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Evaluation of the performance and cost of pavement marking materials: The case of white lane line marking in Addis Ababa City arterial streets

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By

Berihun Wondimu

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Advisor

Dr. Habtamu Melese

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Evaluation of the performance and cost of pavement marking materials: The case of white lane line marking in Addis Ababa City arterial streets

By
Berihun Wondimu Desalegn

Addis Ababa Institute of Technology
School of Civil and Environmental Engineering

Approved by Board Examiners

Dr. Habtamu Melese (PhD., P.E.) *Adviser*	..... *Signature*	..... *Date*
Mr. Abel *External Examiner*	..... *Signature*	..... *Date*
Dr. Bikila Teklu *Internal Examiner*	..... *Signature*	..... *Date*
_____ *Cherman*	..... *Signature*	..... *Date*

UNDERTAKING

I certify that research work titled “Evaluation of the performance and cost of pavement marking materials: The case of white lane line marking in Addis Ababa City arterial streets” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/referred.

Berihun Wondimu	……..	…….
Name	Signature	Date

ABSTRACT

Most Addis Ababa City arterial streets furnished with inappropriate faded pavement markings which increase the exposure are road users for the accident. Understanding the durability performance of pavement marking material over time is important to establishing an optimum pavement marking strategy. In general, pavement marking performance is judged by two criteria: durability and visibility. Durability refers to the amount of material remaining on the pavement surface over time. This paper mainly focuses on durability performance, because it affects both the daytime and nighttime appearance of markings, for development of pavement marking degradation model.

The percentage of pavement marking remaining on the pavement surface was collected from 37 arterial streets in the Addis Ababa City which has almost the same traffic volume, pavement condition, drainage condition and different in service life. From those streets, 24 roads are painted by thermoplastic and the remaining is painted by traffic paint pavement marking materials. Based on the durability and age as a dependent and independent variable respectively, degradation model was developed and used to estimate the safe service life of pavement markings. Estimated life cycles and total installation costs were used to determine the materials' annual costs.

The research finding indicated that linear model is more reasonable than the polynomial and exponential models. The durability degradation rate per month was 3.36% for thermoplastic and 5.48% for traffic paint. It will take about 340 days (approximately 1 year) and 680 days (approximately 2 years) for white traffic paint and thermoplastic lane line markings respectively, to reach the threshold values which is 50% marking remaining on the pavement surface, hence need maintenance. And also the estimated annual cost were indicates that thermoplastic was more economical under most condition relative to traffic paint.

Keywords

PAVEMENT MARKING, DURABILITY, DEGRADATION, THERMOPLASTIC, TRAFFIC PAINT, ECONOMICAL

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LIST OF ABBREVIATION

AACRA: Addis Ababa City Road Authority

AASHTO: American Association of State Highway and Transport Officials

AADT: Average Annual Daily Traffic

AC: Asphalt Concert

ADOE: Alaska Department of Education

ADOT: Alabama Department of Transportation

ANOVA: Analysis of Variance

ASTM: American Standard for Testing and Material

BBF: Brightness Benefit Factor

D_R: Durability

ERA: Ethiopian Road Authority

EPA: Environmental Protection Agency

EUAC: Equivalent Uniform Annual Cost

LCCA: Life Cycle Cost Analysis

MOFED: Ministry Of Finance and Economic Development

MUTCD: Manual on Uniform Traffic Control Devise

NPV: Net Present Value

PCC: Portland Concrete Cement

ODOT: Ohio Department of Road Transportation

OLS: Ordinary Least Square

RL: Retroreflected Luminance

UDOT: Utah Department of Road Transportation

VDOT: Virginia Department of Road Transportation

VOC: Volatile Organic Compound

CHAPTER 1 INTRODUCTION

1.1 Background

Road traffic safety aims to reduce the harms (death, injuries and property damage) resulting from crashes of road vehicles traveling on public roads. The main goal of road traffic safety is protection and security of all those who travel on roads (MUTCD, 2009). Major factors that contribute to the road traffic safety can be grouped into three categories:

- Road characteristics
- Vehicle characteristics and
- Pedestrians and drivers' behavior

In this paper, focus on the pavement markings as one of key elements of roads. Pavement markings, as an important traffic control facilities, play a key role in defining the right of way, warning of a dangerous condition, and offering auxiliary information. City engineers and other public officials understand the need to mark roadways. Pavement markings play a key role in the driver's understanding of the roadway and ability to stay on lane. By helping the driver stay on course, pavement markings reduce the risk of accidents.

