ANALYSIS OF FACTORS AFFECTING PAVEMENT MARKINGS AND PAVEMENT MARKING RETROREFLECTIVITY IN TENNESSEE HIGHWAYS

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ABSTRACT

Pavement markings are lines drawn on a pavement surface to provide vital information to road users pertaining to lane restrictions and vehicle movements, which if adhered to, results in improved safety and smooth travelling to road users.

Pavement markings' visibility is quantified into a parameter called retroreflectivity, which is a measure of how well the markings can be seen by road users.

The importance of the factors affecting pavement markings differs from one publication to another, which cause the effective management of pavement markings a difficult process. In addressing this concern, this thesis investigated factors affecting pavement markings and marking retroreflectivity in Tennessee highways using retroreflectivity data collected on asphalt highways. Quantifiable factors affecting pavement markings retroreflectivity are analyzed, and linear degradation models are developed using regression analysis. The analysis shows that age and traffic have significant impacts on pavement marking retroreflectivity degradation.

DEDICATION

This is dedicated to my family: the family of Rev. & Mrs. Aaron Malyuta, who always supported my endeavors. Their love, devotion and prayers have been inspiring me to continuously strive in life for intellectual achievements. I know how much this will mean to them.

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CHAPTER 1

INTRODUCTION

1.1 Pavement Markings

Pavement markings are traffic control lines that convey continuous information to the motorists and pedestrians about the roadway path and restrictions [MUTCD, 2009 – (Traffic)]. They play an essential role in providing safe and efficient movement of traffic by maintaining a safe driving setting for road users. They also provide information related to passing, driving direction, lateral lane position and boundaries of a roadway segment. According to the Manual on Uniform Traffic Control Devices-MUTCD, 2009, pavement markings on highways provide guidance and information such as to:

- Guide users with directional information supplementing road signs and signals.
- Warn users about their position with center, lane and edge markings.
- Inform users about the course of the road like no-passing or overtaking zones.

  [MUTCD, 2009 – (Traffic)]

1.2 Retroreflectivity

Retroreflectivity, sometimes called retro-reflection, is an optical property or phenomenon in which reflected rays of light are preferentially returned or reflected back in directions close to the opposite of the direction from which the rays came [MUTCD, 2009 – (Traffic)].

This property is maintained over wide variations of the direction of the incident rays. Retroreflection is achieved through multiple reflections within a retroreflector, called a “Glass Bead”. Pavement marking retroreflectivity is a measure, in milli-candela per square meter per lux, of how well the markings can be seen by road users, especially at night. Retroreflectivity may also be referred to as nighttime visibility.

Candela, symbol cd, is the SI base unit of luminous intensity, that is, power emitted by a light source in a particular direction, weighted by the luminosity function. A common candle emits light with a luminous intensity of roughly one candela [MUTCD, 2009 – (Traffic)]. Candela means candle in Latin, as well as in some Romance languages.

Lux, symbolized lx, is the unit of illuminance in the International System of Units (SI). It is defined in terms of lumens per meter squared (lm/m^2). Reduced to SI base units, one lux is equal to 0.00146 kilogram per second cubed (1.46×10^{-3} kg / s^3). Illuminance is a measure of how much luminous flux is spread over a given area.

Pavement markings play an important role in reducing congestion, raising roadway capacity, improving safety by guiding traffic flows, providing modal separation, getting the attention of drivers at critical locations, and providing information that promotes safe and smooth vehicular and pedestrian movement. Markings comprise different materials including various types of paints, thermoplastics, preformed thermoplastic, tape, polymer materials, and other categories of discrete physical markers.

Retroreflection technology can also be used for measuring distances. The method used for measuring distance is called time-of-flight measurement, which can be used for great distances. In time-of-flight measurements, the distance from light source to target is determined by measuring the time it takes light to travel to the target and return to the sensor. Time-of-flight

distance measurements can be made using pulsed-type systems or modulated beam systems. Pulsed-type systems are used for measuring great distances, whereas modulated beam systems are typically used for intermediate range distance measurements.

1.3 Objectives of the Study

Literature has revealed that numerous factors affect pavement marking retroreflectivity, such as traffic, marking age, geographical locations, nature and type of pavement surface and environmental conditions such as temperature, snow, and rainfall. This study uses pavement marking retroreflectivity data collected in the state of Tennessee, to analyze factors affecting pavement marking retroreflectivity on the selected state highways. The overarching goal of this thesis is to produce models that can serve as the underlying algorithm in a pavement marking management system. To meet this goal the following objectives were accomplished:

(i) To evaluate (investigate) factors affecting pavement markings and pavement marking retroreflectivity on selected Tennessee highways.

(ii) To analyze factors affecting pavement marking retroreflectivity using the regression analysis method. (for factors which can be quantified)

(iii) To develop pavement marking retroreflectivity degradation models for use in predicting when to schedule rehabilitation measures.

1.4 Scope of the Study

For this study:

(i) Retroreflectivity data was collected approximately every six weeks using a hand-operated retroreflectometer.

(ii) Information related to factors affecting pavement marking and pavement marking retroreflectivity, such as traffic volume, nature and type of the pavement surface, highway elevations, climatic regions and environmental conditions (temperature, snow and rainfall) was obtained.

(i) Regression analysis was used to identify impacts of quantified factors affecting pavement marking retroreflectivity and to develop relationships (regression models) comprising these factors and pavement marking retroreflectivity.

1.5 Problem Statement

Numerous studies have been performed to determine factors contributing to the deterioration of pavement markings and pavement marking retroreflectivity. From the findings, the importance of the factors differs from one publication to another. For instance, (Abboud and Bowman 2002) had annual average daily traffic (AADT) as the factor affecting retroreflectivity, but (Lee 2011) did not consider AADT an important factor on pavement markings deterioration. Due to the presence of all these factors, some within and some outside the control of the transportation agencies, effective management of pavement markings is a difficult process (Benz, Pike et al. 2009). Due to difficulties in pavement marking management, some agencies retrace pavement markings after a certain period of time regardless of the prevailing retroreflectivity levels. Sometimes this happened when the markings were well within the

acceptable retroreflectivity levels. In pavement marking management, the following question is being asked:

> What factors should be considered in repainting the pavement markings so as to not let the retroreflectivity value drop below the acceptable threshold, such as time range, traffic, geographical conditions, and others?

This study used linear regression method to come up with predictive models, which relate factors affecting pavement markings to the pavement marking retroreflectivity. These models provide useful relationships on how age and traffic can affect the pavement marking retroreflectivity, in such a way that they can be used to predict serviceability age of the pavement markings.

1.6 Thesis Overview

This thesis is divided into seven (VII) chapters. Chapter I presents an introduction, which includes objectives, scope, study overview and the problem statement. Chapter II is a literature review that briefly describes different factors affecting the deterioration of the pavement markings and pavement marking retroreflectivity, from previous studies of the same nature in the field of pavement markings. Chapter III explains the methodology used in achieving the objectives of this study, in which participants, equipment used, data collection sites, and data collection process and the method used in data analysis are explained. Chapter IV includes results and analysis, wherein all the generated predictive models are presented for different categories of paint markings. Chapter V presents the discussion of the results and all the findings, for different factors affecting pavement markings. In Chapter VI, the conclusion,

recommendations and suggestions of this study are provided. Chapter VII presents some limitations and problems encountered in this study.

CHAPTER 2

LITERATURE REVIEW

Over the years, there have been a number of studies evaluating the factors affecting pavement markings and pavement marking retroreflectivity, with results leading to several proposals from government agencies and professional organizations recommending minimum pavement marking retroreflectivity levels in relation to the factors affecting them.

This chapter provides information through a review of the different literatures from Tennessee, the United States and all over the world, with the same nature of research on pavement marking degradation, including time, analysis and modeling, along with factors affecting the pavement markings' retroreflectivity and visibility.

Through the different studies, it is revealed that retroreflectivity quality can be affected by several factors including traffic volume and composition, nature of the pavement surface, type of the marking materials, environmental or weather conditions, and pavement marking age. All these and other factors result in pavement marking degradation, and hence retroreflectivity quality (Sitzabee, Hummer et al. 2009).

The following are the different factors affecting pavement markings as published by different researchers such as pavement marking materials, traffic, marking age, climatic conditions, and pavement type:

Clarke, et al. (2009), conducted a study for Tennessee Department of Transportation (TDOT) to examine the retroreflectivity performance of several pavement marking types used on

Tennessee state highways. This study considered several pavement marking materials (40 mil spray thermoplastic, 90 mil spray thermoplastic, rumble stripe, wet reflective tape and patterned reflective tape), the retroreflectivity behavior in colors (white or yellow), flexible and rigid pavement types (ACC or PCC), and traffic volume. The research team selected 121 test sites having the target marking types on state highways throughout the state. The research utilized a handheld LTL-X Retroreflectometer to take measurements at the test sites. This study revealed that markings tested met the minimum retroreflectivity standards after 500 – 600 service days (deterioration time) when measured in a dry state and all marking types exhibited very low retroreflectivity when wet (simulated rain). The more dry the pavement marking, the higher the retroreflectivity value, and vice versa. The study also revealed that yellow markings had a consistently lower dry reflectivity than their white counterparts (Clarke et al, 2011).

Pavement markings are sometimes defined by type of marking material. Migletz and Graham (2002) listed 16 types of line marking materials available on the market as of 2002 (Migletz and Graham 2002). The majority of the materials are defined as durable pavement markings, which simply means that they are expected to last longer than one year. Waterborne and solvent-based paints are typically considered to be nondurable pavement markings. These are expected to have a short service life of not more than a year. The North Carolina Department of Transportation (NCDOT) primarily uses four pavement marking materials: paint, thermoplastics, epoxy, and polyurea. Paints make up nearly 60 percent of the pavement marking inventory for the NCDOT while thermoplastics represent another 23 percent. In 2003 the NCDOT decided to use polyurea instead of epoxy for concrete applications. Epoxy is still used in some limited applications but is in the process of being phased out of the inventory (Howard 2006).

Various types of materials are used for pavement markings in the U.S. The effects and performances of these materials have been examined by a number of state and federal highway agencies. Gates et al. 2003, studied the effectiveness of pavement marking materials on concrete pavements. They indicated that some state Departments of Transportation have had great success with thermoplastic on concrete, while many others discourage its use on concrete. Their study results showed that the thermoplastic marking material used in Texas did not perform well on concrete pavements, while epoxy marking materials performed better. As they stated, many materials exist that may be used for pavement markings on concrete roadway surfaces. However the service life and cost of the various materials vary greatly. As with other traffic control devices, maintaining pavement markings that are highly visible and long lasting presents a major challenge to transportation agencies (Gates, Hawkins et al. 2003).

Thomas and Schloz (2001) did a synthesis on durability and cost-effectiveness of pavement marking materials for the Iowa Department of Transportation. They indicated that pavement marking technology is a continually evolving subject. There are numerous types of materials used in the field today, including paint, epoxy, tape, and thermoplastic. Each material has its own set of unique characteristics related to durability, retroreflectivity/visibility, installation cost, and life-cycle cost (Thomas and Schloz 2001).

Based on the National Cooperative Highway Research Program (NCHRP) study, the major types of pavement marking materials used in the states include the following: waterborne paints, conventional solvent paints, thermoplastics, tape, epoxy, methyl methacrylate, polyester, and polyurea, Different studies, [including, (Migletz and Graham 2002); (Gates, Hawkins et al. 2003); (Andrady 1997); (Lee 2011); and (McGinnis 2001)] have been performed to identify durability, performance and any other properties of each material. (Bahar, Masliah et al.)

Andrady (1997) sponsored by the NCHRP, developed one of the first degradation models by different researchers for pavement marking retroreflectivity. Andrady's study was focused on determining the environmental impact of volatile organic compounds and to identify alternative pavement marking materials. Part of Andrady's study was to evaluate the performance characteristics of pavement markings in terms of retroreflectivity. Andrady created the logarithmic model shown below for thermoplastics:

$$T_{100} = 10^{\left(\frac{R_0 - 100}{b}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where:

T_{100} = Time in months for the retroreflectivity to reach 100 mcd/m^2/lx

R_o = Estimate of the initial retroreflectivity value

b = Gradient of the semi-logarithmic plot of retroreflectivity

The end of service life for this model was defined by reaching a retroreflectivity value of 100mcd/m^2/lx. No goodness of fit measures have been published for this model (Andrady 1997).

Lee, et al., (1999) at Michigan State University (MSU) evaluated the performance of several pavement marking materials for the Michigan DOT. Their study sought to provide insight and guidance on how to implement cost effective procedures for pavement marking management. Focusing on four major marking materials (paints, thermoplastics, thermosets, and tapes) the study used 50 sample sites throughout Michigan to determine degradation rates for the various materials and a minimum threshold value of 100mcd/m^2/lx to indicate satisfactory marking performance. This study used the Mirolux 12 for pavement marking measurements. The study reported that there was a great deal of variability in the measurements provided by this

device and that any future studies should consider better data collection equipment and methods. Large variances in service life were reported. Data collection limitations minimized the amount of data that could be compared over time. Although the degradation rates seemed to be linear, the R^2 values seemed low (R^2 = 0.14), providing little confidence that a linear degradation model was the best fit to the data. In this study, snowfall (and snow plowing) was highly correlated to retroreflectivity degradation. Alternatively, AADT, speed limit, and percent commercial traffic showed no correlation with degradation of retroreflectivity and were eliminated from the model. The study determined degradation rates of these different materials on the basis of a minimum acceptable retroreflectivity level of 100mcd/m²/lux, and revealed that waterborne paints were found to have a service life of 445 days, or about 15 months. This conclusion was based on reasonable performance compared to the low cost. Other materials performed better but the cost involved did not justify the improved service life. They came up with the following model for thermoplastics:

$$R_L = -0.3622*X + 254.82, \qquad R^2 = 0.14 \quad \text{..... (2.2)}$$

Where:

R_L = Retroreflectivity of pavement marking (mcd/m^2/lux)

X = Age of the pavement marking in days (Lee 2011)

Lee (2011) evaluated the life cycle of pavement markings in Maryland with data collected for four years. Different marking types were investigated: inlaid tape, thermoplastic, and waterborne paint, which was used as reference paint as it is considered nondurable. It was found that linear function had the best fit compared to other functions for both markings, and

yellow inlaid tape had higher initial retroreflectivity but deteriorated faster than yellow thermoplastic (Lee 2011).

Migletz, et al. (2000) conducted a study that used regression analysis to evaluate various materials and establish a predictive degradation curve of material performance over time. The model evaluated pavement marking material type, road surface type, and marking material color as independent variables. The study used a Laserlux mobile retroreflectometer for data collection. The study took about 4 years, from 1994 to 1998, with a purpose to evaluate the life of durable pavement markings. Included in the study, as a benchmark, was some limited evaluation of waterborne paints. The researchers collected data on 362 longitudinal (edge, center, and lane) pavement marking lines from 85 sites across 19 states.

Results from the regression analysis indicated there was a great deal of variation in the performance of identical materials at different sites. The variation was attributed to differences in roadway type, region of the country, marking specifications, quality control, and winter maintenance. Analysis indicated that yellow lines performed better than white but this was attributed to the use of a lower retroreflectivity threshold rather than to superior durability (Migletz and Enterprises 2000).

In a follow up study, Migletz, et al. established a service life matrix that provided degradation rates for each color of each material type sorted by cumulative traffic passages and elapsed months. Cumulative traffic passages are the cumulative sum of the AADT over time. The matrix provides average service lives, standard deviations, and service life ranges in months. The following are the findings for the two most common pavement marking materials:

- Average life of waterborne white paint markings was 10.4 months

- Average life of thermoplastics was 26.2 months (white) and 27.5 months (yellow). (Migletz and Graham 2002)

Abboud and Bowman (2002) conducted a study that explored the application cost, service life, and user cost related to crashes, compared to pavement marking retroreflectivity for the Alabama DOT. They developed an exponential regression model to depict the relationship between pavement marking retroreflectivity and vehicle exposure (VE) which is a function of time and AADT. In their model, there is an absence of marking color and surface material.

The degradation model presented for paint was:

$$R_L = -19.457 * \ln(VE) + 26.27, \qquad R^2 = 0.31 \quad (2.3)$$

The model for white thermoplastic edge lines was:

$$R_L = -70.806 * \ln(VE) + 150.55, \qquad R^2 = 0.58 \quad (2.4)$$

Where:

R_L = Pavement marking retroreflectivity (mcd/m^2/lx)

ln = Natural logarithm

VE = Vehicle Exposure = AADT x PM age x 0.0304

AADT = Annual Average Daily Traffic

PM age = Age in months (Abboud and Bowman 2002).

Abboud and Bowman (2002), conducted another study to evaluate cost and longevity of paint and thermoplastic striping to determine a useful paint lifetime. They used a minimum

retroreflectivity threshold of 150mcd/m²/lux, determined from their previous study of crash data and traffic exposure on state highways in Alabama. Abboud and Bowman concluded that the useful lifetime (in months) for low-AADT (<2500 vehicles per day) highways is 22 months; mid-AADT (2500 to 5000 vpd) highways is 7.5 months; and high-AADT (>5000 vpd) highways is 4.5 months. (Abboud and Bowman 2002)

Sarasua, et al. (2003) of Clemson University, South Carolina, performed a study to evaluate the effective life cycle of pavement marking retroreflectivity over time. They aimed at developing the predictive models that could estimate the rate of pavement marking degradation. These developed models could then be applied in an overall pavement markings management plan. They collected data from interstate highways for a period of 2 years and 4 months, and evaluated pavement marking retroreflectivity performance during this period. Data were collected 6 times over 150 sites throughout the South Carolina interstate system. An average retroreflectivity value was established from a series of 11 measurements taken with an LTL-2000 at each data collection site for each collection interval, and used in analysis (Sarasua, Clarke et al. 2003).

In this study retroreflectivity performance as a dependent variable was analyzed based on four major independent variables which are surface type, marking material, marking color, and maintenance practices. Different factors (independent variables) were to be considered, but only these four were identified to be major independent variables that affected the performance of pavement markings over time in this study. The data analysis was done by regression analysis. The dependent variables were the differences in retroreflectivity values and the percent differences in retroreflectivity values. Traffic volume was one variable that was initially thought and considered to affect performance but was later eliminated due to being observed that it was

not impacting the marking performance. Traffic volume was inversely correlated to the dependent variables and was considered to be accounted for by the age of the pavement marking. They developed two types of models for each combination of marking material, surface material, and color. One model was non-linear and represented the initial break-in period while the second model was linear and represented the degradation of the pavement marking retroreflectivity after the break-in period. The models were developed for thermoplastics and epoxy. The thermoplastics on asphalt models are shown below.

Model for white thermoplastics:

$$\text{Diff} = -0.06*(\text{Days}) - 6.80, \qquad (R^2 = 0.47) \quad (2.5)$$

$$\%\ \text{Diff} = -0.03*(\text{Days}) - 3.29, \qquad (R^2 = 0.39) \quad (2.6)$$

Model for yellow thermoplastics:

$$\text{Diff} = -0.03*(\text{Days}) - 3.63, \qquad (R^2 = 0.21) \quad (2.7)$$

$$\%\ \text{Diff} = -0.02*(\text{Days}) - 2.35, \qquad (R^2 = 0.24) \quad (2.8)$$

Where:

Diff = Difference in retroreflectivity over time

% Diff = Percentage of difference in retroreflectivity over time

Days = Time in days

The end of service life for this model was defined by reaching a retroreflectivity value of 100mcd/m^2/lx. (Sarasua, Clarke et al. 2003)

Bahar et al. (2006) used the following inverse polynomial model to estimate the retroreflectivity as a function of age:

$$\mathrm{R} = \frac{1}{\beta_0 + \beta_1 \times Age + \beta_2 \times Age^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.9)$$

Where:

R = retroreflectivity of pavement markings (mcd/m^2/lx)

Age = age of marking in months, and

β_0, β_1, β_2 = model parameters to be estimated from analysis (such as polynomial regression analysis), considering age as dependent variable and retroreflectivity as independent variable. Other variables considered by Bahar et al (2006), included color, material, traffic volume, pavement surface type, climatic region, and snow removal. Traffic (AADT) has inconsistent effects across different material types, and for some materials, the effects are unexplained. As a result, AADT was not used in the models. Different models were estimated based on the combination of the rest of the variables. (Bahar, Masliah et al.)

