRT_R	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	SQRT_SU_MC	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
3	Deflection(deg)	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
4	SL(mph)	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
5	Retro*(DorN)	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
a. Dependent Variable: Speed(mph)(MC)			

Table 21 Stepwise Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.566[a]	.320	.320	6.45284
2	.622[b]	.387	.387	6.12948
3	.639[c]	.408	.408	6.02281
4	.642[d]	.412	.411	6.00453
5	.642[e]	.412	.412	6.00173
a. Predictors: (Constant), SQRT_R				
b. Predictors: (Constant), SQRT_R, SQRT_SU_MC				
c. Predictors: (Constant), SQRT_R, SQRT_SU_MC, Deflection(deg)				
d. Predictors: (Constant), SQRT_R, SQRT_SU_MC, Deflection(deg), SL(mph)				
e. Predictors: (Constant), SQRT_R, SQRT_SU_MC, Deflection(deg), SL(mph), Retro*(DorN)				
f. Dependent Variable: Speed(mph)(MC)				

APPENDIX C

COMPARISON OF DAYTIME AND NIGHTTIME SPEED

Day and Night Speed Using Side friction Demand and Retroreflectivity

Table 22 Method 1 Multiple Comparisons

(I) Category_ Numerical	(J) Category_ Numerical	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A_D	A_N	1.07338*	.27905	.002	.2781	1.8687
	B_D	6.96978*	.12652	.000	6.6092	7.3304
	B_N	6.35974*	.36205	.000	5.3279	7.3916
	C_D	9.77712*	.11360	.000	9.4534	10.1009
	C_N	10.25322*	.27425	.000	9.4716	11.0348
A_N	A_D	-1.07338*	.27905	.002	-1.8687	-.2781
	B_D	5.89641*	.28219	.000	5.0922	6.7006
	B_N	5.28636*	.44125	.000	4.0288	6.5439
	C_D	8.70374*	.27664	.000	7.9153	9.4922
	C_N	9.17984*	.37261	.000	8.1179	10.2418
B_D	A_D	-6.96978*	.12652	.000	-7.3304	-6.6092
	A_N	-5.89641*	.28219	.000	-6.7006	-5.0922
	B_N	-.61005	.36447	.549	-1.6488	.4287
	C_D	2.80734*	.12110	.000	2.4622	3.1525
	C_N	3.28343*	.27744	.000	2.4927	4.0741
B_N	A_D	-6.35974*	.36205	.000	-7.3916	-5.3279
	A_N	-5.28636*	.44125	.000	-6.5439	-4.0288
	B_D	.61005	.36447	.549	-.4287	1.6488
	C_D	3.41738*	.36019	.000	2.3908	4.4439
	C_N	3.89348*	.43823	.000	2.6445	5.1424
C_D	A_D	-9.77712*	.11360	.000	-10.1009	-9.4534
	A_N	-8.70374*	.27664	.000	-9.4922	-7.9153
	B_D	-2.80734*	.12110	.000	-3.1525	-2.4622
	B_N	-3.41738*	.36019	.000	-4.4439	-2.3908
	C_N	.47610	.27179	.497	-.2985	1.2507
C_N	A_D	-10.25322*	.27425	.000	-11.0348	-9.4716
	A_N	-9.17984*	.37261	.000	-10.2418	-8.1179
	B_D	-3.28343*	.27744	.000	-4.0741	-2.4927

	B_N	-3.89348*	.43823	.000	-5.1424	-2.6445
	C_D	-.47610	.27179	.497	-1.2507	.2985

Table 23 Method 2 Multiple Comparisons

(I) Category_ Numerical	(J) Category_ Numerical	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A_D	A_N	1.07338*	.27914	.002	.2778	1.8689
	B_D	6.96978*	.12656	.000	6.6091	7.3305
	B_N	6.35974*	.36216	.000	5.3276	7.3919
	C_D	9.15342*	.11682	.000	8.8205	9.4864
	C_N	9.64269*	.29301	.000	8.8076	10.4778
A_N	A_D	-1.07338*	.27914	.002	-1.8689	-.2778
	B_D	5.89641*	.28228	.000	5.0919	6.7009
	B_N	5.28636*	.44139	.000	4.0284	6.5443
	C_D	8.08004*	.27805	.000	7.2876	8.8725
	C_N	8.56932*	.38667	.000	7.4673	9.6713
B_D	A_D	-6.96978*	.12656	.000	-7.3305	-6.6091
	A_N	-5.89641*	.28228	.000	-6.7009	-5.0919
	B_N	-.61005	.36459	.550	-1.6491	.4290
	C_D	2.18363*	.12414	.000	1.8298	2.5374
	C_N	2.67291*	.29600	.000	1.8293	3.5165
B_N	A_D	-6.35974*	.36216	.000	-7.3919	-5.3276
	A_N	-5.28636*	.44139	.000	-6.5443	-4.0284
	B_D	.61005	.36459	.550	-.4290	1.6491
	C_D	2.79368*	.36132	.000	1.7639	3.8234
	C_N	3.28296*	.45029	.000	1.9996	4.5663
C_D	A_D	-9.15342*	.11682	.000	-9.4864	-8.8205
	A_N	-8.08004*	.27805	.000	-8.8725	-7.2876
	B_D	-2.18363*	.12414	.000	-2.5374	-1.8298
	B_N	-2.79368*	.36132	.000	-3.8234	-1.7639
	C_N	.48928	.29197	.548	-.3428	1.3214
C_N	A_D	-9.64269*	.29301	.000	-10.4778	-8.8076
	A_N	-8.56932*	.38667	.000	-9.6713	-7.4673
	B_D	-2.67291*	.29600	.000	-3.5165	-1.8293
	B_N	-3.28296*	.45029	.000	-4.5663	-1.9996
	C_D	-.48928	.29197	.548	-1.3214	.3428

Table 24 Method 3 Multiple Comparisons

(I) Category_ Numerical	(J) Category_ Numerical	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A_D	A_N	-.10721	.23902	.970	-.7213	.5069
	B_D	6.05200*	.11049	.000	5.7681	6.3359
	B_N	6.54128*	.31041	.000	5.7438	7.3388
A_N	A_D	.10721	.23902	.970	-.5069	.7213
	B_D	6.15922*	.24519	.000	5.5293	6.7892
	B_N	6.64850*	.37982	.000	5.6726	7.6244
B_D	A_D	-6.05200*	.11049	.000	-6.3359	-5.7681
	A_N	-6.15922*	.24519	.000	-6.7892	-5.5293
	B_N	.48928	.31519	.406	-.3205	1.2991
B_N	A_D	-6.54128*	.31041	.000	-7.3388	-5.7438
	A_N	-6.64850*	.37982	.000	-7.6244	-5.6726
	B_D	-.48928	.31519	.406	-1.2991	.3205

Table 25 Method 4 Multiple Comparisons

(I) Category_ Numerical	(J) Category_ Numerical	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A_D	A_N	-.68932	.47163	.689	-2.0335	.6548
	B_D	6.75930*	.14625	.000	6.3425	7.1761
	B_N	6.53516*	.27641	.000	5.7474	7.3229
	C_D	11.05652*	.15037	.000	10.6280	11.4851
	C_N	11.54580*	.31249	.000	10.6552	12.4364
A_N	A_D	.68932	.47163	.689	-.6548	2.0335
	B_D	7.44862*	.46059	.000	6.1359	8.7613
	B_N	7.22448*	.51688	.000	5.7514	8.6976
	C_D	11.74585*	.46192	.000	10.4294	13.0623
	C_N	12.23513*	.53704	.000	10.7046	13.7657
B_D	A_D	-6.75930*	.14625	.000	-7.1761	-6.3425
	A_N	-7.44862*	.46059	.000	-8.7613	-6.1359
	B_N	-.22414	.25714	.953	-.9570	.5087
	C_D	4.29723*	.11104	.000	3.9808	4.6137
	C_N	4.78651*	.29558	.000	3.9441	5.6289
B_N	A_D	-6.53516*	.27641	.000	-7.3229	-5.7474
	A_N	-7.22448*	.51688	.000	-8.6976	-5.7514
	B_D	.22414	.25714	.953	-.5087	.9570