Perrin et al. (1998), utilized data from Utah, and found that the relationship between service life and AADT is a hyperbolic curve, and the product of AADT and service life is a constant. The relationship is shown in the following equation:

$$\mathrm{U} = \frac{\mathrm{K}}{\mathrm{V}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.10)$$

Where:

U = useful life (months),

V = AADT/lane, and

K is a constant defined as:

$$K = \frac{I - M}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2.11)$$

Where:

I = initial retroreflectivity (mcd/m^2/lx)

M = minimum acceptable retroreflectivity (mcd/m^2/lx)

D = average deterioration rate (mcd/m^2/lx/month/AADT/lane)

(Perrin, Martin et al. 1998)

Sitzabee, et al. (2008) developed pavement marking degradation modeling of paint and thermoplastic markings. The data were collected by mobile Laselux reflectometer, mounted on a Chevy Suburban using standard 30 meter geometry. About 56 thermoplastic and 37 paint segments were used in the analysis. They developed linear models for both marking types, which produced a coefficient of determination (R^2) of 0.6 for thermoplastic and 0.75 for paints. The author concluded that the degradation rate per month was 2.09 mcd/m^2/lx for thermoplastic and 4.17 mcd/m^2/lx for paints (Sitzabee, Hummer et al. 2009).

Sitzabee and Dowining (2012) evaluated performance of polyurea pavement markings in North Carolina by using Ordinary Least Squares (OLS) models. The study utilized data collected for five years with initial readings taken after 30 days of installation. The constructed performance models for polyurea pavement markings were based on the independent variables of

time, initial retroreflectivity, lateral line location, and annual average daily traffic. It was found that the type of glass bead used in the marking significantly affects polyurea pavement marking degradation rate. Also decay rate of retroreflectivity does not follow a linear trend, but appears more of an exponential decay and changes depending on bead type (Sitzabee, White et al. 2012).

Kopf (2004) investigated the degradation trends of pavement marking in Washington state roads using 80 test sections. Waterborne and solvent paint markings were tested during the study. Data was collected using Laserlux retroreflectometer with a minimum of 100mcd/m^2/lx as a retroreflectivity threshold value. It was concluded that no strong correlation exists between retroreflectivity degradation rates and time because of huge variability of data collected (Kopf 2004).

Fitch and Ahearn (2007) used a logarithmic model to evaluate the performance of epoxy paints, thermoplastic and polyurea markings in Vermont. Data were collected for three years with the minimum acceptable retroreflectivity of 100 mcd/m^2/lx, below which is considered for repaint. The authors studied the effect of traffic volume and geographic regions toward retroreflectivity degradation. They found that traffic volume was significant in retroreflectivity life-cycle with the higher the AADT the higher the degradation rate. The coefficient of determination varied from 0.4339 to 0.8046 for paint and thermoplastic respectively. With respect to geographical regions, warmer regions were found to have low degradation rates compared to the relatively colder regions (Fitch 2007).

Mitkey et al. (2012) investigated durability of rumble stripes and standard paint markings in different weather conditions. Data were collected using LTL-X and LTL-2000 retroreflectometers for wet and dry weather conditions respectively. The threshold retroreflectivity was 100 and 65mcd/m^2/lx for white and yellow markings respectively. It was

found that a dry condition retroreflectivity for a rumble stripe with glass beads surpassed the standard painted line by approximately 95% for white and 80% for yellow. The study also observed that in a corridor with paint containing a blend of elements designed for enhanced retroreflectivity, the rumble stripe exceeded the edge line by approximately 90% for white and 260% for yellow (Mitkey, Brennan Jr et al. 2012).

Karwa and Donnell (2011) used data collected by mobile retroreflectometer for predicting pavement marking retroreflectivity in North Carolina. The study which focused on thermoplastic only was conducted in three districts with a total of 11 segments collected for 7 months varied by initial retroreflectivity, age of markings, traffic flow and route location. They used an artificial neural network considered as a nonlinear relationship to predict retroreflectivity. It was concluded that degradation of retroreflectivity follows a nonlinear trend and differs among marking types. Traffic volume was found to have no significant association with decay of retroreflectivity (Karwa and Donnell 2011).

Zhang and Wu (2006) developed a methodology to predict service life of a pavement marking material based on its retroreflectivity. Pavement marking material test decks from the 2002 National Transportation Product Evaluation Program (NTPEP) in Mississippi were used to develop the model and for validation. The smoothing spline method and time series modeling were applied to estimate the service lives of different type of materials. It was found that service lives of the materials from the two methods were very close within a difference of two months (Zhang and Wu 2010).

Pike, et al. (2011) evaluated influences of stepping distance on average dry retroreflectivity measurements of profiled and rumble stripe pavement markings using a portable handheld retroreflectometer. The measurements of the handheld were compared to mobile

retroreflectometers. It was concluded that stepping distance has no practical influence on averaged retroreflectivity measurements of evaluated marking types when measured according to the American Society for Testing and Materials (ASTM). However, it was suggested that the use of a properly calibrated mobile retroreflectometer operated by an experienced user will result in dry retroreflectivity measurements with no significant difference to handheld retroreflectometer measurements measured according to ASTM standards, which prove the ability of the handheld retroreflectometer to measure profiled and rumbles stripe pavement markings (Pike, Ballard et al. 2011).

Narci and Lindly (2003) evaluated service life and cost life cycle of flat thermoplastic edge markings (FTM) and rumble stripes on highways maintained by the Alabama Department of Transportation. Night time dry and wet retroreflectivity were measured using a mobile retroreflectometer. The initial dry retroreflectivity of newly installed FTM and new rumble stripes were 320 and 236 mcd/m^2/lx respectively. It was found that the rumble stripes lost dry retroreflectivity at a lower rate compared to rumble stripes with the same cumulative traffic volume (AADT). Also, average wet retroreflectivity of the rumble stripe at the beginning of its service life was found to be higher than the average wet retroreflectivity of FTM (Lindly and Narci 2006).

Literature has revealed that numerous factors affect pavement marking retroreflectivity, such as traffic, marking age, geographical locations, nature and type of pavement surface and environmental conditions. This study uses pavement marking retroreflectivity data collected on asphalt highways in the state of Tennessee, to evaluate and analyze factors affecting pavement markings and pavement marking retroreflectivity by using the regression analysis method for

quantifiable factors. After regression analysis, pavement marking retroreflectivity degradation models are developed.

CHAPTER 3

METHODOLOGY

3.1 Overview

This study is aimed at analyzing factors contributing to the degradation of pavement markings and pavement marking retroreflectivity and then developing relationships (predictive models) between these factors and pavement marking retroreflectivity.

A comprehensive literature review was conducted on publications related to pavement marking deterioration, pavement marking retroreflectivity, factors affecting their performance and management of pavement markings in general. This study intends to evaluate the longevity and durability of the pavement markings by providing the relationship between time and deterioration of pavement marking retroreflectivity considering different factors (performance over time).

3.2 Participants

The University of Tennessee, Chattanooga (UTC) in collaboration with Tennessee State University (TSU) conducted this study, funded by the Tennessee Department of Transportation (TDOT), to evaluate the performance of pavement markings and the deterioration of pavement marking retroreflectivity on some highways in the state of Tennessee. Participants in data

collection attended a traffic safety training, and training on using the hand-operated retroreflectometer (LTL-X).

3.3 Equipment

The Hand-held Retroreflectometer [LTL – X. No. 851 and LTL – X. No. 852] (Figure 3.1) is used for data collection in this study. Traffic control safety gear such as cones, stop/slow sign, and reflectors are used in controlling traffic during the data collection process. Other equipment were two-way radios that are used in communication during traffic control; a GPS that is used to locate data collection sites every time the team went to collect data; and data recording sheets for recording data on site.



Figure 3.1 Hand-Held Retroreflectometer

3.4 Data Collection Sites

This study includes 60 data collection sites, all in the state of Tennessee. As the data collection process proceeded, some of these sites were dropped due to reasons including resurfacing and challenges in traffic control due to high traffic.

3.5 Data Collection Process

The research team visited all the sites for data collection and obtained the appropriate coordinates for every site, and then a database with the GPS coordinates of selected locations was created for data collection.

The data collection process was performed using the handheld retroreflectometer, following the retroreflectometer's TDOT data collection procedures and the procedures explained in the equipment manual, including calibration of the unit. The collected measurements were recorded on data sheets and kept in a notebook, then saved in an Excel data file. Data collection was performed at each site approximately every 45 days.

3.6 Data Analysis

For this thesis, data analysis was performed using a regression analysis method, where linear regression models were formulated that relate retroreflectivity as dependent variable, with other factors, such as pavement marking age and traffic, as independent variables.

The regression analysis was used to develop models that can predict how a single dependent variable, such as retroreflectivity, is affected by the values of one or more independent

variables, such as age and traffic. The factors considered for regression analysis in this study are retroreflectivity as a dependent variable, and age and traffic as independent variables. This is because retroreflectivity measurements were collected from highways with known traffic for a known range of time (age). Other factors such as rainfall and snow were not monitored or simulated so as to be eligible for regression analysis.

From the regression analysis, three components were obtained:

- Regression statistics table, from which coefficient of determination was obtained, which indicates the overall goodness-of-fit measures
- Analysis of variances (ANOVA) table, from which p-value was obtained for the overall test of significance of the regression parameters
- Regression coefficients table, from which the model coefficients were obtained along with their individual p-values for testing the hypothesis of zero slope coefficient (test of statistical significance)

In creating models, the following criteria are taken into account:

- Number of observations (>30)
- Coefficient of determination, R^2 (at least 25%)
- Hypothesis tests (p-value) have to indicate statistical significance of regression coefficients.

After verification, the models generated from this study could be used in management of the pavement marking, specifically paints and thermoplastics, as they can be used to predict retroreflectivity values for a particular range of time. Due to that, these models could be useful in making scientific decisions for repainting frequency of the pavement markings with respect to traffic.

More information about regression analysis, output generation and interpretation of output parameters is explained in chapter 4.

CHAPTER 4

DATA ANALYSIS AND RESULTS

Retroreflectivity data collection was performed on selected locations (sites) on highways in the state of Tennessee. As explained in section 3.5, the data collection was performed approximately every 45 days for a period of two years. Data analysis was performed using regression analysis method, using Microsoft Excel Data Analysis tool. Data exploration was accomplished via 3D scatter plots generated using Minitab software. A visual representation of the fitted regression model was shown by generating a response function surface plot (plane) also using Minitab.

In the regression analysis, the following factors were considered in generating predictive models: traffic, pavement marking age, pavement marking material type and color.
Though the analysis was performed without taking into account any category other than color (white and yellow) and type (paints and thermoplastics), the traffic was further categorized into for groups as follows:

- AADT less than 5,000 vehicles per day (vpd)
- AADT between 5,000 vpd and 10,000 vpd
- AADT between 10,000 vpd and 20,000 vpd
- AADT more than 20,000 vpd.

Pavement age represents the age (in days) of the pavement marking from the pavement marking application to the date of data collection. Pavement marking types considered for

analysis were thermoplastic and paint, and colors are white and yellow. The regression analysis was used for the data analysis and development of the pavement marking retroreflectivity prediction models.

4.1 Data Analysis

Multiple linear regression statistical analysis method was used for data analysis and model development. This analysis method is briefly explained in Appendix A. Section 4.2 presents a typical data analysis using data collected on selected locations for traffic less than 5,000 vpd, white and yellow pavement marking color and paint (pavement marking material type). The rest of the analysis with different types of pavement marking materials, color and traffic (AADT) are briefly explained in section 4.3 and listed in the appendix B.

4.2 Paints with AADT below 5,000 vpd

The sample analysis was performed on selected sites with paint pavement markings having AADT less than 5,000 vpd. Section 4.2.1 and 4.2.2 comprise of the analysis of white and yellow pavement markings respectively.

4.2.1 White Paints with AADT below 5,000 vpd

This section presents the analysis performed on data collected from highways comprising white pavement markings. Figure 4.1 presents the collected data in 3D (cubical) scatterplot of retroreflectivity values against age and AADT for white paints with AADT below 5,000 vpd.

From Figure 4.1, the data trend indicates a linear relationship with retroreflectivity decreasing with increase in pavement marking age and AADT. This influenced the decision of using a linear model. Otherwise the model could have been, quadratic, or exponential. Hence a linear relationship model was considered as it is more likely to reflect the trend in pavement marking deterioration. The 3D surface plot (Figure 4.2) shows the deterioration trend more clearly.

With this data, regression analysis was performed and the results obtained are presented in Table 4.1. As it can be seen in the table, this data had 97 observations with coefficient of determination (R^2) of 0.45 and adjusted R^2 of 0.44. The regression analysis used a confidence level of 95%.

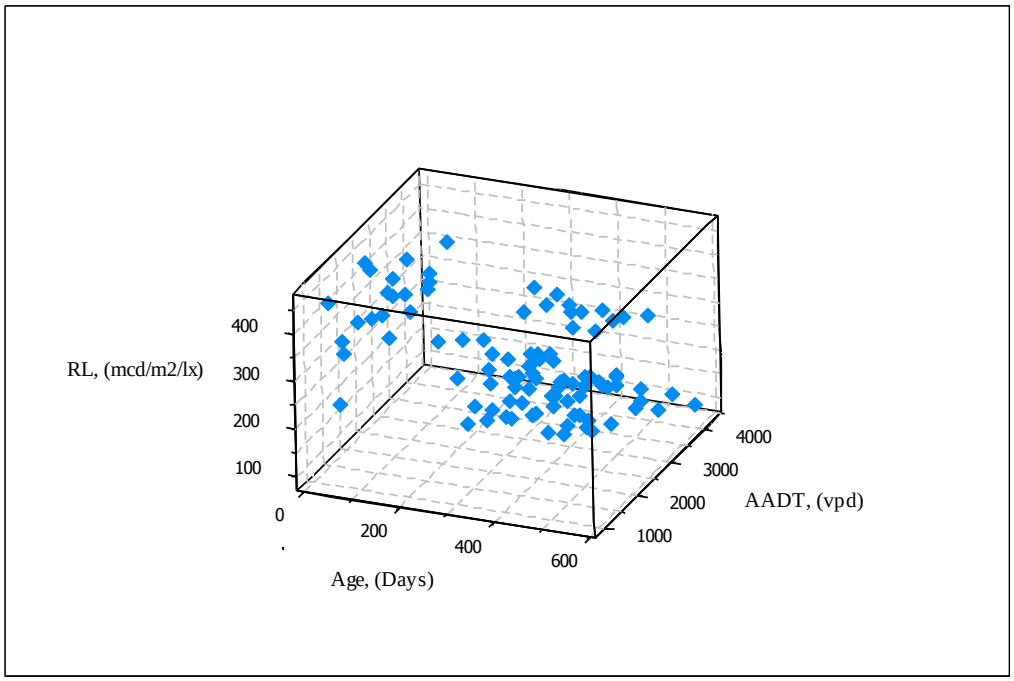


Figure 4.1 Scatter Plot, R_L vs Age vs AADT for White Paints with AADT below 5,000 vpd

The output of the regression analysis for white paints with AADT less than 5,000 vpd has three components:

- Regression statistics table for the determination of R^2 as shown in Table 4.1
- Table of analysis of variance (ANOVA) for null hypothesis analysis is depicted in Table 4.2; and
- Regression coefficients table (Table 4.2), which provides the model coefficients.

Table 4.1 Regression Statistics Output

		Explanation
Multiple R	0.672449	R = square root of R^2
R^2	0.452187	R^2 known as coefficient of determination
Adjusted R Square	0.440532	Adjusted R^2 used if more than one x variable
Standard Error	58.68803	This is the sample estimate of the standard deviation of the error u
Observations	97	Number of times data was collected for number of sites (n)

Table 4.2 Analysis of Variance (ANOVA) Output

	df	SS	MS	F	Significance F
Regression	2	267247	133623.5	38.79572	5.2E-13
Residual	94	323762.7	3444.285		
Total (n)	96	591009.8			

Table 4.3 Regression Coefficients Output

	Coefficient	St. error	t-Stat	P-value	Lower 95%	Upper 95%
Intercept	442.1558	20.20514	21.88333	1.15E-38	402.038	482.2736
Age	-0.25948	0.036495	-7.11	2.24E-10	-0.33194	-0.18702
Traffic, AADT	-0.03189	0.005595	-5.70002	1.37E-07	-0.043	-0.02078

If β_j denotes the population coefficient of the jth regressor (intercept, age and AADT), then a summary of the output in Tables 4.1-4.3, results in equation 4.1 which is the linear model for white paints, with AADT below 5,000 vpd:

$$R_L = 442.16 - 0.2595*(Age) - 0.0319*(AADT) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

4.2.1.1 Test of Statistical Significance

From Table 4.3 it can be seen that the coefficient of age (x_1) has a value of – 0.2595 with estimated standard error of 0.036495, t-statistic of -7.11 and p-value of 2.24E-10 < 0.05. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05. Otherwise it could be insignificant.

The coefficient of AADT (x_2) has a value of – 0.0319 with estimated standard error of 0.005595, t-statistic of -5.70002 and p-value of 1.37E-07. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05. Otherwise it could be insignificant.

Test H0: $\beta_1 = 0$ and $\beta_2 = 0$ versus Ha: at least one of β_2 and β_3 does not equal zero.

From the ANOVA table the F-test statistic is 38.79572 with p-value of 5.2E-13. Since the p-value is less than 0.05, then we reject the null hypothesis that the regression parameters are zero at significance level 0.05 and conclude that age and AADT are statistically

significant at significance level 0.05. Otherwise we could not reject the null hypothesis, and the parameters (age and AADT) could be statistically insignificant. Therefore age and AADT are contributing factors to the deterioration of pavement marking retroreflectivity.

4.2.1.2 Plots of Regression Model, Collected Data and Residuals

This section presents plots and graphs generated after data analysis to include: 3D predictive model surface plot; and 2D plot of the residual. Figure 4.2 presents the 3D surface plot of retroreflectivity values against age and AADT for the generated model (equation 4.1) of white paints with AADT below 5,000 vpd. The plot indicates that, in general, pavement marking retroreflectivity decreases with increase in age and/or AADT.

The predictive surface plot in Figure 4.2, shows the graphic image of the generated model, equation 4.1. It presents the relationship between retroreflectivity values and age and traffic (AADT) of the white paints pavement markings with AADT below 5,000 vpd. It can be observed that at any constant AADT, the retroreflectivity values decrease with the increase in pavement marking age. This means that, for the given asphalt highway, with known AADT, the deterioration of its white paint makings retroreflectivity is proportional to the age of the markings.

From the surface plot in Figure 4.2, it can also be observed that at any constant age, the retroreflectivity values decrease with the increase in traffic (AADT). In a practical use, it can be explained that, there is a decrease in white paints retroreflectivity of a given highway, at a given time, if there is an increase in traffic volume.

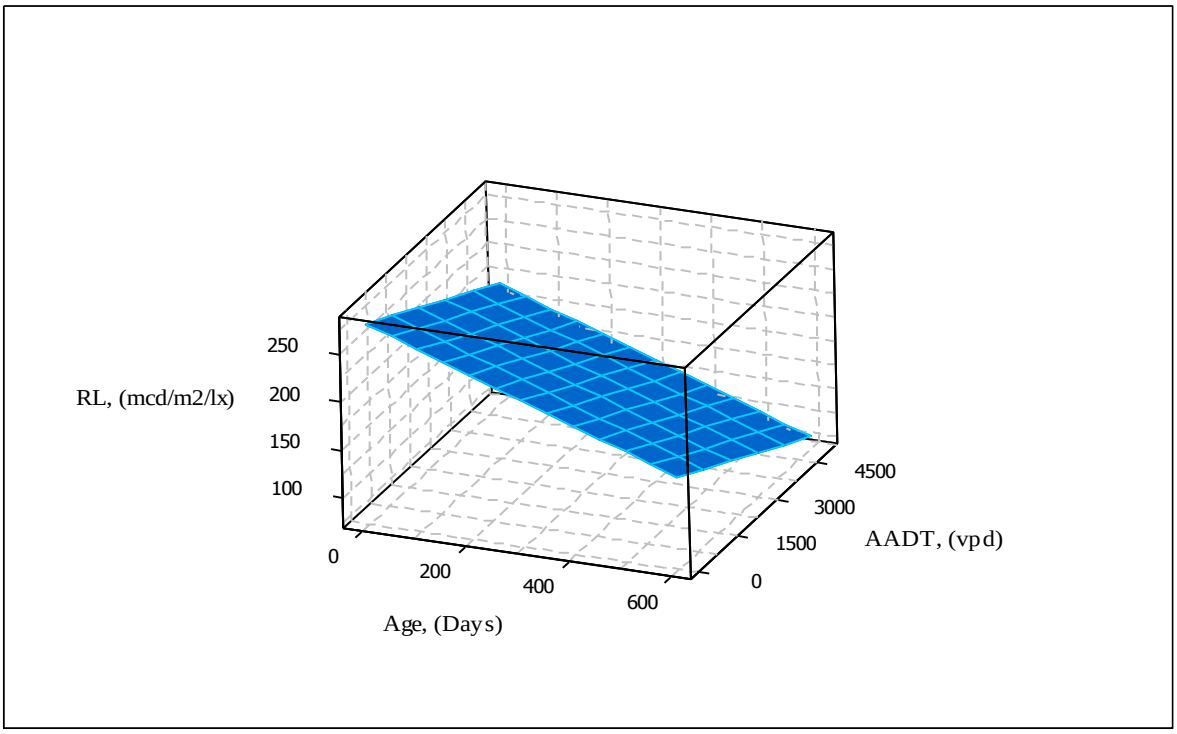


Figure 4.2 Surface Plot, R_L vs Age vs AADT for White Paints with AADT below 5,000 vpd

Generally, it can be observed in Figure 4.2 that retroreflectivity is inversely proportional to age and AADT. That is, there is a decrease in retroreflectivity values as age and traffic increase.