	C_D	4.52137*	.25951	.000	3.7818	5.2610
	C_N	5.01065*	.37734	.000	3.9352	6.0861
C_D	A_D	-11.05652*	.15037	.000	-11.4851	-10.6280
	A_N	-11.74585*	.46192	.000	-13.0623	-10.4294
	B_D	-4.29723*	.11104	.000	-4.6137	-3.9808
	B_N	-4.52137*	.25951	.000	-5.2610	-3.7818
	C_N	.48928	.29764	.569	-.3590	1.3376
C_N	A_D	-11.54580*	.31249	.000	-12.4364	-10.6552
	A_N	-12.23513*	.53704	.000	-13.7657	-10.7046
	B_D	-4.78651*	.29558	.000	-5.6289	-3.9441
	B_N	-5.01065*	.37734	.000	-6.0861	-3.9352
	C_D	-.48928	.29764	.569	-1.3376	.3590

Table 26 Method 5 Multiple Comparisons

(I) Category_ Numerical	(J) Category_ Numerical	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A_D	A_N	-1.21073	.53324	.206	-2.7306	.3091
	B_D	6.64613*	.16402	.000	6.1786	7.1136
	B_N	6.46323*	.32290	.000	5.5429	7.3836
	C_D	9.25758*	.19383	.000	8.7051	9.8100
	C_N	8.62264*	.48499	.000	7.2403	10.0050
A_N	A_D	1.21073	.53324	.206	-.3091	2.7306
	B_D	7.85686*	.52261	.000	6.3673	9.3464
	B_N	7.67396*	.59201	.000	5.9866	9.3613
	C_D	10.46831*	.53272	.000	8.9500	11.9866
	C_N	9.83336*	.69386	.000	7.8558	11.8110
B_D	A_D	-6.64613*	.16402	.000	-7.1136	-6.1786
	A_N	-7.85686*	.52261	.000	-9.3464	-6.3673
	B_N	-.18290	.30502	.991	-1.0523	.6865
	C_D	2.61145*	.16231	.000	2.1488	3.0741
	C_N	1.97651*	.47328	.000	.6276	3.3254
B_N	A_D	-6.46323*	.32290	.000	-7.3836	-5.5429
	A_N	-7.67396*	.59201	.000	-9.3613	-5.9866
	B_D	.18290	.30502	.991	-.6865	1.0523
	C_D	2.79435*	.32203	.000	1.8765	3.7122
	C_N	2.15941*	.54896	.001	.5948	3.7240
C_D	A_D	-9.25758*	.19383	.000	-9.8100	-8.7051
	A_N	-10.46831*	.53272	.000	-11.9866	-8.9500
	B_D	-2.61145*	.16231	.000	-3.0741	-2.1488

	B_N	-2.79435*	.32203	.000	-3.7122	-1.8765
	C_N	-.63494	.48442	.779	-2.0156	.7457
C_N	A_D	-8.62264*	.48499	.000	-10.0050	-7.2403
	A_N	-9.83336*	.69386	.000	-11.8110	-7.8558
	B_D	-1.97651*	.47328	.000	-3.3254	-.6276
	B_N	-2.15941*	.54896	.001	-3.7240	-.5948
	C_D	.63494	.48442	.779	-.7457	2.0156