Three residual plots for retroreflectivity (R_L) residuals against retroreflectivity fitted values obtained from the model, age and AADT are also presented in 2D, so as to observe the adequacy of the generated model (Figures 4.3, 4.4 and 4.5).

Residual (or error, or deviation) is the difference between the observed value y* of the dependent variable for the jth experimental data point (x_{1j}, x_{2j}, …, …, …, x_{pj}, y_j*) and the corresponding value y_j given by the regression function (model) $y_j = b_0 + b_1*x_{1j} + b_2*x_{2j} + \ldots\ldots + b_p*x_{pj}$. (e. g $R_L = 442.16 – 0.2595*Age – 0.0319*AADT$, in this case)

Parameters b (b_0, b_1, b_2, ……., b_p) are coefficients obtained from the regression analysis table as discussed before. The residual is given by, $r_j = y_j^* - y_j$.

If there is an obvious correlation between the residuals and the fitted values or independent variable x (say, residuals systematically increase with increasing x), it means that the chosen model is not adequate to fit the experiment (may need to add an extra term x_3, for other factors to our model). A plot of residuals is very helpful in detecting such a correlation. Figure 4.3 presents retroreflectivity residuals against retroreflectivity fitted values obtained from the model. Figures 4.4 and 4.5, depict plots of retroreflectivity residuals against age and AADT respectively, for this traffic category.

It can be observed from Figure 4.3 that there is no obvious correlation between the residuals and the fitted value generated from the model. This means that the chosen model is adequate to fit the experiment.

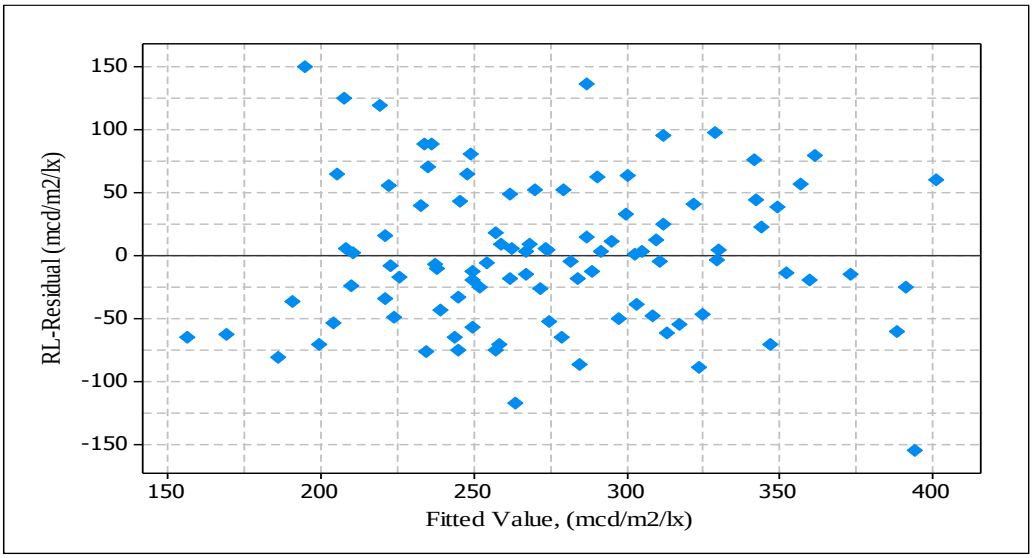


Figure 4.3 R_L-Residuals against Fitted Values for White Paints with AADT below 5,000 vpd

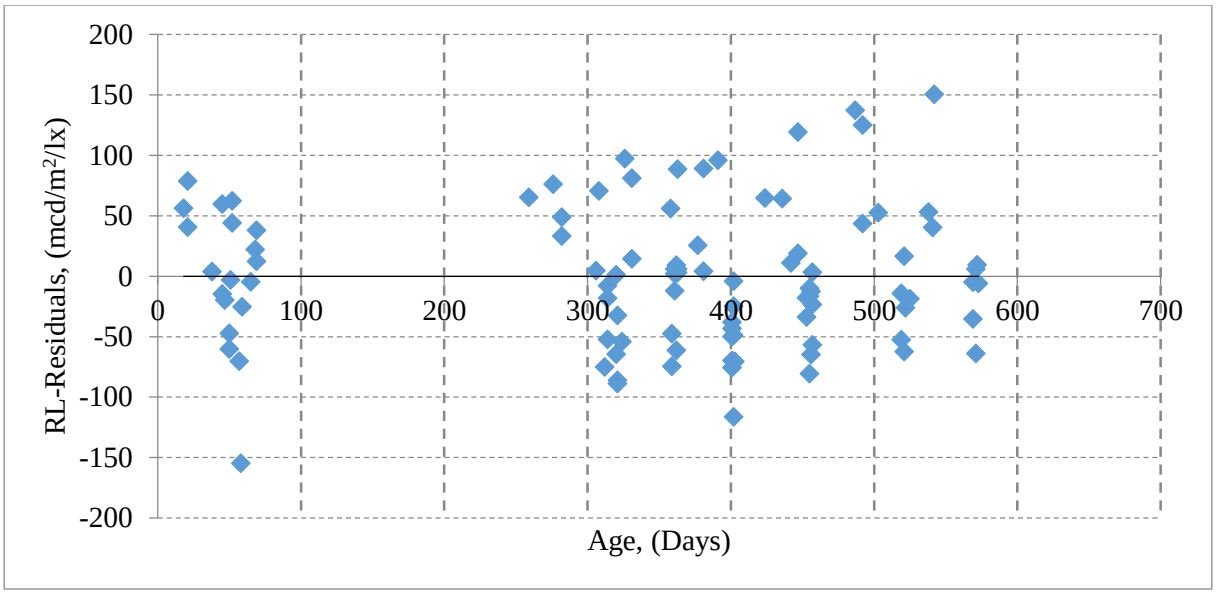


Figure 4.4 R_L-Residuals against Age for White Paints with AADT below 5,000 vpd

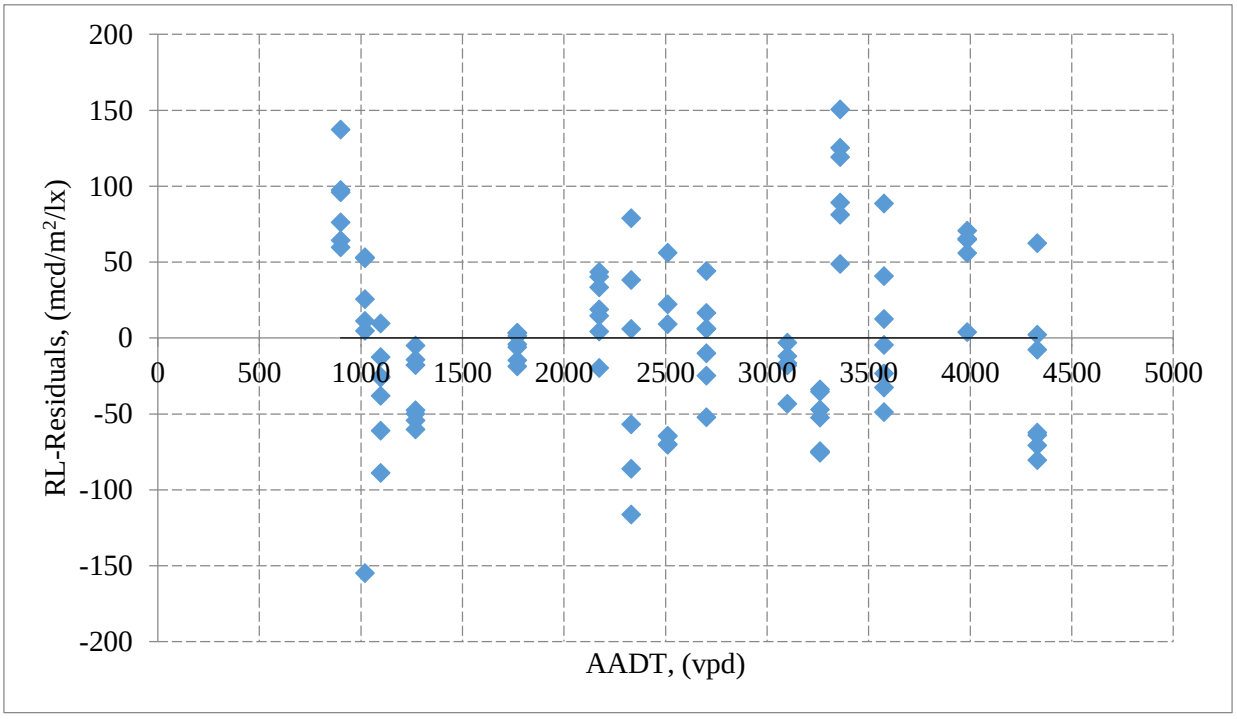


Figure 4.5 R_L-Residuals against AADT for White Paints with AADT below 5,000 vpd

Generally, the fact that all the residuals look random and that there is no obvious correlation (pattern) with the fitted values, age and AADT, does not necessarily mean that by itself the model is adequate. This is considered with other parameters such as R^2 and a p-value test. Since these have already been considered, it can be concluded that the model is adequate. Therefore, the model (equation 4.1) generated under this category, can be considered in management of pavement markings of the same category (white paints with AADT < 5,000 vpd).

4.2.2 Yellow Paints with AADT below 5,000 vpd

The analysis was performed on selected sites having yellow pavement markings and with AADT less than 5,000 vpd. Figure 4.6 presents the collected data in 3D (cubical) scatterplot of retroreflectivity values against age and AADT for yellow paints with AADT below 5,000 vpd.

From Figure 4.6, the data trend indicates a linear relationship with retroreflectivity decreasing with increase in pavement marking age and AADT. This influenced the decision of using a linear model. Otherwise the model could have been, quadratic, or exponential. Hence a linear relationship model was considered as it is more likely to reflect the trend in pavement marking deterioration. The 3D surface plot (Figure 4.7) shows the deterioration trend more clearly.

Under this category, there are 99 observations with coefficient of determination (R^2) of 0.38 that means 38% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

From analysis of variance, significance F = p-value = 1.02E-10 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is a relation between the two variables. That is, we reject the null hypothesis that age and AADT are zero at significance level 0.05. The variables (age and AADT) are jointly statistically significant

at significance level 0.05. From the regression coefficient table, age coefficient has an estimated p-value of 3.44E-10. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05. Otherwise it could be insignificant. AADT coefficient has an estimated p-value of 0.00047. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05. Therefore, age and AADT are contributing to the deterioration of pavement marking retroreflectivity.

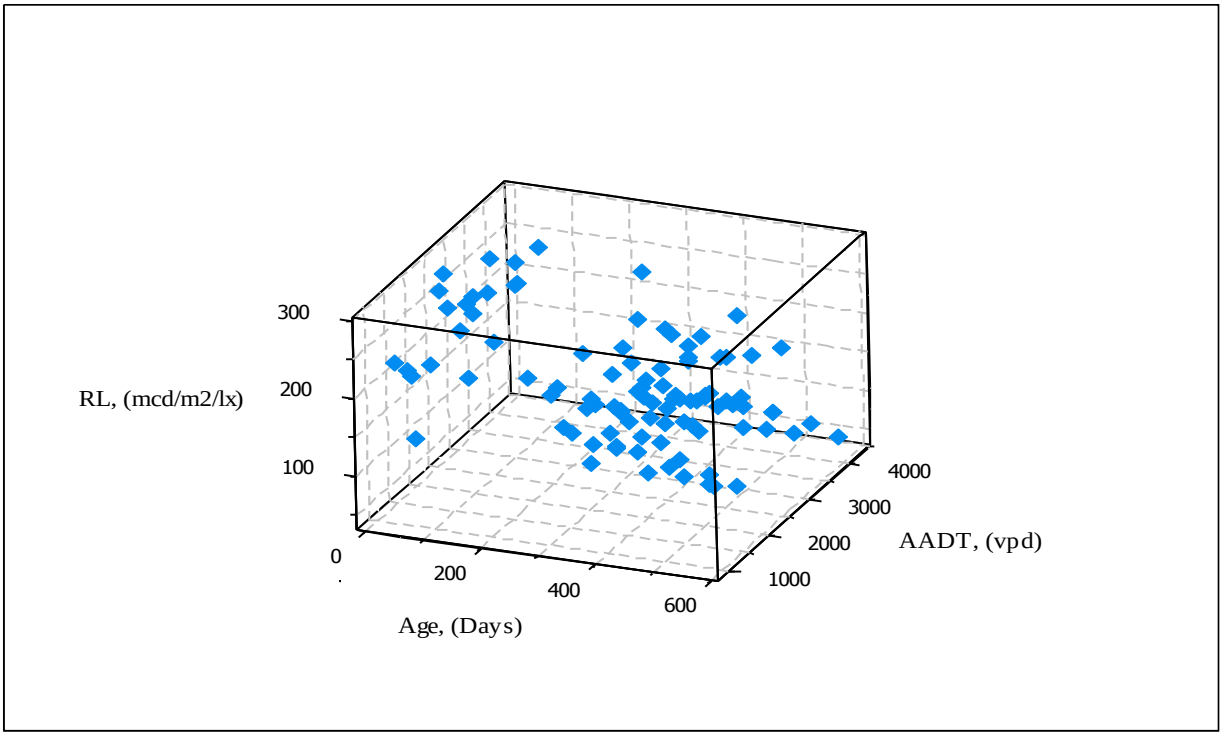


Figure 4.6 Scatter Plot, R_L vs Age vs AADT for Yellow Paints with AADT below 5,000 vpd

A summary of the output results in the following fitted line which is the linear model for yellow paints, with AADT below 5,000 vpd:

$$R_L = 269.85 - 0.1859*(Age) - 0.0148*(AADT) \qquad \ldots\ldots\ldots\ldots (4.2)$$

Figure 4.7 presents a 3D (cubical) surface plot, which is plotted from the generated model, equation 4.2, for yellow paints with AADT below 5,000 vpd. It shows the graphic image of the generated model. This Figure presents the relationship between retroreflectivity values and age and AADT of the yellow paints pavement markings with AADT below 5,000 vpd.

It can be observed that at any constant AADT, the retroreflectivity values decrease with the increase in pavement marking age. This means that, for the given highway, with known AADT, the deterioration of its yellow paint makings is proportional to the age of the markings.

The surface plot in Figure 4.7 is generated from the model, equation 4.2. It presents the relationship between retroreflectivity against age and AADT of the yellow paint pavement markings with AADT below 5,000 vpd. It can be observed that at any constant age, the retroreflectivity values decrease with the increase in traffic (AADT). In a practical use, it can be explained that, there is a decrease in yellow paints retroreflectivity of a given highway, at a given time, if there is an increase in traffic volume.

Generally, it can be observed from Figure 4.7 that retroreflectivity is inversely proportional to age and AADT for the yellow marking under this traffic category. That is, there is a decrease in retroreflectivity values as age and traffic increase.

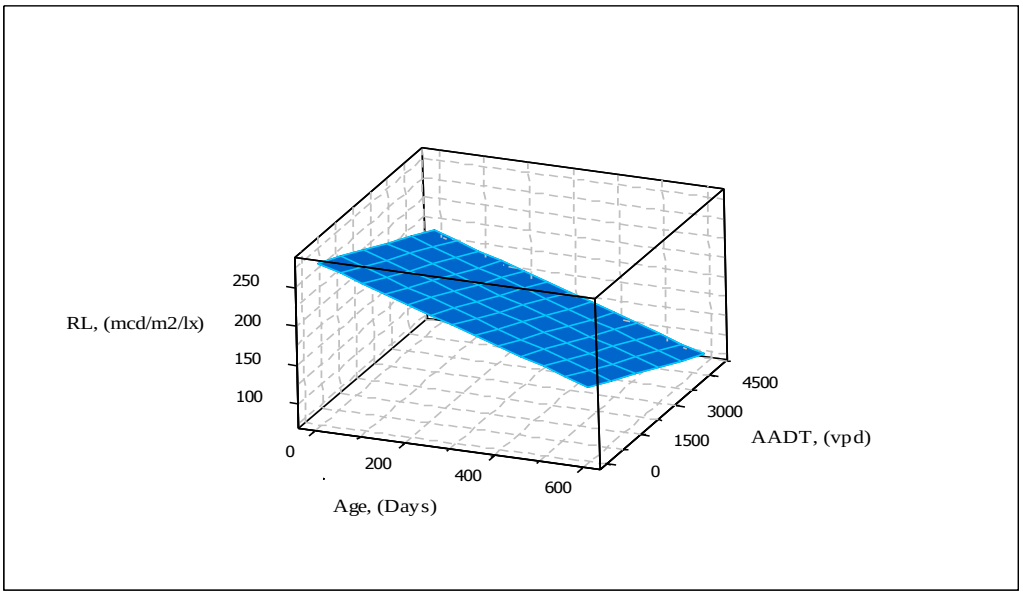


Figure 4.7 Surface Plot, R_L vs Age vs AADT for Yellow Paints with AADT below 5,000 vpd

Figure 4.8 presents retroreflectivity residuals against retroreflectivity fitted values obtained from the model. Figures 4.9 and 4.10, depict plots of retroreflectivity residuals against age and AADT respectively, for this traffic category.

It can be observed from Figure 4.8 that there is no obvious correlation between the residuals and the fitted value generated from the model. This means that the generated model is adequate to fit the experiment.

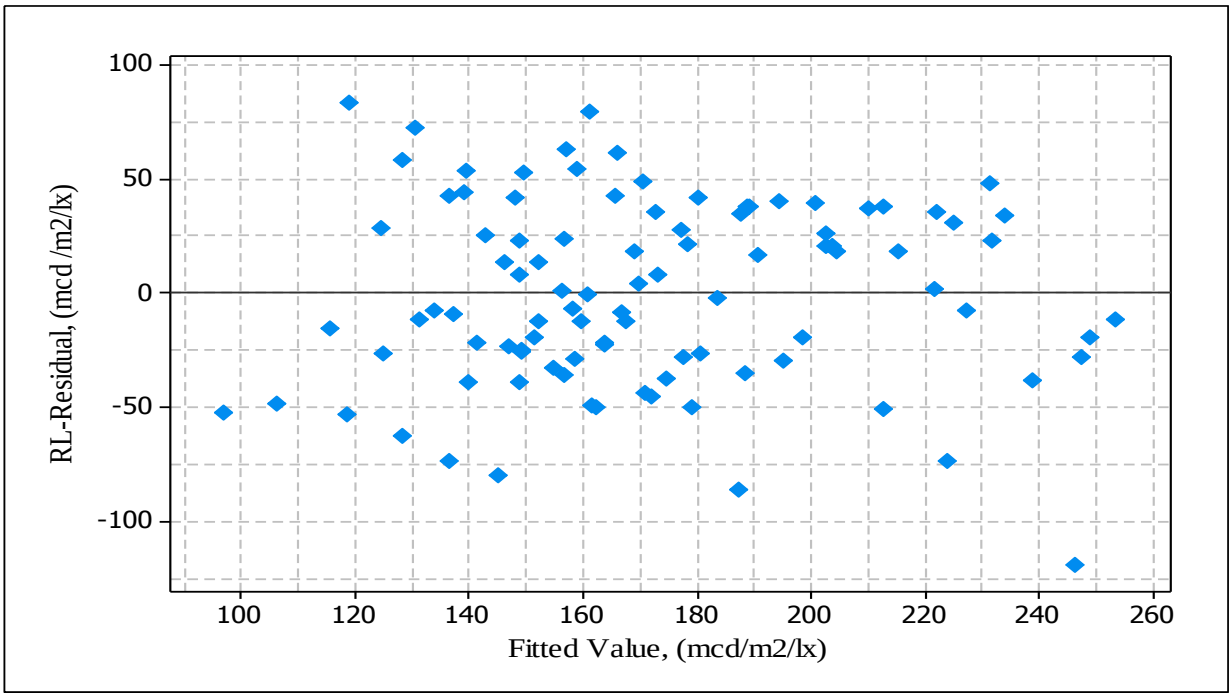


Figure 4.8 R_L-Residuals against Fitted Values for Yellow Paints with AADT below 5,000 vpd

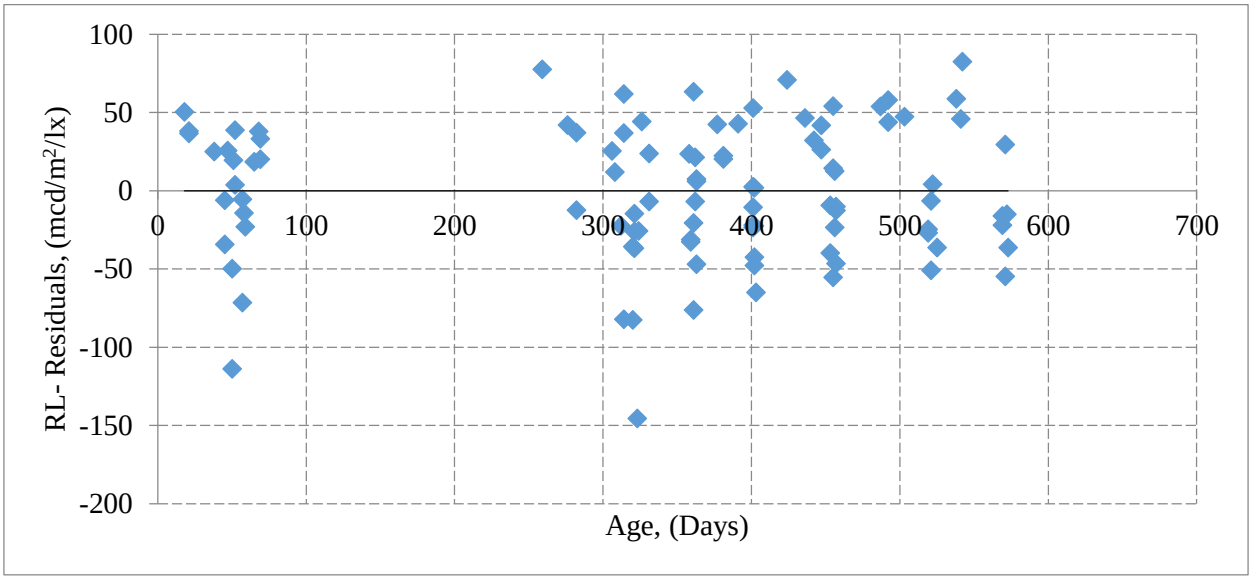


Figure 4.9 R_L-Residuals against Age for Yellow Paints with AADT below 5,000 vpd

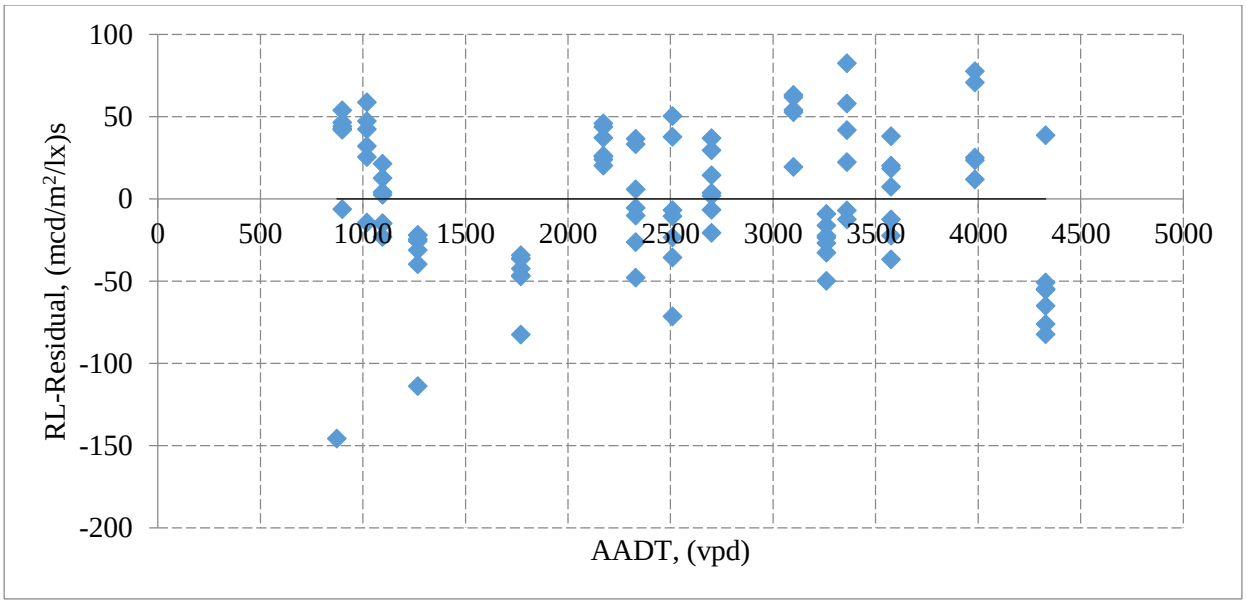


Figure 4.10 R_L-Residuals against AADT for Yellow Paints with AADT below 5,000 vpd

4.3 Analysis of other AADT Categories

The same analysis was performed on other traffic categories listed at the beginning of this chapter, and the analysis for each category is performed in the same way as in section 4.2. The 3D scatter plot, predictive model surface plot, and residual 2D plots, for every generated model, which qualify the criteria explained in section 3.6, are plotted.

4.3.1 White Paints with AADT between 5,000 and 10,000 vpd

The analysis was performed on selected sites having white paints pavement markings and with AADT between 5,000 and 10,000 vpd. Under this category, there are 52 observations with coefficient of determination (R^2) of 0.316, which means 31.6% of retroreflectivity (R_L) is explained by the regressors (age and AADT). Significance F = p-value = 9.2E-05 < 0.05. Then

we reject the null hypothesis that the two variables (age and AADT) are unrelated. From the regression coefficient table, age coefficient has an estimated p-value of 1.89E-05. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05. AADT coefficient has an estimated p-value of 0.53. It is therefore statistically insignificant at significance level $\alpha = 0.05$ as p-value > 0.05. Therefore, AADT is not contributing to the deterioration of pavement marking retroreflectivity under this traffic category.

4.3.2 Yellow Paints with AADT between 5,000 and 10,000 vpd

The analysis was performed on selected sites having yellow paints pavement markings and with AADT between 5,000 and 10,000 vpd.

Figure 4.11 presents the collected data in 3D scatterplot of retroreflectivity values against age and AADT for yellow paints with AADT between 5,000 and 10,000 vpd.

From Figure 4.11, the data trend indicates a linear relationship with retroreflectivity decreasing with increase in pavement marking age, and retroreflectivity increasing with increase in AADT. This also influenced the decision of using a linear model, although the trends are somehow different from the previous models (Equations 4.1 and 4.2). Since the trend is neither quadratic nor exponential, a linear relationship model was considered as it is more likely to reflect the trend in pavement marking deterioration. The 3D surface plot (Figure 4.12) shows the deterioration trend more clearly. More discussion about the trends on this model is made on chapter 5.

Under this category, there are 52 observations with coefficient of determination (R^2) of 0.46, which means 46% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

Significance F = p-value = 2.5E-07 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is a relation between the two variables at significance level 0.05.

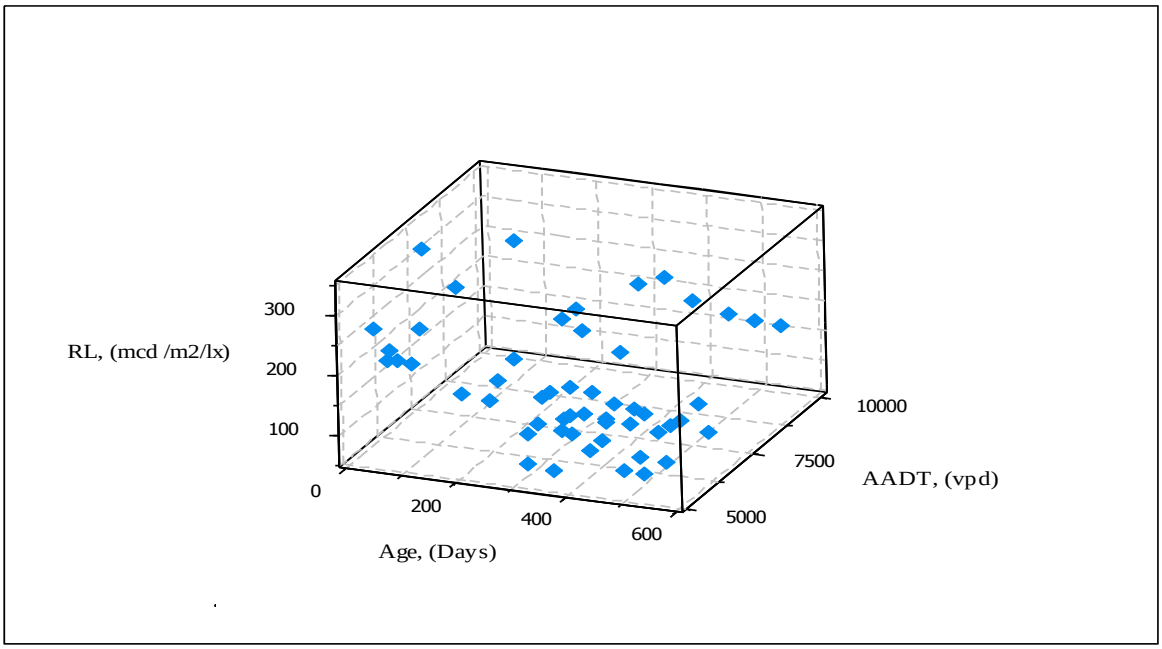


Figure 4.11 Scatter Plot of R_L vs Age vs AADT for Yellow Paints with AADT between 5,000 and 10,000 vpd

From regression coefficient table, age coefficient has an estimated p-value of 3.13E-07. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05. AADT coefficient has an estimated p-value of 0.02155. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05.

Therefore age and AADT are contributing to the deterioration of pavement marking retroreflectivity.

A summary of the output results in the following fitted line which is the linear model for yellow paints, with AADT between 5,000 and 10,000 vpd:

$$R_L = 186.92 - 0.2206*(Age) + 0.0089*(AADT) \quad \text{……..…….……} \quad (4.3)$$

Figure 4.12 presents the 3D (cubical) surface plot, which plotted from the generated model, equation 4.3, for yellow paints with AADT between 5,000 and 10,000 vpd. It indicates the graphical presentation of the generated model, equation 4.3. It shows the relationship between retroreflectivity against age and traffic (AADT) of the yellow paints pavement markings with AADT between 5,000 and 10,000 vpd.

It can be observed that at any constant AADT, the retroreflectivity values decrease with the increase in pavement marking age. This means that, for the given highway, with known AADT, the retroreflectivity deterioration of its yellow paint makings is proportional to the age of the markings.

The surface plot in Figure 4.12 is generated from the model, equation 4.3. It presents the relationship between retroreflectivity measurements, age and AADT of the yellow paint markings with AADT between 5,000 and 10,000 vpd. It can be observed that at any constant age, the retroreflectivity values increase with the increase in traffic volume.

Generally, it can be observed from Figure 4.12 that there is a decrease in retroreflectivity values as age and traffic increase.

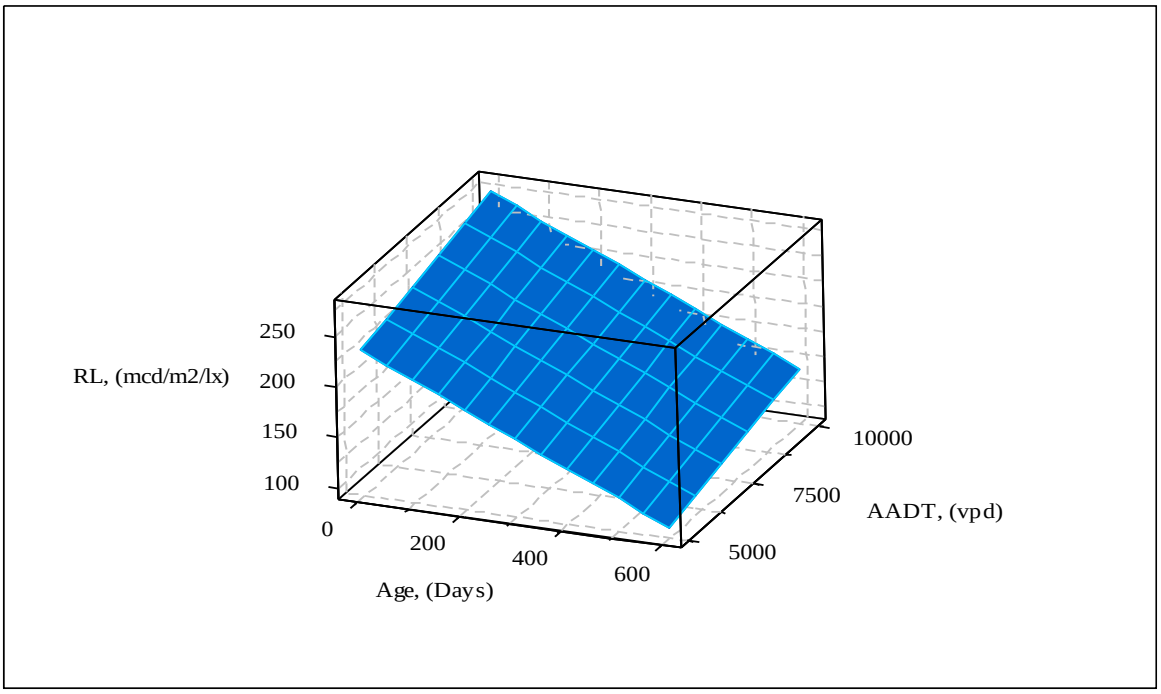


Figure 4.12 Surface Plot, R_L vs Age vs AADT for Yellow Paints with AADT between 5,000 and 10,000 vpd

Figure 4.13 presents retroreflectivity residuals against retroreflectivity fitted values obtained from the model, equation 4.3. Figures 4.14 and 4.15 depict plots of retroreflectivity residuals against age and AADT respectively, for this traffic category.

It can be observed from Figure 4.13 that there is no obvious correlation (pattern) between the residuals and the fitted value generated from the model. This means that the generated model is adequate to fit the experiment.

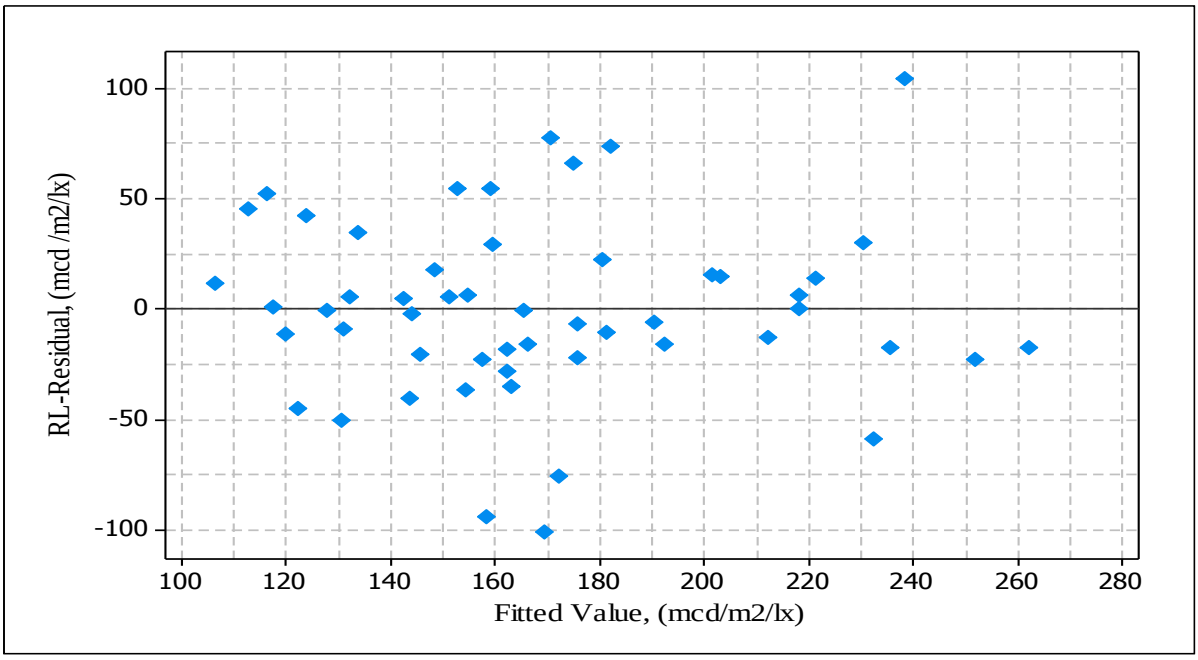


Figure 4.13 R_L-Residuals against Fitted Values for Yellow Paints with AADT between 5,000 and 10,000 vpd

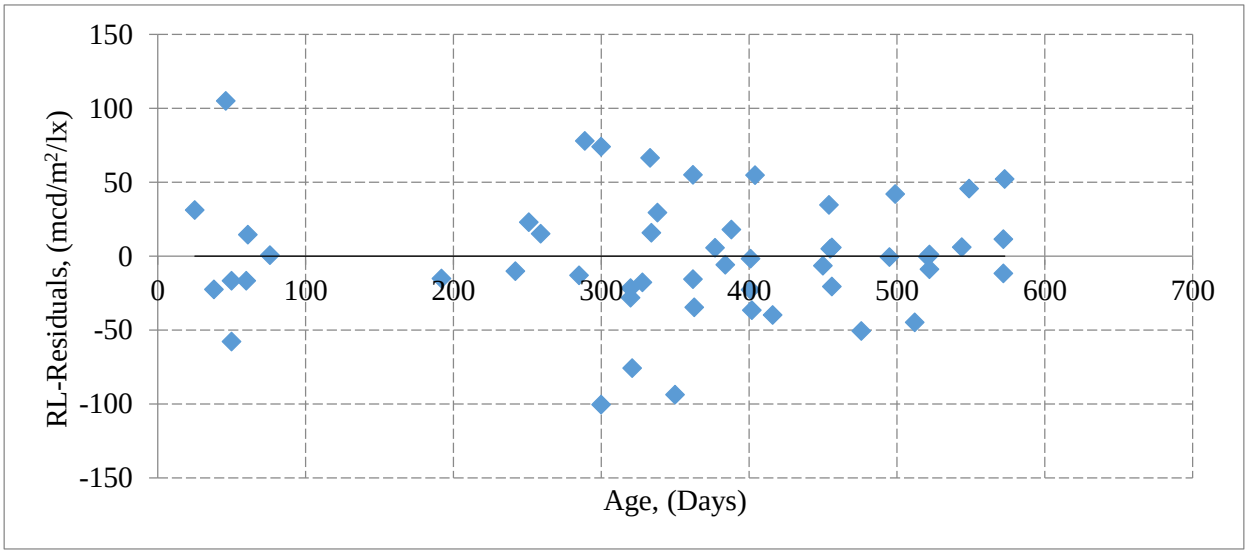


Figure 4.14 R_L-Residuals against Age for Yellow Paints with AADT between 5,000 and 10,000 vpd

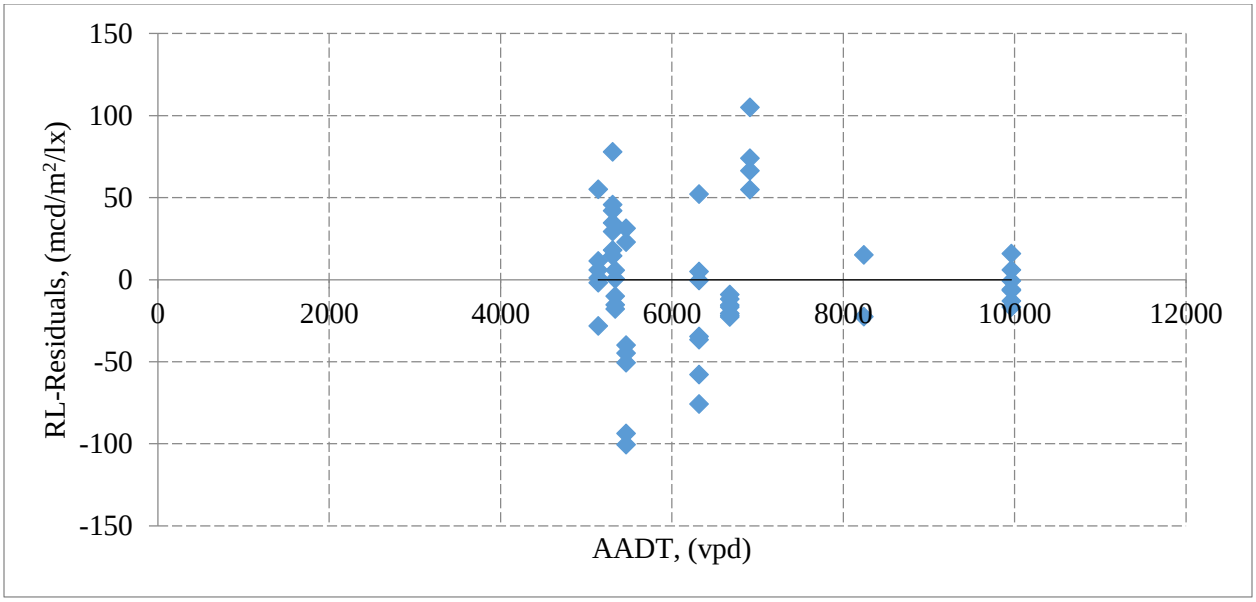


Figure 4.15 R_L-Residuals against AADT for Yellow Paints with AADT between 5,000 and 10,000 vpd

4.3.3 White Paints with AADT between 10,000 and 20,000 vpd

The analysis was performed on selected sites having white paints pavement markings and with AADT between 10,000 and 20,000 vpd. There are 10 observations with coefficient of determination (R^2) of 0.82, which means 82% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

Significance F = p-value = 0.002 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is a relation between the two variables at significance level 0.05. The parameters are jointly statistical significance at significance level 0.05.