Table 27 Method 6 Multiple Comparisons

(I) Category_ Numerical	(J) Category_ Numerical	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A_D	A_N	-1.21073	.52774	.393	-2.8805	.4591
	B_D	4.76811*	.19043	.000	4.1656	5.3706
	B_N	4.67153*	.45568	.000	3.2297	6.1133
	C_D	6.64613*	.16233	.000	6.1325	7.1598
	C_N	6.46323*	.31957	.000	5.4521	7.4744
	D_D	9.25758*	.19183	.000	8.6506	9.8645
	D_N	8.62264*	.47999	.000	7.1039	10.1413
	E_D	11.69734*	.17228	.000	11.1522	12.2425
	E_N	12.95816*	.39290	.000	11.7150	14.2013
A_N	A_D	1.21073	.52774	.393	-.4591	2.8805
	B_D	5.97884*	.52671	.000	4.3123	7.6454
	B_N	5.88226*	.66993	.000	3.7626	8.0019
	C_D	7.85686*	.51722	.000	6.2204	9.4934
	C_N	7.67396*	.58590	.000	5.8201	9.5278
	D_D	10.46831*	.52722	.000	8.8002	12.1365
	D_N	9.83336*	.68669	.000	7.6606	12.0061
	E_D	12.90807*	.52043	.000	11.2614	14.5547
	E_N	14.16889*	.62891	.000	12.1790	16.1588
B_D	A_D	-4.76811*	.19043	.000	-5.3706	-4.1656
	A_N	-5.97884*	.52671	.000	-7.6454	-4.3123
	B_N	-.09658	.45449	1.000	-1.5346	1.3414
	C_D	1.87801*	.15896	.000	1.3751	2.3810
	C_N	1.69512*	.31787	.000	.6894	2.7009
	D_D	4.48947*	.18898	.000	3.8915	5.0874
	D_N	3.85452*	.47886	.000	2.3394	5.3697
	E_D	6.92923*	.16911	.000	6.3942	7.4643

	E_N	8.19005*	.39152	.000	6.9513	9.4288
B_N	A_D	-4.67153*	.45568	.000	-6.1133	-3.2297
	A_N	-5.88226*	.66993	.000	-8.0019	-3.7626
	B_D	.09658	.45449	1.000	-1.3414	1.5346
	C_D	1.97460*	.44345	.000	.5715	3.3777
	C_N	1.79170*	.52194	.021	.1403	3.4431
	D_D	4.58605*	.45508	.000	3.1462	6.0259
	D_N	3.95110*	.63300	.000	1.9483	5.9539
	E_D	7.02581*	.44719	.000	5.6109	8.4407
	E_N	8.28663*	.56980	.000	6.4838	10.0895
C_D	A_D	-6.64613*	.16233	.000	-7.1598	-6.1325
	A_N	-7.85686*	.51722	.000	-9.4934	-6.2204
	B_D	-1.87801*	.15896	.000	-2.3810	-1.3751
	B_N	-1.97460*	.44345	.000	-3.3777	-.5715
	C_N	-.18290	.30187	1.000	-1.1380	.7723
	D_D	2.61145*	.16064	.000	2.1032	3.1197
	D_N	1.97651*	.46840	.001	.4945	3.4585
	E_D	5.05121*	.13670	.000	4.6187	5.4837
	E_N	6.31204*	.37865	.000	5.1140	7.5101
C_N	A_D	-6.46323*	.31957	.000	-7.4744	-5.4521
	A_N	-7.67396*	.58590	.000	-9.5278	-5.8201
	B_D	-1.69512*	.31787	.000	-2.7009	-.6894
	B_N	-1.79170*	.52194	.021	-3.4431	-.1403
	C_D	.18290	.30187	1.000	-.7723	1.1380
	D_D	2.79435*	.31871	.000	1.7859	3.8028
	D_N	2.15941*	.54329	.003	.4404	3.8784
	E_D	5.23411*	.30734	.000	4.2617	6.2066
	E_N	6.49493*	.46813	.000	5.0137	7.9761
D_D	A_D	-9.25758*	.19183	.000	-9.8645	-8.6506
	A_N	-10.46831*	.52722	.000	-12.1365	-8.8002
	B_D	-4.48947*	.18898	.000	-5.0874	-3.8915
	B_N	-4.58605*	.45508	.000	-6.0259	-3.1462
	C_D	-2.61145*	.16064	.000	-3.1197	-2.1032
	C_N	-2.79435*	.31871	.000	-3.8028	-1.7859
	D_N	-.63494	.47942	.948	-2.1519	.8820
	E_D	2.43976*	.17069	.000	1.8997	2.9798
	E_N	3.70058*	.39221	.000	2.4596	4.9415
D_N	A_D	-8.62264*	.47999	.000	-10.1413	-7.1039
	A_N	-9.83336*	.68669	.000	-12.0061	-7.6606
	B_D	-3.85452*	.47886	.000	-5.3697	-2.3394
	B_N	-3.95110*	.63300	.000	-5.9539	-1.9483
	C_D	-1.97651*	.46840	.001	-3.4585	-.4945

	C_N	-2.15941*	.54329	.003	-3.8784	-.4404
	D_D	.63494	.47942	.948	-.8820	2.1519
	E_D	3.07470*	.47194	.000	1.5815	4.5679
	E_N	4.33553*	.58942	.000	2.4706	6.2005
E_D	A_D	-11.69734*	.17228	.000	-12.2425	-11.1522
	A_N	-12.90807*	.52043	.000	-14.5547	-11.2614
	B_D	-6.92923*	.16911	.000	-7.4643	-6.3942
	B_N	-7.02581*	.44719	.000	-8.4407	-5.6109
	C_D	-5.05121*	.13670	.000	-5.4837	-4.6187
	C_N	-5.23411*	.30734	.000	-6.2066	-4.2617
	D_D	-2.43976*	.17069	.000	-2.9798	-1.8997
	D_N	-3.07470*	.47194	.000	-4.5679	-1.5815
	E_N	1.26083*	.38303	.034	.0489	2.4727
E_N	A_D	-12.95816*	.39290	.000	-14.2013	-11.7150
	A_N	-14.16889*	.62891	.000	-16.1588	-12.1790
	B_D	-8.19005*	.39152	.000	-9.4288	-6.9513
	B_N	-8.28663*	.56980	.000	-10.0895	-6.4838
	C_D	-6.31204*	.37865	.000	-7.5101	-5.1140
	C_N	-6.49493*	.46813	.000	-7.9761	-5.0137
	D_D	-3.70058*	.39221	.000	-4.9415	-2.4596
	D_N	-4.33553*	.58942	.000	-6.2005	-2.4706
	E_D	-1.26083*	.38303	.034	-2.4727	-.0489

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Table 28 Method 7 Multiple Comparisons