Age coefficient has estimated p-value of 0.27 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$. AADT coefficient has an estimated p-value of 0.001 < 0.05 It is therefore statistically significant at significance level $\alpha = 0.05$.

Therefore, age is not contributing to the deterioration of pavement marking retroreflectivity, though AADT is contributing. Also, under this category, data are not sufficient to create a model as there are only 10 observations. There should be at least 30 observations (to represent a statistical population) that could be used to create the model. Hence, model was not created.

4.3.4 Yellow Paints with AADT between 10,000 and 20,000 vpd

The analysis was performed on selected sites having yellow paints pavement markings and with AADT between 10,000 and 20,000 vpd. There are 10 observations with coefficient of determination (R^2) of 0.49, which means 49% of retroreflectivity (R_L) is explained by the regressors (Age and AADT).

Significance F = p-value = 0.09 > 0.05. Then we do not reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is no relation between the two variables, age and AADT, at significance level 0.05. Age coefficient has an estimated p-value of 0.11 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$. AADT coefficient has an estimated p-value of 0.22 > 0.05 It is therefore statistically insignificant at significance level $\alpha = 0.05$

Therefore, age and AADT are not contributing to the deterioration of pavement marking retroreflectivity under this category.

4.3.5 White Paints Analysis (all locations)

The analysis was performed on all selected sites having white paints pavement markings. There are 161 observations with coefficient of determination (R^2) of 0.33, which means 33% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

Figure 4.16 presents the collected data in 3D (cubical) scatterplot of retroreflectivity values against age and AADT for white paints.

From Figure 4.16, the data trend indicates a linear relationship with retroreflectivity decreasing with increase in pavement marking age and AADT. This influenced the decision of using a linear model. Otherwise the model could have been, quadratic, or exponential. Hence a linear relationship model was considered as it is more likely to reflect the trend in pavement marking deterioration. The 3D surface plot (Figure 4.17) shows the deterioration trend more clearly.

Significance F = p-value = 1.8E-14 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is a relation between the two variables at significance level 0.05. Age and AADT are jointly statistically significant at significance level 0.05. Age coefficient has estimated p-value of 1.04E-14 < 0.05. It is therefore statistically significant at significance level $\alpha = 0.05$. AADT coefficient has estimated p-value of 0.003 < 0.05 It is therefore statistically significant at significance level $\alpha = 0.05$

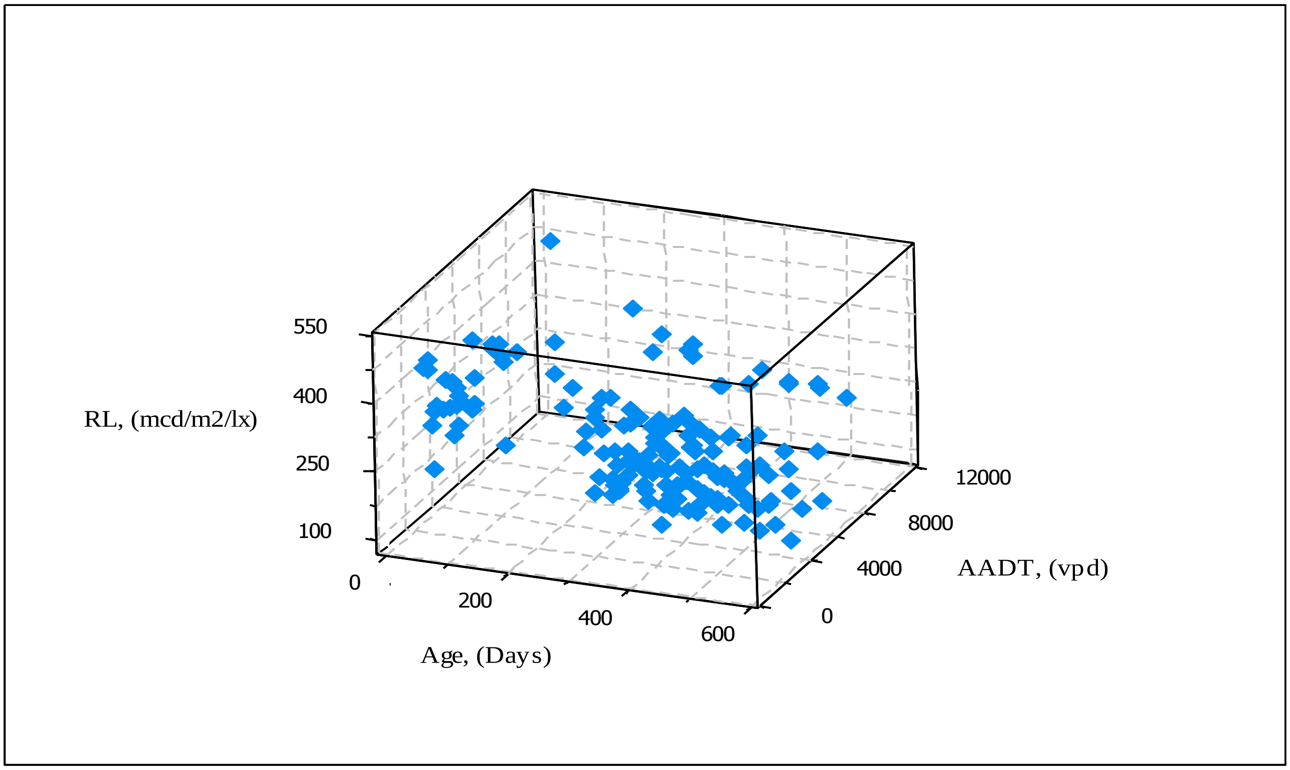


Figure 4.16 Scatter Plot, R_L vs Age vs AADT for White Paints

Therefore, age and AADT are contributing to the deterioration of white paints pavement marking retroreflectivity, and the following fitted line is the linear model for white paints on asphalt surface:

$$R_L = 383.105 - 0.2737*(Age) - 0.0056*(AADT) \quad \text{………………………..……. (4.4)}$$

Figure 4.17 presents the 3D surface plot, which plotted from the generated model, equation 4.4 for white paints. It is the graphical presentation of the generated model.

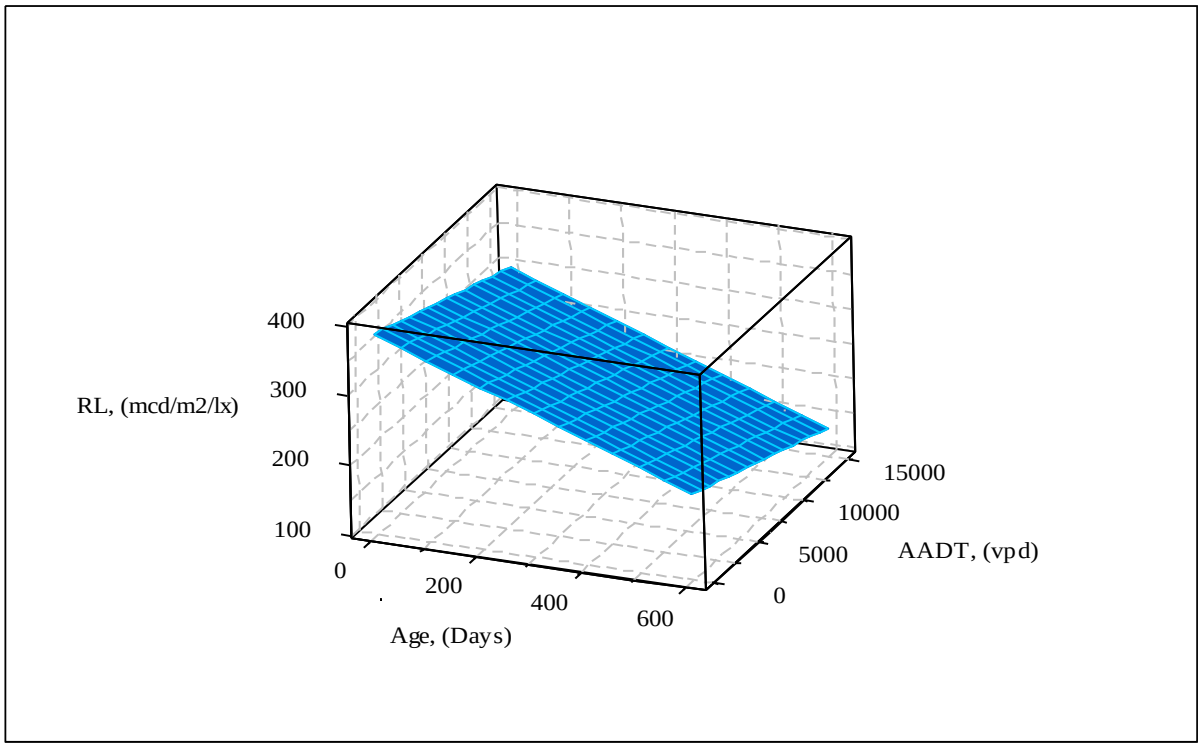


Figure 4.17 Surface Plot, R_L vs Age vs AADT for White Paints

The surface plot in Figure 4.17 indicates the graphic image of the generated model, equation 4.4. It presents the relationship between retroreflectivity values against age and traffic (AADT) of the white paint pavement markings.

It can be observed that at any constant AADT, the retroreflectivity values decrease with the increase in pavement marking age. This means that, with the given highway, with known AADT, the retroreflectivity deterioration of its white paint makings is proportional to the age of the markings.

It can be observed in Figure 4.17 that at any constant age, the retroreflectivity values decrease with the increase in traffic volume (AADT). In a practical use, it can be explained that,

there is a decrease in white paints retroreflectivity of a given highway, at a given time, if there is an increase in traffic volume.

Generally, it can be revealed in Figure 4.17 that retroreflectivity is inversely proportional to age and AADT. That is, there is a decrease in retroreflectivity values of white paint markings as age and traffic increase.

Figure 4.18 presents retroreflectivity residuals against retroreflectivity fitted values obtained from the model. Figures 4.19 and 4.20 depict plots of retroreflectivity residuals against age and AADT respectively, for this traffic category.

It can be observed in Figure 4.18 that there is no obvious correlation between the residuals and the fitted value generated from the model. This means that the chosen model is adequate to fit the experiment.

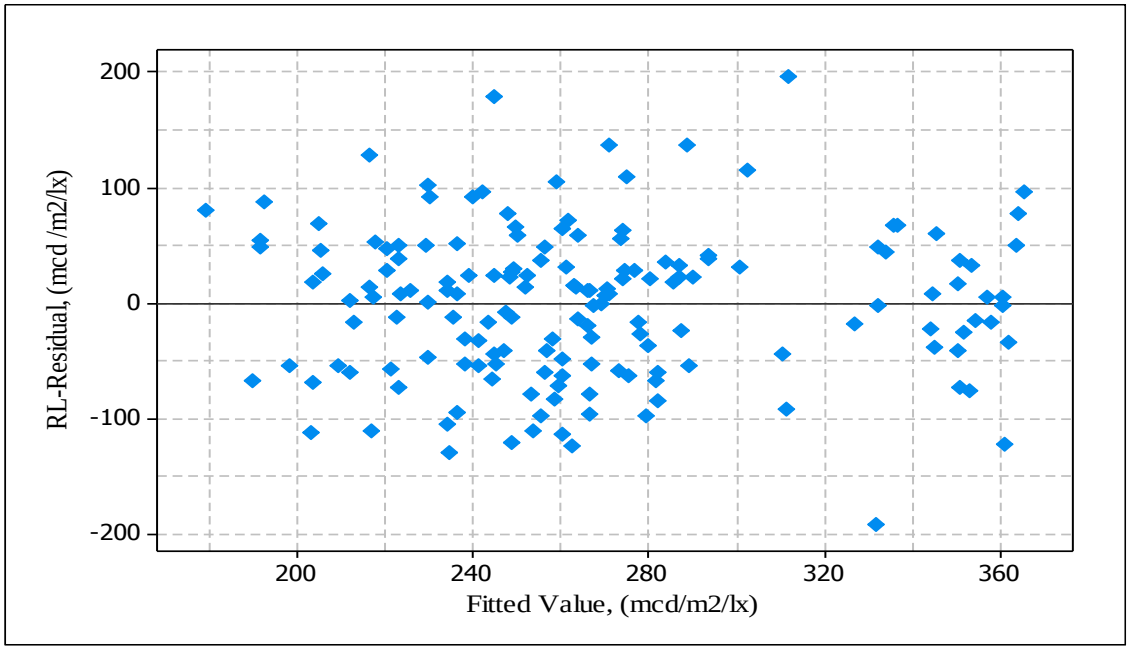


Figure 4.18 R_L-Residuals against Fitted Values for White Paints

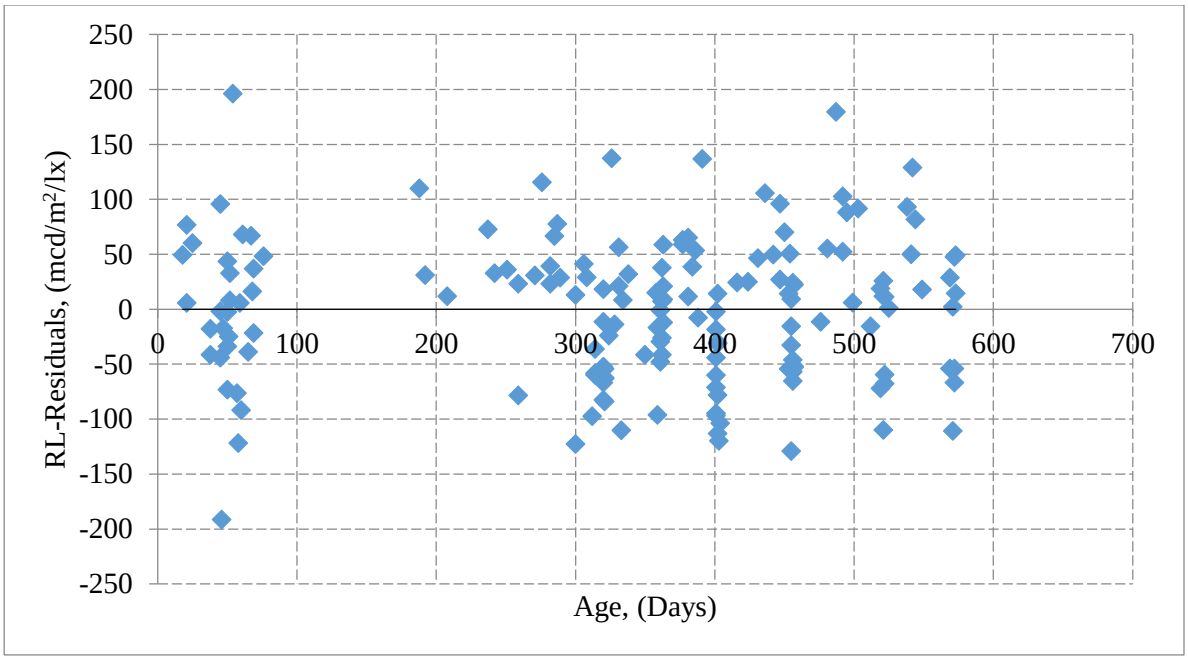


Figure 4.19 R_L-Residuals against Age for White Paints

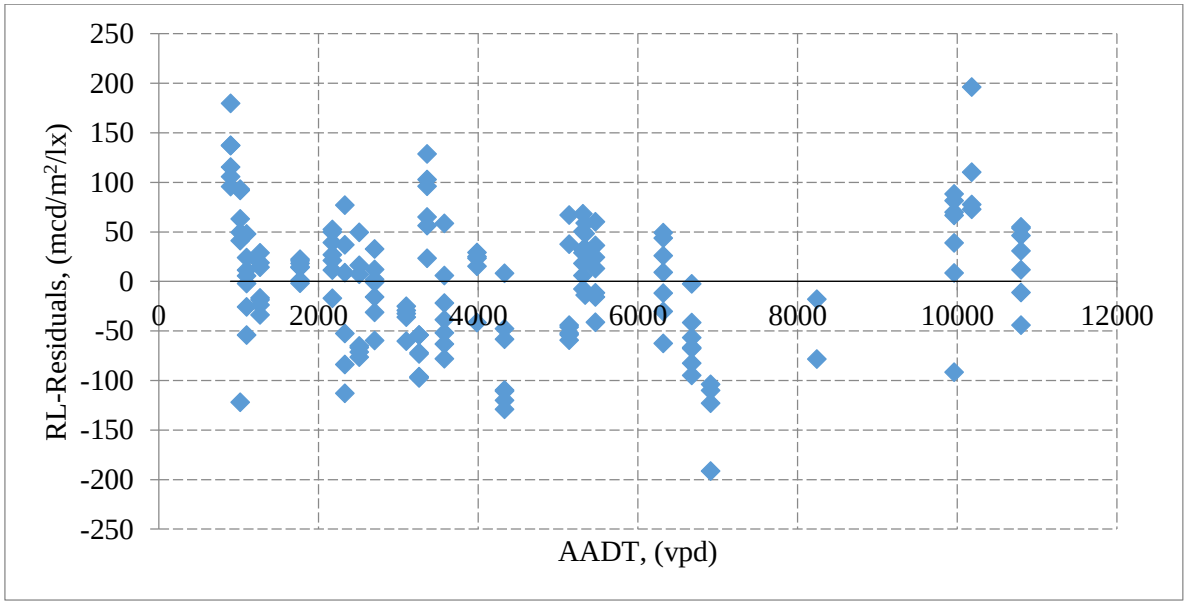


Figure 4.20 R_L-Residuals against AADT for White Paints

Generally, however, the fact that all the residuals look random and that there is no obvious correlation (pattern) with the fitted values, age and AADT, does not necessarily mean by itself that the model is adequate. More considerations are needed, such as R^2 and a p-value test. This was considered before, and hence the model is adequate. Due to this, the model generated under this category (equation 4.4), can therefore be considered in management of pavement markings of white paint markings.

4.3.6 Yellow Paints Analysis (all locations)

The analysis was performed on all selected sites having yellow paints pavement markings. Figure 4.21 presents the collected data in 3D scatterplot of retroreflectivity values against age and AADT for yellow paints for all locations.

From Figure 4.21, the data trend indicates a linear relationship with retroreflectivity decreasing with increase in pavement marking age, and retroreflectivity increasing with increase in AADT. This also influenced the decision of using a linear model, although the trends are somehow different from the previous models (Equations 4.1, 4.2 and 4.4). Since the trend is neither quadratic nor exponential, a linear relationship model was considered as it is more likely to reflect the trend in pavement marking deterioration. The 3D surface plot (Figure 4.22) shows the deterioration trend more clearly. More discussion about the trends on this model is made on chapter 5.

There are 161 observations with coefficient of determination (R^2) of 0.35, which means 35% of retroreflectivity (R_L) is explained by the regressors (Age and AADT).

Significance F = p-value = 8.85E-16 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is a relation between the two

variables at significance level 0.05. Age and AADT are jointly statistically significant at significance level 0.05. Age coefficient has an estimated p-value of 1.04E-14 < 0.05. It is therefore statistically significant at significance level $\alpha = 0.05$. AADT coefficient has an estimated p-value of 0.003 < 0.05 It is therefore statistically significant at significance level $\alpha = 0.05$. Therefore, age and AADT are contributing to the deterioration of yellow paints pavement marking retroreflectivity.