(I) Category_ Numerical	(J) Category_ Numerical	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
A_D	A_N	.48928	.29054	.698	-.3914	1.3700
	B_D	.23067	.13157	.652	-.1681	.6295
	B_N	-.29500	.37686	.994	-1.4373	.8473
	C_D	-11.05652*	.14679	.000	-11.5015	-10.6116
	C_N	-11.74585*	.45090	.000	-13.1126	-10.3791
	D_D	-6.21612*	.12262	.000	-6.5878	-5.8444
	D_N	-5.53680*	.30028	.000	-6.4470	-4.6266
A_N	A_D	-.48928	.29054	.698	-1.3700	.3914
	B_D	-.25861	.29801	.989	-1.1620	.6447
	B_N	-.78428	.46209	.689	-2.1850	.6164
	C_D	-11.54580*	.30504	.000	-12.4704	-10.6212
	C_N	-12.23513*	.52422	.000	-13.8242	-10.6461
	D_D	-6.70540*	.29417	.000	-7.5971	-5.8137
	D_N	-6.02608*	.40208	.000	-7.2449	-4.8073
B_D	A_D	-.23067	.13157	.652	-.6295	.1681
	A_N	.25861	.29801	.989	-.6447	1.1620
	B_N	-.52566	.38265	.869	-1.6856	.6342
	C_D	-11.28719*	.16107	.000	-11.7754	-10.7990
	C_N	-11.97651*	.45575	.000	-13.3580	-10.5951
	D_D	-6.44678*	.13940	.000	-6.8693	-6.0242
	D_N	-5.76747*	.30751	.000	-6.6996	-4.8353
B_N	A_D	.29500	.37686	.994	-.8473	1.4373
	A_N	.78428	.46209	.689	-.6164	2.1850
	B_D	.52566	.38265	.869	-.6342	1.6856
	C_D	-10.76153*	.38815	.000	-11.9381	-9.5850
	C_N	-11.45085*	.57656	.000	-13.1985	-9.7032
	D_D	-5.92112*	.37967	.000	-7.0720	-4.7703
	D_N	-5.24180*	.46827	.000	-6.6612	-3.8224
C_D	A_D	11.05652*	.14679	.000	10.6116	11.5015
	A_N	11.54580*	.30504	.000	10.6212	12.4704
	B_D	11.28719*	.16107	.000	10.7990	11.7754
	B_N	10.76153*	.38815	.000	9.5850	11.9381
	C_N	-.68932	.46037	.809	-2.0848	.7062
	D_D	4.84041*	.15385	.000	4.3741	5.3067

	D_N	5.51972*	.31432	.000	4.5669	6.4725
C_N	A_D	11.74585*	.45090	.000	10.3791	13.1126
	A_N	12.23513*	.52422	.000	10.6461	13.8242
	B_D	11.97651*	.45575	.000	10.5951	13.3580
	B_N	11.45085*	.57656	.000	9.7032	13.1985
	C_D	.68932	.46037	.809	-.7062	2.0848
	D_D	5.52973*	.45325	.000	4.1559	6.9036
	D_N	6.20905*	.52968	.000	4.6035	7.8146
D_D	A_D	6.21612*	.12262	.000	5.8444	6.5878
	A_N	6.70540*	.29417	.000	5.8137	7.5971
	B_D	6.44678*	.13940	.000	6.0242	6.8693
	B_N	5.92112*	.37967	.000	4.7703	7.0720
	C_D	-4.84041*	.15385	.000	-5.3067	-4.3741
	C_N	-5.52973*	.45325	.000	-6.9036	-4.1559
	D_N	.67932	.30379	.330	-.2415	1.6002
D_N	A_D	5.53680*	.30028	.000	4.6266	6.4470
	A_N	6.02608*	.40208	.000	4.8073	7.2449
	B_D	5.76747*	.30751	.000	4.8353	6.6996
	B_N	5.24180*	.46827	.000	3.8224	6.6612
	C_D	-5.51972*	.31432	.000	-6.4725	-4.5669
	C_N	-6.20905*	.52968	.000	-7.8146	-4.6035
	D_D	-.67932	.30379	.330	-1.6002	.2415

Table 29 Method 8 Multiple Comparisons

(I) Category_ Numerical	(J) Category_ Numerical	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A_D	A_N	-.63494	.43211	.824	-1.9449	.6750
	B_D	3.83485*	.18799	.000	3.2650	4.4047
	B_N	3.51036*	.57879	.000	1.7558	5.2649
	C_D	-9.25758*	.17290	.000	-9.7817	-8.7334
	C_N	-10.46831*	.47520	.000	-11.9088	-9.0278
	D_D	-5.40785*	.15385	.000	-5.8742	-4.9415
	D_N	-4.48728*	.31737	.000	-5.4494	-3.5252
A_N	A_D	.63494	.43211	.824	-.6750	1.9449
	B_D	4.46979*	.43888	.000	3.1394	5.8002
	B_N	4.14530*	.70162	.000	2.0184	6.2722
	C_D	-8.62264*	.43263	.000	-9.9341	-7.3112
	C_N	-9.83336*	.61894	.000	-11.7096	-7.9571