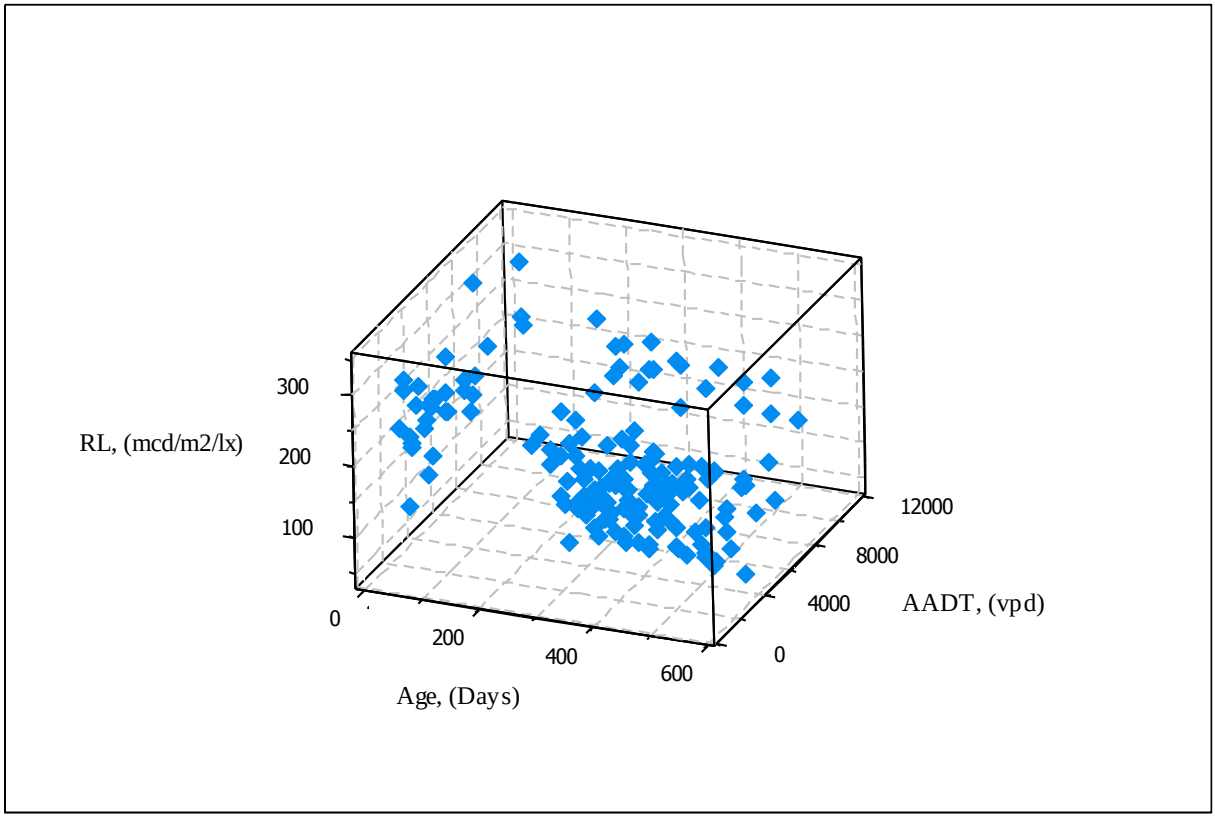


Figure 4.21 Scatter Plot, R_L vs Age vs AADT for Yellow Paints

A summary of the output results in the following fitted line which is the linear model for yellow paints on asphalt surface.

$$R_L = 234.10 - 0.1985*(Age) + 0.0013*(AADT) \quad \text{………………….……..……. (4.5)}$$

Figure 4.22 presents the 3D surface plot, which plotted from the generated model, equation 4.5, for yellow paints. It indicates the graphic image of the generated model, equation 4.5. It shows the relationship between retroreflectivity against age and traffic (AADT) of yellow paint markings.

In Figure 4.22, it can be observed that at any constant AADT, the retroreflectivity values decrease with the increase in pavement marking age. This means that, for the given asphalt highway, with known AADT, the deterioration of its yellow paint makings is proportional to the age of the markings.

The 3D surface plot in Figure 4.22 indicates that at any constant age, the retroreflectivity values increase with the increase in traffic volume (AADT). Generally, it can be revealed in Figure 4.22 that there is a decrease in retroreflectivity values as age and traffic both increase simultaneously.

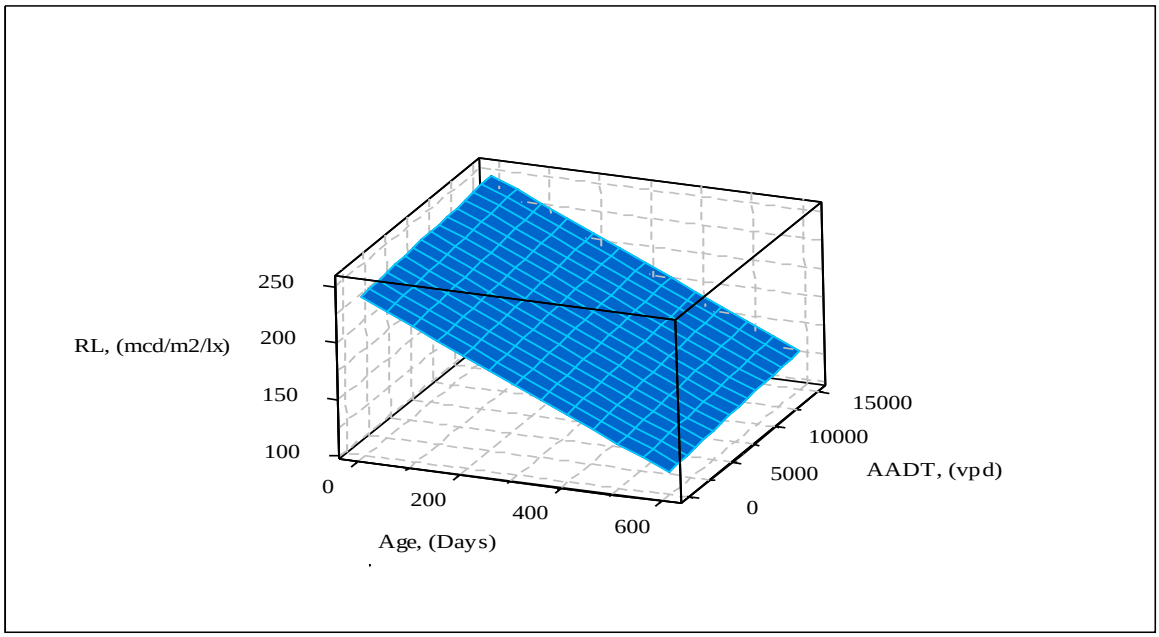


Figure 4.22 Surface Plot, R_L vs Age vs AADT for Yellow Paints

Figure 4.23 presents retroreflectivity residuals against retroreflectivity fitted values obtained from the model, equation 4.5. Figures 4.24 and 4.25 depict 2D plots of retroreflectivity residuals against age and AADT respectively, for yellow paint markings.

It can be observed in Figure 4.23 that there is no obvious correlation between the residuals and the fitted value generated from the model. This means that the chosen model is adequate to fit the experiment.

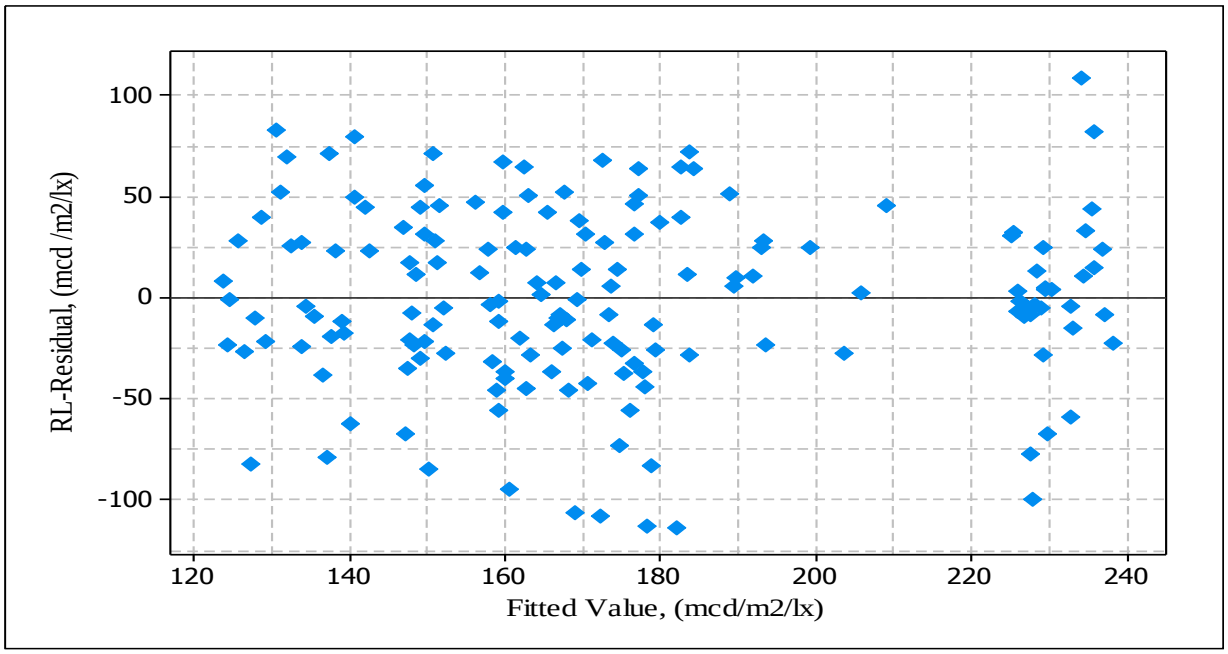


Figure 4.23 R_L-Residuals against Fitted Values for Yellow Paints

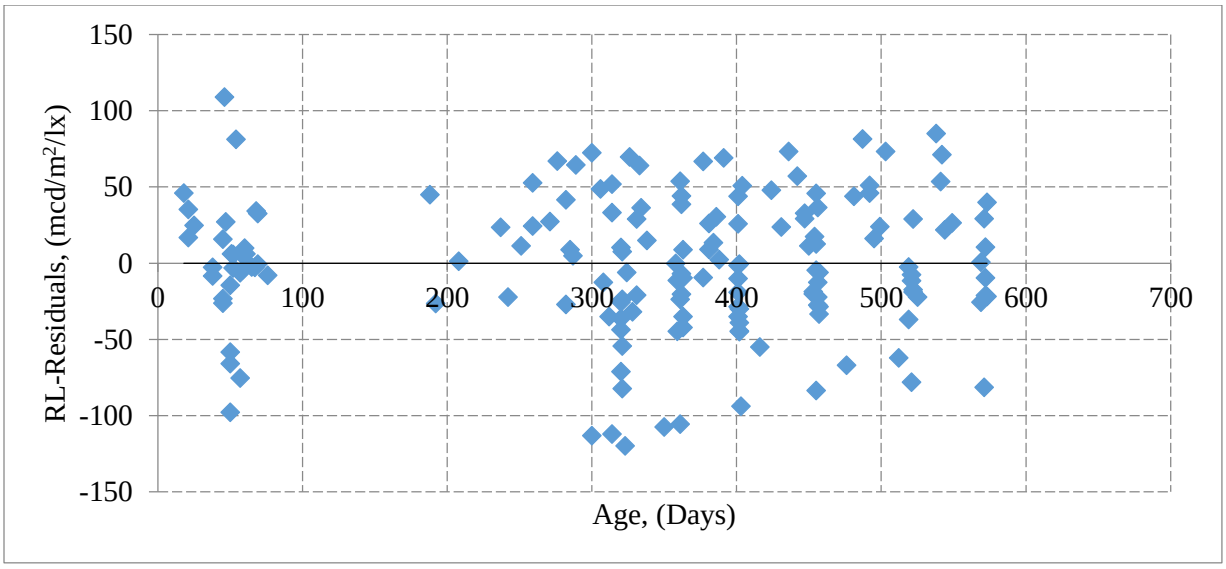


Figure 4.24 R_L-Residuals against Age for Yellow Paints

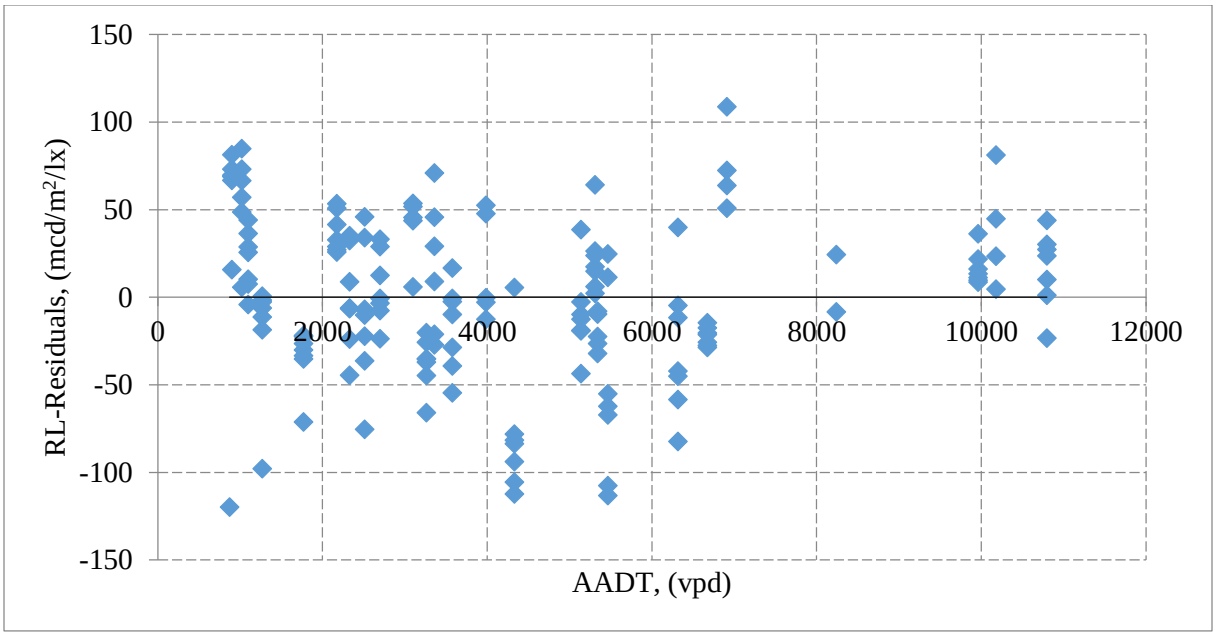


Figure 4.25 R_L-Residuals against AADT for Yellow Paints

Generally, the fact that all the residuals look random and that there is no obvious correlation (pattern) with the fitted values, age and AADT, does not necessarily mean by itself that the model is adequate. R^2 and a p-value test were also considered to ascertain that the model is adequate. Due to this, the model generated under this category (equation 4.1), can therefore be considered in management of pavement markings of yellow paints markings.

4.3.7 White Thermoplastics with AADT below 5,000 vpd

The analysis was performed on selected sites having white thermoplastics pavement markings and with AADT less than 5,000 vpd. There are 19 observations with coefficient of determination (R^2) of 0.717, which means 71.7% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

Significance F = p-value = 4.09E-05 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is a relation between the two variables at significance level 0.05. Age and AADT are jointly statistically significant at significance level of 0.05.

Age coefficient has an estimated p-value of 0.08 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$, which means age is not contributing to the deterioration of retroreflectivity. AADT coefficient has an estimated p-value of 9E-06 < 0.05 It is therefore statistically significant at significance level $\alpha = 0.05$.

Under this category, data are not sufficient to create a model as there are only 19 observations. There should be at least 30 observations (to represent a statistical population) that could be used to create the model.

4.3.8 Yellow Thermoplastics with AADT below 5,000 vpd

The analysis was performed on selected sites having yellow thermoplastics pavement markings and with AADT less than 5000 vpd. There are 19 observations with coefficient of determination (R^2) of 0.57, which means 57% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

Significance F = p-value = 0.001 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is a relation between the two variables at significance level 0.05. The parameters are jointly statistically significant at significance level of 0.05. Age coefficient has an estimated p-value of 0.76 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$. AADT coefficient has an estimated p-value of 0.0005

< 0.05 It is therefore statistically significant at significance level α = 0.05. Age is not contributing while AADT is contributing to the deterioration of retroreflectivity.

Under this category, data are not sufficient to create a model as there are only 19 observations. There should be at least 30 observations (to represent a statistical population) that could be used to create the model.

4.3.9 White Thermoplastics with AADT between 5,000 and 10,000 vpd

The analysis was performed on selected sites having white thermoplastics pavement markings and with AADT between 5,000 and 10,000 vpd. There are 82 observations with coefficient of determination (R^2) of 0.036 (very low, not reasonable), which means 3.6% of retroreflectivity (R_L) is explained by the regressors (age and AADT). Significance F = p-value = 0.23 > 0.05. Then we do not reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is no relation between the two variables at significance level 0.05. Age and AADT are jointly statistically insignificant at significance level of 0.05.

Age coefficient has an estimated p-value of 0.61 > 0.05. It is therefore statistically insignificant at significance level α = 0.05. AADT coefficient has an estimated p-value of 0.12 > 0.05 It is therefore statistically insignificant at significance level α = 0.05. Therefore, the general hypothesis test shows age and AADT are jointly statistical insignificance, which means they are not contributing to the deterioration of thermoplastic marking retroreflectivity.

4.3.10 Yellow Thermoplastics with AADT between 5,000 and 10,000 vpd

The analysis was performed on selected sites having yellow thermoplastics pavement markings and with AADT between 5,000 and 10,000 vpd. There are 82 observations with

coefficient of determination (R^2) of 0.004 (very low, not reasonable), which means 0.4% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

Significance F = p-value = 0.85 > 0.05. Then we do not reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is no relation between the age and AADT at significance level 0.05. Age and AADT are jointly statistically insignificant at significance level of 0.05. Age coefficient has estimated p-value of 0.6 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$. AADT coefficient has estimated p-value of 0.88 > 0.05 It is therefore statistically insignificant.

Therefore, the general hypothesis test shows age and AADT are jointly statistical insignificance, and do not contribute to the deterioration of thermoplastic pavement marking retroreflectivity.

4.3.11 White Thermoplastics with AADT between 10,000 and 20,000 vpd

The analysis was performed on selected sites having white thermoplastics pavement markings and with AADT between 10,000 and 20,000 vpd. There are 64 observations with coefficient of determination (R^2) of 0.063 (very low, not reasonable), which means 6.3% of retroreflectivity (R_L) is explained by the regressors (age and AADT). Significance F = p-value = 0.073 > 0.05. Then we do not reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is no relation between age and AADT at significance level 0.05.

Age coefficient has an estimated p-value of 0.26 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$. AADT coefficient has an estimated p-value of 0.12 > 0.05 It is therefore statistically insignificant at significance level $\alpha = 0.05$. Therefore, the general

hypothesis test shows the parameters, age and AADT are jointly statistical insignificance, and do not contribute to the deterioration of thermoplastic marking retroreflectivity.

4.3.12 Yellow Thermoplastics with AADT between 10,000 and 20,000 vpd

The analysis was performed on selected sites having yellow thermoplastics pavement markings and with AADT between 10,000 and 20,000 vpd. There are 64 observations with coefficient of determination (R^2) of 0.042 (very low, not reasonable), which means 4.2% of retroreflectivity (R_L) is explained by the regressors (Age and AADT).

Significance F = p-value = 0.27 > 0.05. Then we do not reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is no relation between age and AADT at significance level 0.05. Age and AADT are jointly statistically insignificant at significance level of 0.05, which means they are not contributing to the deterioration of the marking retroreflectivity.

Age coefficient has an estimated p-value of 0.77 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$. AADT coefficient has an estimated p-value of 0.13 > 0.05 It is therefore statistically insignificant at significance level $\alpha = 0.05$.

Therefore, the general hypothesis test shows that age and AADT are jointly statistically insignificant, and are not contributing to the deterioration of thermoplastic marking retroreflectivity.

4.3.13 White Thermoplastics with AADT above 20,000 vpd

The analysis was performed on selected sites having white thermoplastics pavement markings and with AADT above 20,000 vpd. There are 27 observations with coefficient of

determination (R^2) of 0.69, which means 69% of retroreflectivity (R_L) is explained by the regressors (Age and AADT).

Significance F = p-value = 6.9E-07 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is a relation between the two variables at significance level 0.05. Age coefficient has an estimated p-value of 0.9 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$, and do not contribute to deterioration. AADT coefficient has an estimated p-value of 1.45E-07 < 0.05 It is therefore statistically significant at significance level $\alpha = 0.05$

Under this category, data are not sufficient to create a model as there are only 27 observations. There should be at least 30 observations (to represent a statistical population) that could be used to create the model.

4.3.14 Yellow Thermoplastics with AADT above 20,000 vpd

The analysis was performed on selected sites having yellow thermoplastics pavement markings and with AADT above 20,000 vpd. There are 27 observations with coefficient of determination (R^2) of 0.689, which means 68.9% of retroreflectivity (R_L) is explained by the regressors (age and AADT). Significance F = p-value = 8.2E-07 < 0.05. Then we reject the null hypothesis that the two variables (age and AADT) are unrelated. Age coefficient has an estimated p-value of 0.65 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$, which means it is not contributing to deterioration under this category. AADT coefficient has an estimated p-value of 2.1E-07 < 0.05 It is therefore statistically significant.

Under this category, data are not sufficient to create a model as there are only 27 observations. There should be at least 30 observations (to represent a statistical population) that could be used to create the model.

4.3.15 White Thermoplastics Analysis (all locations)

The analysis was performed on all selected sites having white thermoplastics pavement. Figure 4.26 presents the collected data in 3D (cubical) scatterplot of retroreflectivity values against age and AADT for white thermoplastic markings.

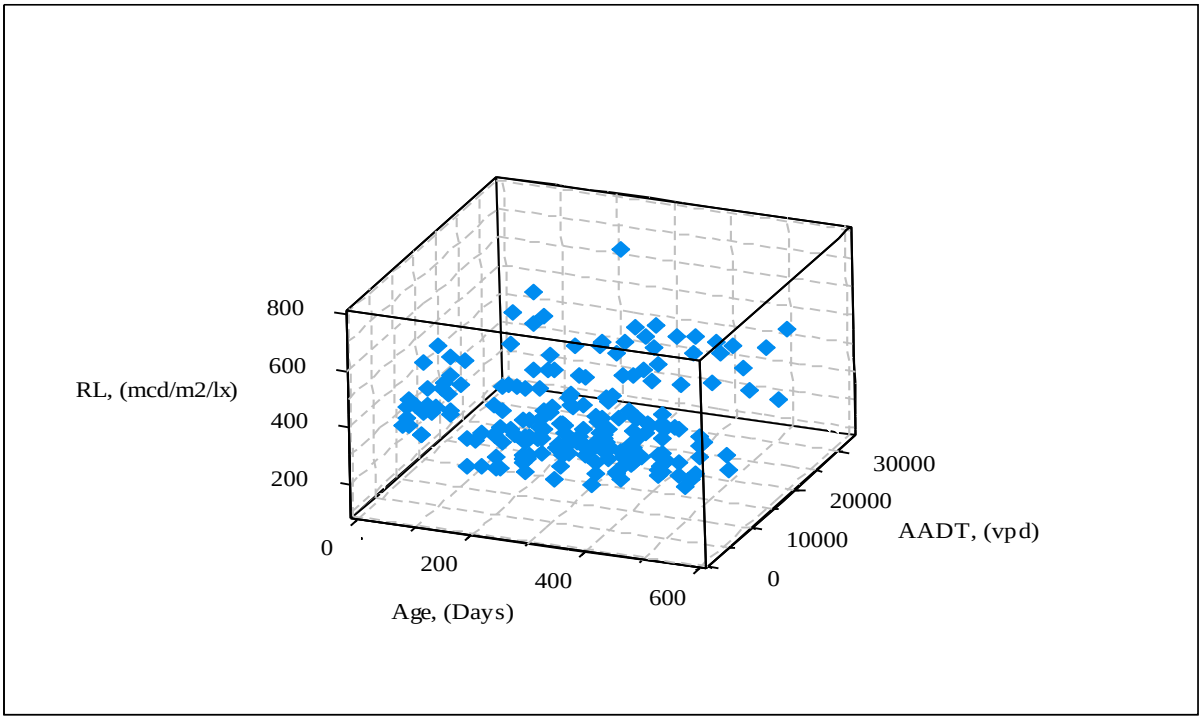


Figure 4.26 Scatter Plot, R_L vs Age vs AADT for White Thermoplastics

There are 195 observations with coefficient of determination (R^2) of 0.017 (very low, not reasonable), which means 1.7% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

Significance F = p-value = 0.2 > 0.05. Then we do not reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is no relation between age and AADT at significance level 0.05. Age and AADT are jointly statistically insignificant at significance level of 0.05 and do not contribute to the deterioration of white thermoplastics retroreflectivity. Age coefficient has an estimated p-value of 0.14 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$. AADT coefficient has estimated p-value of 0.32 > 0.05 It is therefore statistically insignificant at significance level $\alpha = 0.05$.

Therefore, the general hypothesis test shows that age and AADT are jointly statistically insignificant, which means they are not contributing to the deterioration of the thermoplastics white marking retroreflectivity. Analysis indicates that marking age and traffic are not contributing to the deterioration of the thermoplastics white marking retroreflectivity.

4.3.16 Yellow Thermoplastics Analysis (all locations)

The analysis was performed on all selected sites having yellow thermoplastics pavement. Figure 4.27 presents the collected data in 3D (cubical) scatterplot of retroreflectivity values against age and AADT for yellow thermoplastics.

There are 195 observations with coefficient of determination (R^2) of 0.016 (very low, not reasonable), which means 1.6% of retroreflectivity (R_L) is explained by the regressors (age and AADT).

Significance F = p-value = 0.2 > 0.05. Then we do not reject the null hypothesis that the two variables (age and AADT) are unrelated, and hence there is no relation between age and AADT at significance level 0.05. Age and AADT are jointly statistically insignificant at significance level of 0.05 under this category. Age coefficient has an estimated p-value of 0.58 > 0.05. It is therefore statistically insignificant at significance level $\alpha = 0.05$

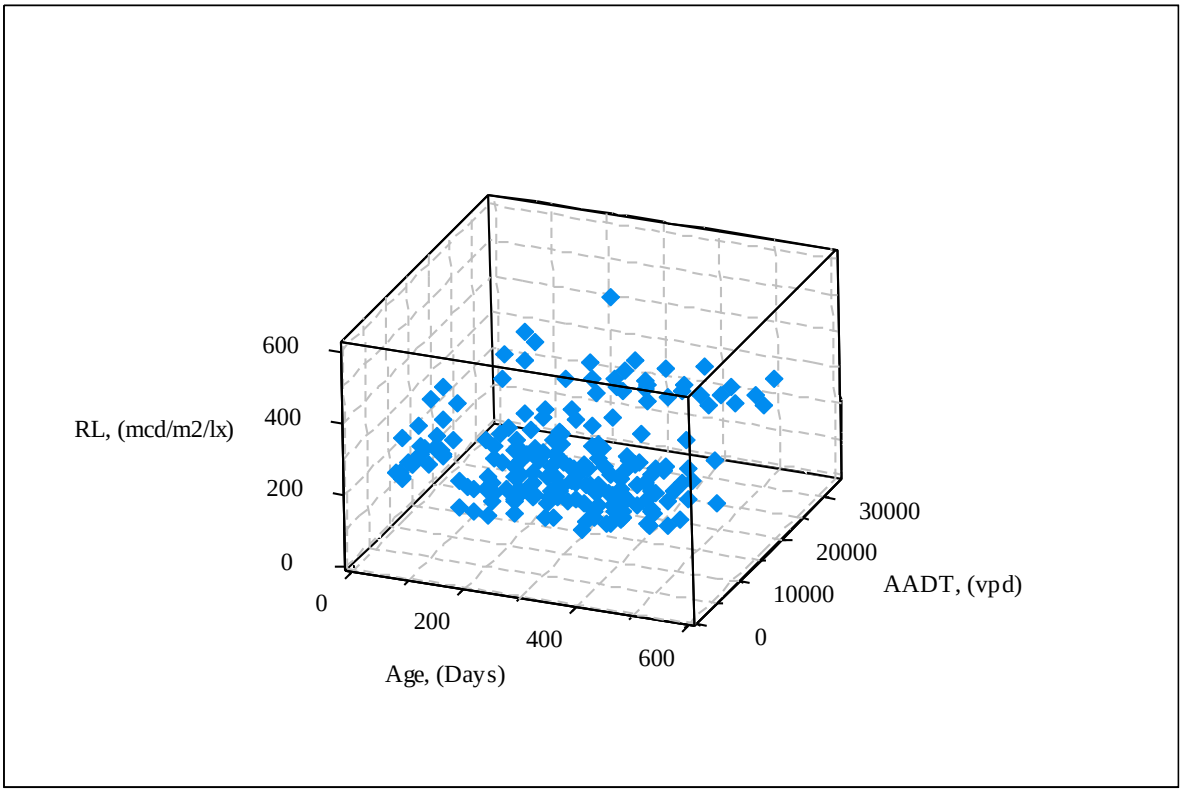


Figure 4.27 Scatter Plot, R_L vs Age vs AADT for Yellow Thermoplastics

AADT coefficient has an estimated p-value of 0.09 > 0.05 It is therefore statistically insignificant at significance level $\alpha = 0.05$. Therefore, the general hypothesis test shows that age

and AADT are jointly statistically insignificant, which means they are not contributing to the deterioration of the thermoplastics yellow marking retroreflectivity. Analysis indicates that marking age and traffic are not contributing to the deterioration of the thermoplastics yellow marking retroreflectivity.

CHAPTER 5

DISCUSSION OF THE FINDINGS

As explained in Chapter 4, the data analysis was performed in four different traffic categories for paint and thermoplastic, white and yellow pavement markings. These traffic categories are:

1. AADT less than 5,000 vehicles per day (vpd)
2. AADT between 5,000 vpd and 10,000 vpd
3. AADT between 10,000 vpd and 20,000 vpd
4. AADT more than 20,000 vpd.

Normally, paint markings are applied on roads with relatively low traffic volumes and thermoplastic markings are applied on highways with relatively high traffic volumes. Therefore of the four traffic categories, the first category had mainly paint markings and the last category had all thermoplastic markings. The collected data was analyzed using a linear regression analysis tool in Excel software and 3D scatter plots and a visual representation of a fitted prediction model plots were generated using Minitab software.

From the analysis, five prediction models were generated for paint pavement markings with coefficient of determination, R^2, ranging from 0.33 to 0.46 (equations 4.1 to 4.5). The coefficient of determination is the value that helps to determine how close or far the predicted values are from the observed values. A value of 1.0 indicates a perfect fit and 0 indicates no correlation.

5.1 Paint Pavement Markings

For paint pavement markings, the first three traffic categories were considered for analysis. In the first category with AADT < 5,000 vpd, two prediction models, equations 4.1 and 4.2, were developed for white and yellow markings with coefficients of determination, R^2, of 0.45 and 0.38 respectively. Both prediction models had similar trends as it can be seen on Figures 4.2 and 4.7. Both models show a decrease in pavement marking retroreflectivity with increase in pavement marking age and with increase in AADT although the rates of marking deterioration are different.

For the second traffic category with AADT between 5,000 vpd and 10,000 vpd, only one prediction model for yellow paint markings was developed, equation 4.3, with a coefficient of determination, R^2, of 0.46. For some reason this model had a different trend on AADT as compared to the two previous models (equations 4.1 and 4.2). Like the previous models the pavement marking retroreflectivity decreases with increase in pavement marking age, but the pavement marking retroreflectivity at a constant age, increases with increase in AADT. This trend was not expected. However the regression analysis indicates that AADT is contributing to retroreflectivity deterioration, this model indicates that AADT is not impacting the retroreflectivity deterioration. The reason could be either the markings on pavements with higher traffic volumes in this category had a better quality paint materials, (this is because the type of paint marking materials used was categorized for this study), or it could be due to the fact that pavements with higher traffic volumes had four lanes divided highway where yellow lines are on the edges only and traffic rarely drive on the markings therefore the deterioration rate of those yellow lines will be lower than on undivided pavements with yellow lines in the middle.

Since AADT (traffic) showed little significance on deterioration of pavement marking, further analysis was performed considering retroreflectivity and age. The 2D linear model, equation 5.1, was created with a coefficient of determination, R^2, of 0.29. With these results it is still recommended to perform a separate analysis for divided highways and undivided highways since the 2D model has even lower R^2 value.

$$R_L = 241.44 - 0.1617*(Age) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.1)$$

Figure 5.1 indicates the graphic image of the generated model, equation 5.1. It presents the relationship between retroreflectivity values against pavement marking age for yellow paints with AADT between 5,000 and 10,000 vpd, analyzed without AADT. It can be observed that retroreflectivity decreases with the increase in pavement markings age.

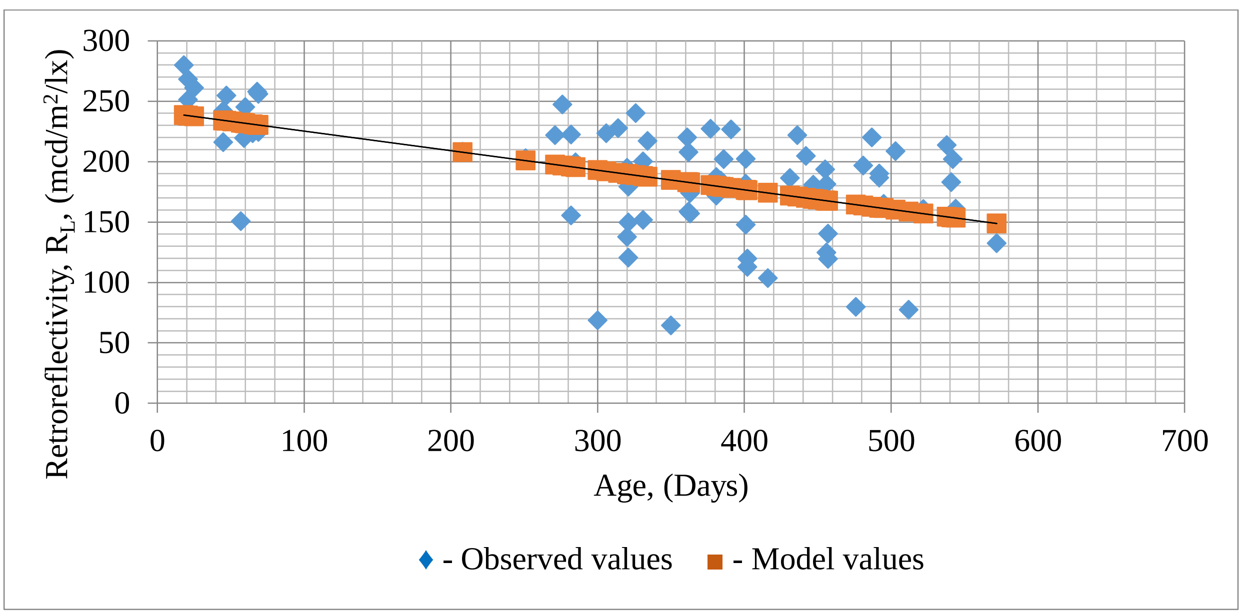


Figure 5.1 R_L against Age for Yellow Paints with AADT between 5,000 and 10,000 vpd

A prediction model for white pavement markings with AADT between 5,000 and 10,000 vpd could not be developed because the analysis revealed that for the p-value for AADT was greater than 0.05, therefore the model was insignificant at 95% confidence level.

For the third traffic category with AADT between 10,000 vpd to 20,000 vpd, prediction models could not be generated because on white markings, the pavement marking age was statistically insignificant with p-value > 0.05, therefore not a contributing factor to pavement marking deterioration, and yellow markings had a p-value > 0.05 indicating that age and AADT are not related and they are not contributing factors to the deterioration of pavement marking retroreflectivity.

Two prediction models were developed for all data without traffic categorization for white and yellow pavement markings, equations 4.4 and 4.5, with the coefficient of determination, R^2, of 0.38 and 0.35 respectively. It can be seen from Figures 4.17 and 4.22 that for both white and yellow pavement markings the pavement marking retroreflectivity decreases with increase in pavement marking age, this means that the pavement marking deteriorates with increase in age. Considering AADT, different trends were observed for white and yellow markings. White markings have retroreflectivity decreasing with increase in AADT.

With yellow markings, the same situation as that for yellow markings with AADT between 5,000 vpd and 10,000 vpd exist. Retroreflectivity increases with increase in AADT. This could be caused by high traffic volume pavements having yellow lines on the edges only and therefore their rate of deterioration is lower than undivided pavements with yellow lines in the middle. An example could be on the data collected in the counties of Knox and Hamilton; these were divided highways with high traffic volume, and high retroreflectivity values that showed low deterioration rates. Considering data collected in Rhea County, undivided highway

with low traffic volume, low retroreflectivity values, but showed high deterioration rate. Further analysis is recommended separating divided highways from undivided highways. Due to this, regression analysis without AADT was performed for this category, and the following model, equation 5.2, was created with a coefficient of determination, R^2, of 0.35.

$$R_L = 238.76 - 0.1948*(Age) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.2)$$

Figure 5.2 indicates the graphic image of the generated model, equation 5.2. It presents the relationship between retroreflectivity values against pavement marking age for yellow paints, analyzed without traffic consideration. It can be observed that retroreflectivity decreases with the increase in pavement markings age.

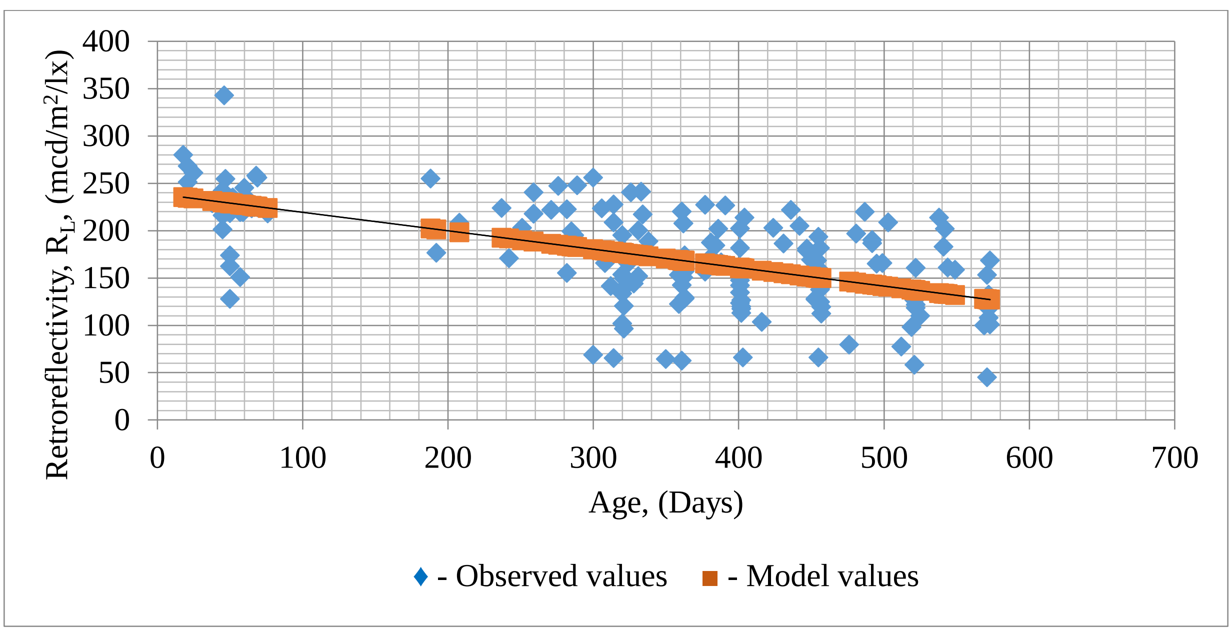


Figure 5.2 R_L against Age for Yellow Paints (all locations, with no traffic)

5.2 Thermoplastic Pavement Markings

The first category with AADT < 5000 vpd had 19 observations for each white and yellow pavement markings. The analysis revealed that both white and yellow markings had p-values >0.05 indicating that the model is not statistically significant and both age and AADT are not contributing factors to pavement marking deterioration. This was the trend for thermoplastic markings at all traffic categories and therefore no prediction models were developed for thermoplastic pavement markings. As it can be seen on the 3D scatter plots of all thermoplastic markings, without traffic categorization, Figures 4.26 and 4.27, the data does not reveal any specific trend. Therefore it is hard to develop a deterioration model. This is why most of the models developed in the literature are for paints rather than thermoplastic markings.

Furthermore, it has been revealed from literature that thermoplastic markings perform for longer period of time than paint markings, approximately average life of 26.2 months (approximately 786 days) for white and 27.5 months (approximately 825 days) for yellow thermoplastics. This take into account of retroreflectivity threshold values of 150 and 100mcd/m^2/lx for white and yellow thermoplastics markings respectively (Migletz and Graham 2002). Bowman (1992) from Auburn University reported that in the southern states thermoplastics markings can last up to 10 years (Bowman, Kowshik et al. 1992). The thermoplastic markings presented in this study had an age of approximately 590 days which is below the life expectancy of thermoplastic markings. Perhaps a longer observation period is required to a point where pavement marking deterioration will be noticed, and then prediction models could be developed. Likewise, retroreflectivity on thermoplastic depends on beads exposure, marking cleanliness, etc., this could contribute on the fluctuations observed on the pavement marking retroreflectivity of thermoplastic markings.