	D_D	-4.77290*	.42537	.000	-6.0624	-3.4834
	D_N	-3.85234*	.50793	.000	-5.3921	-2.3126
B_D	A_D	-3.83485*	.18799	.000	-4.4047	-3.2650
	A_N	-4.46979*	.43888	.000	-5.8002	-3.1394
	B_N	-.32449	.58386	.999	-2.0944	1.4454
	C_D	-13.09243*	.18917	.000	-13.6659	-12.5190
	C_N	-14.30315*	.48136	.000	-15.7624	-12.8440
	D_D	-9.24270*	.17193	.000	-9.7639	-8.7215
	D_N	-8.32213*	.32652	.000	-9.3119	-7.3323
B_N	A_D	-3.51036*	.57879	.000	-5.2649	-1.7558
	A_N	-4.14530*	.70162	.000	-6.2722	-2.0184
	B_D	.32449	.58386	.999	-1.4454	2.0944
	C_D	-12.76794*	.57917	.000	-14.5237	-11.0122
	C_N	-13.97867*	.72894	.000	-16.1884	-11.7689
	D_D	-8.91821*	.57377	.000	-10.6576	-7.1789
	D_N	-7.99764*	.63739	.000	-9.9298	-6.0654
C_D	A_D	9.25758*	.17290	.000	8.7334	9.7817
	A_N	8.62264*	.43263	.000	7.3112	9.9341
	B_D	13.09243*	.18917	.000	12.5190	13.6659
	B_N	12.76794*	.57917	.000	11.0122	14.5237
	C_N	-1.21073	.47567	.177	-2.6527	.2312
	D_D	3.84973*	.15529	.000	3.3790	4.3205
	D_N	4.77030*	.31807	.000	3.8061	5.7345
C_N	A_D	10.46831*	.47520	.000	9.0278	11.9088
	A_N	9.83336*	.61894	.000	7.9571	11.7096
	B_D	14.30315*	.48136	.000	12.8440	15.7624
	B_N	13.97867*	.72894	.000	11.7689	16.1884
	C_D	1.21073	.47567	.177	-.2312	2.6527
	D_D	5.06046*	.46908	.000	3.6385	6.4824
	D_N	5.98103*	.54506	.000	4.3287	7.6333
D_D	A_D	5.40785*	.15385	.000	4.9415	5.8742
	A_N	4.77290*	.42537	.000	3.4834	6.0624
	B_D	9.24270*	.17193	.000	8.7215	9.7639
	B_N	8.91821*	.57377	.000	7.1789	10.6576
	C_D	-3.84973*	.15529	.000	-4.3205	-3.3790
	C_N	-5.06046*	.46908	.000	-6.4824	-3.6385
	D_N	.92057	.30813	.057	-.0135	1.8546
D_N	A_D	4.48728*	.31737	.000	3.5252	5.4494
	A_N	3.85234*	.50793	.000	2.3126	5.3921
	B_D	8.32213*	.32652	.000	7.3323	9.3119
	B_N	7.99764*	.63739	.000	6.0654	9.9298
	C_D	-4.77030*	.31807	.000	-5.7345	-3.8061

	C_N	-5.98103*	.54506	.000	-7.6333	-4.3287
	D_D	-.92057	.30813	.057	-1.8546	.0135

VITA

Ridwan B. A. Quaium

Address

Department of Civil Engineering
C/O Dr. Gene Hawkins
Texas A&M University
College Station, TX, 77843-3135

Email Address

ridwanq@gmail.com

Education

B.S., Civil Engineering, Virginia Polytechnic Institute and State University, May 2007.
M.S., Civil Engineering, Texas A&M University, May 2010.

Work Experience

Texas Transportation Institute, June 2007 – August 2009.

Professional Affiliations and Societies

Institute of Transportation Engineers
American Society of Civil Engineers
Association of Student Planners

Areas of Interest

Retroreflectivity of Pavement Markings
Traffic Signal Design
Highway Design
Sustainable Transportation Planning