5.3 Other Factors

This study analyzed only two factors affecting pavement marking retroreflectivity, AADT and pavement marking age, it is important to mention that more factors that were not considered in this study could contribute to the deterioration of pavement markings. These factors include but not limited to weather condition (winter, summer), effects of snow plough on pavement markings, presence of moisture on the surface, pavement marking material, nature of the road surface (concrete or Asphalt), distresses on pavement markings and chemistry issues such as material bonding (Gates, Hawkins et al. 2003).

CHAPTER 6

CONCLUSION AND RECOMMENDATION

From this study it can be concluded that the deterioration of the pavement marking retroreflectivity is impacted by pavement marking age and traffic. Generally, it can be revealed from the developed models that there is a decrease in retroreflectivity values as age and traffic increase simultaneously.

In a practical use, it can be explained by considering the following two models:

(i) Degradation models for white paints materials (for all locations), with coefficients of determination of 0.33.

$R_L = 383.105 – 0.2737*(Age) – 0.0056*(AADT)$

(ii) Degradation models for yellow paints materials with, with AADT below 5,000 vpd, with coefficients of determination of 0.38.

$R_L = 269.85 – 0.1859*(Age) – 0.0148*(AADT)$

For a given asphalt highway having paint markings, and with known AADT, repainting and/or rehabilitation period of the pavement marking can be designed, provided there is a known retroreflectivity threshold. For example, consider a highway with AADT of 5,000 vpd, and retroreflectivity thresholds of 150 and 100mcd/m^2/lx for white and yellow markings respectively. It will take about 749 days (approximately 2 years) for white markings, and 516 days (approximately 1.4 years) for yellow markings, to reach the threshold values, hence need maintenance.

No model was created for thermoplastics as the analysis indicated that there was no statistical significance and correlation of age and AADT on thermoplastics retroreflectivity. Therefore the objective of model creation for thermoplastics was not achieved.

6.1 Other Factors for Future Studies

Further studies are recommended in pavement marking management by the consideration of more factors rather than only retroreflectivity value, age and traffic, so as to investigate how other factors affect/contribute to deterioration of pavement markings.

The deterioration of the pavement marking can be contributed to by other factors such as:

Thickness, width and position of pavement markings: The durability or lifetime of a pavement marking also relies on how much of the material is applied. If a thicker and wider layer of paint is applied, the marking will most likely last longer. However, applying thicker and wider materials can be expensive (Thomas and Schloz 2001). Simple observations show that the position of the pavement marking (centerlines and/or edge lines) impacts the deterioration rates. Studies on how to quantify the deterioration of the pavement marking in relation to the position of the pavement markings—edge line, center line—are recommended.

Climatic Conditions: Further studies are recommended to investigate the impact of the climatic conditions, such as temperature and rainfall, in deterioration of pavement markings and marking retroreflectivity.

Nature of the Pavement Surface: In this research, the pavement marking deterioration with respect to pavement surface nature, the nature of rigid pavement (PCC surface) and flexible pavement (AC surface), cannot be made. All the locations used for data collection have the same

nature, asphalt concrete surface. Hence, future studies are recommended to investigate how the nature of pavement surface affects the deterioration of pavement markings and pavement marking retroreflectivity.

Pavement Distresses: Pavement distresses are external indicators of pavement deterioration caused by loading, environmental factors, construction deficiencies, or a combination of several deterioration factors. Distresses seem to impact the deterioration of the markings. There are several types of pavement distresses such as: Alligator cracking, bleeding, block cracking, bumps and sags, corrugation, depression, edge cracking, joint reflection cracking, lane/shoulder drop off, longitudinal and transverse cracking, patching and utility cut patching, polished aggregate, potholes, railroad crossing, rutting, shoving, slippage cracking, swell, and weathering/raveling. Typical distresses which seem to cause the deterioration of the pavement markings are cracks, bleeding, rutting, and weathering of the pavement surface.

Pavement marking materials may be good, with good and acceptable quality and retroreflectivity, but due to presence of distresses, pavement markings are removed from the surface. In this study, this situation was observed from different locations such as Jefferson, Loudon and Blount sites. Figures 6.1 and 6.2 shows some distresses that may affect the pavement marking.



Figure 6.1 Distresses on Yellow Marking



Figure 6.2 Distresses on White Marking

CHAPTER 7

LIMITATIONS AND PROBLEMS ENCOUNTERED

This study was performed on only two types of pavement marking materials; thermoplastic and paint marking material, with only two colors; yellow and white, on only one type of pavement surface; flexible pavement. There are several pavement marking materials, in more than two colors applied on different pavement types; rigid and flexible pavements.

This study experienced the variation and non-uniform fluctuation of retroreflectivity measurements of the identical pavement marking materials, during data collection. This may be due to road maintenance, weather condition of the region, road type, or other factors.

The manual data collection using the handheld LTX is less safe especially in terms of traffic on highways. Thinking of collecting data using more modern equipment like automatic and mobile retroreflectometers will be of much importance, however, using mobile retroreflectometers can be expensive. This will help also to investigate the visibility (retroreflectivity) of the pavement marking in dynamic scenarios which is more realistic especially to vehicle drivers, rather than obtaining these retroreflectivity readings in static situations (using handheld retroreflectometers) which seems to be not realistic to the road users and vehicle drivers as vehicles are always in motion, and the drivers have to see the pavement marking while they are in motion.

This study planned to collect data approximately every 45 days, but this was not possible due to factors such as: weather conditions and traffic. When there was rain or snow on the data

collection period, data was not collected. When there was high traffic, especially during holidays, data collection was postponed to another safer day. Therefore data was not collected on exactly 45 days intervals but whenever it was possible to collected data after 45 days from the previous data collection cycle.

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APPENDIX A

REGRESSION ANALYSIS

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REGRESSION ANALYSIS

Regression analysis is a statistical tool used to investigate the relationships between two or more variables. For this case the retroreflectivity measurement is investigated against age of the pavement marking for locations with a specific traffic range in vehicles per day (vpd). Models that relate the parameters were generated. This method assesses the "statistical significance" of the estimated relationships. This is the degree of confidence that the true relationship is close to the estimated relationship. The analysis was performed using a Microsoft Excel data analysis tool. Using the data input of traffic, age and pavement marking retroreflectivity readings, the Excel output was generated comprising of parameters explained below.

1. The overall goodness-of-fit measure is given by the coefficient of determination, R^2. For example, if $R^2 = 0.4522$, it means that 45.22% of the variation of y_i (retroreflectivity) around y-bar ($\bar{y}$ is its mean) is explained by the regressors x_{2i} (age) and x_{3i} (AADT). R^2 is of greatest interest in regression statistics table because it gives the information between the observed data and modeled (predicted) data.
2. The multiple R shows the correlation between y and y-hat ($\hat{y}$). It is a square root of R^2. y-hat ($\hat{y}i$) is the value of yi predicted from the regression line.
3. Adjusted R squared is calculated from: adjusted $R^2 = R^2 – (1 – R2)*(k-1)/(n-k) = 0.44$. k is the number of regressors including the intercept.

4. The standard error refers to the estimated standard deviation of the error term u. It is sometimes called the standard error of the regression. It equals square-root of (SSE/ (n-k). SSE is the error sum of squares.
5. Analysis of variance (ANOVA) parameters: Analysis of Variance (ANOVA) is a statistical method used to test differences between two or more means. It is used to test general rather than specific differences among means. ANOVA parameters obtained after the regression analysis are: Sum of the Squares (SS), F-parameter and significance F.

- df means "the degrees of freedom in the source of the variation in the data." It is given by (k – 1) for regression factor, (n – k) for residual, and (n – 1) for total.
- The value of SS is used in calculation of the coefficient of determination, R^2

  Total sums of squares (SS) = Residual (or error) sum of squares + Regression (or explained) sum of squares.

  R^2 = 1 – Residual SS / Total SS (this is the general formula for R^2)
- The parameter - F gives the overall F-test of the null hypothesis (H0: the paramaters are all zero: i.e $\beta_2 = 0$ and $\beta_3 = 0$) versus Ha: at least one of β_2 and β_3 does not equal zero.

  F is computed as: F = [Regression SS/ (k-1)] / [Residual SS/ (n-k)]
- Significance F has the associated P-value. If p-value < significance level, we reject the null hypothesis, H0, and if p-value > significance level, we do not reject H0.

6. t-Stat gives the computed t-statistic for the null hypothesis (H0: $\beta_j = 0$ against Ha: $\beta_j \neq 0$). This is the coefficient divided by the standard error. It is compared to a t with (n-k) degrees of freedom.
7. p-value gives the value for test of the null hypothesis, H0: $\beta_j = 0$, against Ha: $\beta_j \neq 0$.

8. The population linear regression model is given in the form: $y = \beta_1 + \beta_2 x_2 + \beta_3 x_3 + u$ It is assumed that the error *u* is independent with constant variance (homoskedastic). Excel standard errors, t-statistics and p-values are based on the assumption that the error is independent with constant variance. That is what known as homoskedastic. Due to that, the error *u* is neglected and the model will be in the form of regression line: $y = b_1 + b_2 x_2 + b_3 x_3$

APPENDIX B

ANALYSIS OUTPUTS

APPENDIX B

ANALYSIS OUTPUTS

Table B1. Summary Output, for yellow paints with AADT less than, or equal to 5,000 vpd

Regression Statistics	
Multiple R	0.617054
R Square	0.380756
Adjusted R Square	0.367855
Standard Error	43.36373
Observations	99

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	110996.3	55498.16	29.51381	1.02E-10
Residual	96	180519.7	1880.413		
Total	98	291516			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	269.8454	14.58984	18.49543	2.07E-33	240.8848	298.806
Age	-0.18586	0.026544	-7.00175	3.44E-10	-0.23855	-0.13317
Traffic, AADT	-0.0148	0.004086	-3.62143	0.00047	-0.02291	-0.00669

Table B2. Summary Output, AADT between 5,000 and 10,000 vpd, white paints

Regression Statistics	
Multiple R	0.56185
R Square	0.315676
Adjusted R Square	0.287744
Standard Error	61.95332
Observations	52

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	86757	43378.5	11.30174	9.2E-05
Residual	49	188072.5	3838.214		
Total	51	274829.5			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	354.8215	42.35982	8.37637	5.11E-11	269.6963	439.9468
Age	-0.2616	0.05522	-4.73743	1.89E-05	-0.37257	-0.15063
Traffic, AADT	-0.00348	0.005521	-0.63013	0.531536	-0.01457	0.007616

Table B3. Summary Output, AADT between 5,000 and 10,000 vpd, yellow paints

Regression Statistics	
Multiple R	0.679908
R Square	0.462275
Adjusted R Square	0.440327
Standard Error	41.82683
Observations	52

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	73696.31	36848.16	21.0623	2.5E-07
Residual	49	85724.71	1749.484		
Total	51	159421			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	186.917	28.59858	6.535885	3.47E-08	129.446	244.388
Age	-0.22063	0.037281	-5.91798	3.13E-07	-0.29555	-0.14571
Traffic, AADT	0.00885	0.003728	2.374187	0.02155	0.001359	0.016341

Table B4. Summary Output, AADT between 10,000 and 20,000 vpd, white paints

Regression Statistics	
Multiple R	0.907341
R Square	0.823267
Adjusted R Square	0.772772
Standard Error	23.03614
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	17303.81	8651.907	16.30393	0.002321
Residual	7	3714.647	530.6639		
Total	9	21018.46			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1750.893	280.0189	6.252767	0.000423	1088.754	2413.033
Age	-0.07441	0.062306	-1.19423	0.271283	-0.22174	0.072923
Traffic, AADT	-0.13603	0.026768	-5.08181	0.001428	-0.19932	-0.07273

Table B5. Summary Output, AADT between 10,000 and 20,000 vpd, yellow paints

Regression Statistics	
Multiple R	0.701925
R Square	0.492699
Adjusted R Square	0.347755
Standard Error	16.23108
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1791.051	895.5253	3.399251	0.092989
Residual	7	1844.135	263.4478		
Total	9	3635.185			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	499.5921	197.299	2.532157	0.039109	33.05412	966.1302
Age	-0.07978	0.0439	-1.81735	0.112002	-0.18359	0.024025
Traffic, AADT	-0.02514	0.01886	-1.33313	0.22424	-0.06974	0.019454

Table B6. Summary Output, white paints (all locations)

Regression Statistics	
Multiple R	0.574545
R Square	0.330102
Adjusted R Square	0.321623
Standard Error	65.33054
Observations	161

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	332299.4	166149.7	38.92845	1.8E-14
Residual	158	674356.6	4268.079		
Total	160	1006656			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	383.1048	14.98157	25.57173	4.91E-58	353.5148	412.6948
Age	-0.27367	0.032032	-8.54363	1.04E-14	-0.33693	-0.2104
Traffic, AADT	-0.00556	0.001859	-2.99015	0.003235	-0.00923	-0.00189

Table B7. Summary Output, yellow paints (all locations)

Regression Statistics	
Multiple R	0.59297
R Square	0.351613
Adjusted R Square	0.343509
Standard Error	44.74404
Observations	163

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	173708.8	86854.39	43.38319	8.85E-16
Residual	160	320324.6	2002.029		
Total	162	494033.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	234.0978	10.07831	23.22787	3.98E-53	214.1941	254.0014
Age	-0.19845	0.021718	-9.13731	2.74E-16	-0.24134	-0.15555
Traffic, AADT	0.001318	0.001264	1.042117	0.29893	-0.00118	0.003815

Table B8. Summary Output, AADT below 5,000 vpd, white thermoplastics

Regression Statistics	
Multiple R	0.846905
R Square	0.717249
Adjusted R Square	0.681905
Standard Error	34.17417
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	47400.32	23700.16	20.29342	4.09E-05
Residual	16	18685.99	1167.874		
Total	18	66086.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-481.07	130.045	-3.69926	0.001945	-756.753	-205.387
Age	-0.11224	0.060478	-1.8559	0.081982	-0.24045	0.015966
Traffic, AADT	0.186679	0.029302	6.370778	9.28E-06	0.124561	0.248797

Table B9. Summary Output, AADT below 5,000 vpd, yellow thermoplastics

Regression Statistics	
Multiple R	0.757105
R Square	0.573209
Adjusted R Square	0.51986
Standard Error	23.64479
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	12014.01	6007.005	10.74452	0.001101
Residual	16	8945.219	559.0762		
Total	18	20959.23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-196.893	89.9769	-2.18826	0.043832	-387.635	-6.1504
Age	0.013229	0.041844	0.316144	0.75598	-0.07548	0.101935
Traffic, AADT	0.087807	0.020274	4.330985	0.000516	0.044828	0.130786

Table B10. Summary Output, AADT between 5,000 and 10,000 vpd, white thermoplastics

Regression Statistics	
Multiple R	0.190643
R Square	0.036345
Adjusted R Square	0.011948
Standard Error	79.50125
Observations	82

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	18831.98	9415.989	1.489766	0.231689
Residual	79	499315.5	6320.449		
Total	81	518147.5			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	406.246	40.36999	10.06307	8.33E-16	325.8915	486.6004
Age	-0.0338	0.065591	-0.5153	0.607785	-0.16435	0.096757
Traffic, AADT	-0.00803	0.005156	-1.55733	0.123389	-0.01829	0.002233

Table B11. Summary Output, AADT between 5,000 and 10,000 vpd, yellow thermoplastics

Regression Statistics	
Multiple R	0.063894
R Square	0.004082
Adjusted R Square	-0.02113
Standard Error	74.29991
Observations	82

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1787.702	893.851	0.161916	0.850795
Residual	79	436117.7	5520.477		
Total	81	437905.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	215.7981	37.7288	5.719718	1.83E-07	140.7008	290.8954
Age	0.031973	0.0613	0.521591	0.603415	-0.09004	0.153987
Traffic, AADT	0.000728	0.004819	0.151003	0.880358	-0.00886	0.010319

Table B12. Summary Output, AADT between 10,000 and 20,000 vpd, white thermoplastics

Regression Statistics	
Multiple R	0.250434
R Square	0.062717
Adjusted R Square	0.031986
Standard Error	91.41714
Observations	64

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	34111.39	17055.69	2.040864	0.138694
Residual	61	509782.7	8357.093		
Total	63	543894.1			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	463.3364	69.52057	6.664739	8.7E-09	324.3214	602.3514
Age	-0.15346	0.083997	-1.82699	0.072594	-0.32142	0.0145
Traffic, AADT	-0.00507	0.004432	-1.14439	0.256934	-0.01393	0.00379

Table B13. Summary Output, AADT between 10,000 and 20,000 vpd, yellow thermoplastics

Regression Statistics	
Multiple R	0.203953
R Square	0.041597
Adjusted R Square	0.010174
Standard Error	65.76833
Observations	64

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	11451.84	5725.919	1.323767	0.273667
Residual	61	263853.8	4325.473		
Total	63	275305.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	156.9943	50.01525	3.138928	0.002613	56.98262	257.006
Age	-0.01784	0.06043	-0.29529	0.768777	-0.13868	0.102993
Traffic, AADT	0.004884	0.003188	1.532007	0.130691	-0.00149	0.01126

Table B14. Summary Output, AADT above 20,000 vpd, white thermoplastics

Regression Statistics	
Multiple R	0.832746
R Square	0.693466
Adjusted R Square	0.667921
Standard Error	73.78213
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	295569.5	147784.7	27.14734	6.88E-07
Residual	24	130651.3	5443.802		
Total	26	426220.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1434.729	152.1713	9.428382	1.53E-09	1120.663	1748.795
Age	-0.01268	0.107788	-0.11763	0.907343	-0.23514	0.209784
Traffic, AADT	-0.03657	0.004994	-7.3235	1.45E-07	-0.04688	-0.02627

Table B15. Summary Output, AADT above 20,000 vpd, yellow thermoplastics

Regression Statistics	
Multiple R	0.830009
R Square	0.688916
Adjusted R Square	0.662992
Standard Error	46.87457
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	116781.4	58390.71	26.57475	8.21E-07
Residual	24	52733.4	2197.225		
Total	26	169514.8			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	900.6345	96.67604	9.316005	1.93E-09	701.105	1100.164
Age	0.03149	0.068479	0.459848	0.649764	-0.10984	0.172823
Traffic, AADT	-0.02272	0.003173	-7.15965	2.12E-07	-0.02926	-0.01617

Table B16. Summary Output, white thermoplastics (without traffic categorization)

Regression Statistics	
Multiple R	0.128818
R Square	0.016594
Adjusted R Square	0.00635
Standard Error	91.6181
Observations	195

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	27194.9	13597.45	1.619925	0.200607
Residual	192	1611624	8393.876		
Total	194	1638819			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	360.6984	18.82069	19.165	1.88E-46	323.5766	397.8203
Age	-0.07012	0.047618	-1.4726	0.142496	-0.16404	0.023799
Traffic, AADT	0.00083	0.000834	0.995912	0.320546	-0.00081	0.002474

Table B17. Summary Output, yellow thermoplastics (all locations)

Regression Statistics	
Multiple R	0.126383
R Square	0.015973
Adjusted R Square	0.005722
Standard Error	69.86185
Observations	195

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	15210.73	7605.364	1.55826	0.213152
Residual	192	937090.2	4880.678		
Total	194	952300.9			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	210.2605	14.3514	14.65087	4.06E-33	181.9539	238.5672
Age	0.02006	0.036311	0.552447	0.581285	-0.05156	0.091678
Traffic, AADT	0.001075	0.000636	1.690662	0.092524	-0.00018	0.002328

VITA

Daniel Malyuta is a Tanzanian male, born in Bariadi, Tanzania. He is the son of Rev. Aaron Malyuta and Flora Selemen Bujiku. He is the fourth born of a family of nine children, six brothers and three sisters. He went to primary school in Mwanza, Tanzania, and then to ordinary level secondary education in Shinyanga, Tanzania. He then joined advanced level secondary education in Mwanza, where he graduated in the year 2008, and joined undergraduate studies. He received his Bachelor degree in Civil and Structural Engineering from The University of Dar es Salaam, Tanzania, in November 2012. During his studies at the University of Dar es Salaam, he performed several practical trainings (internships) in his area of study, civil engineering. After graduation, he worked with a consulting company, ENGG Consulting Engineers, for 6 months, as a structural engineer, where he gained experience in structural analysis and design.

Daniel moved to the USA in August 2013 after accepting a Graduate Research Assistantship at the University of Tennessee at Chattanooga, UTC, in the Master of Science in Civil Engineering Program. He graduated with a Master of Science degree in Civil Engineering, in August, 2015.

Daniel is currently a Teaching Assistant at The College of Engineering and Technology of The University of Dar es Salaam, Tanzania.