Today there are several different techniques and technologies for pavement marking materials, from the cheapest (paint) to the most expensive (tape markings). Each technology has its advantage and disadvantage associated with the quality of performance, lifetime, price and implementation techniques. (Thomas, et al., 2001)

In selecting a system for a particular installation, the characteristics of the marking materials that are the greatest interest include:

- Their ability to perform their intended function, which is generally related to their visibility as quantified in terms of retro-reflectivity.
- Their durability, which is affected by the volume of traffic, the orientation of the marking, and the climatic conditions of which they are subjected; and
- Their cost.

Naturally, these characteristics tend to be interrelated, with increased durability, for example, is coupled with increased cost. Therefore, in evaluating cost, it is essential to consider life-cycle cost as opposed to simply initial installation costs.

Pavement marking performance is judged by two criteria: durability and visibility (ASTM-D713, 2009). The durability of pavement marking refers to the amount of material remaining on the pavement surface over time. Durability also affects both the daytime and nighttime performance of markings (ODOT, 2002). Understanding durability performance of pavement marking over time is important to establishing an optimum pavement marking strategy. This thesis provides a basic description of pavement marking durability performance. The durability of the marking is determined by the lasting power of the marking material. It is most often based on a physical measure, such as the percentage of the marking material remaining and the average annual retro-reflectivity of the marking. So, this paper mainly focuses on the percentage of the marking material remaining on the pavement surface to evaluate the durability of pavement marking in Addis Ababa city arterial streets.

The purpose of this paper is to present the results of an analysis of pavement marking deterioration and the predictive models that were established to determine it and provide recommendation that will be useful in selecting cost-effective pavement marking materials. The deterioration models presented in this thesis can readily be used by pavement marking managers to better allocate resources and manage pavement marking plans. AACRA, ERA, or other organizations in Addis Ababa wishing to further their understanding of pavement marking degradation can quickly and easily gain insight into the analysis of the results presented here. While the mode is directly related only to thermoplastics and traffic paint pavement markings, the methodology applies to pavement markings of every type.

At the inception of this research, it was necessary to collect durability performance and installation cost data from Addis Ababa City arterial streets pavement markings and conduct durability performance model and life cycle cost analysis. Thermoplastics and traffic paint are the only pavement marking materials used in the city arterial streets.

1.2 Statement of the Problem

Most Addis Ababa City arterial streets furnished with inappropriate faded pavement markings which increase the exposure are road users for the accident. The practice of pavement marking management in the city is not supported by research. AACRA maintain their pavement markings by conducting condition survey, but it's not systematic. And also there is a public doubt on the pavement marking materials which are best for the city with regard to life-cycle cost. This kind of operation never tells about the future demand for pavement marking maintenances. It is found necessary to devise some mechanism which can help the road agencies to manage their roads asset properly.

Modeling of the deterioration of pavement marking is one of the mechanisms that can help the management of the road markings. It was emphasized that several degradations of pavement marking models have been proposed over the years, but many of these models were developed based on visibility performance of pavement marking. But, in this paper, the degradation model was developed based on the variable of the durability performance of pavement marking, which is the amount of pavement material remaining on the pavement surface over time. This is because, in Addis Ababa city, the traffic flow is more in the daytime rather than nighttime. And also there is poor painting practice, poor drainage condition and poor surface condition which are a significant impact on durability performance rather than visibility performance.

The deterioration models presented in this thesis can readily be used by pavement marking managers to better allocate resources and manage pavement marking plans. AACRA, ERA, or other organizations in Addis Ababa wishing to further their understanding of pavement marking degradation can quickly and easily gain insight into the analysis of the results presented here.

1.2.1 Gaps in Research

Pavement marking performance is judged by two criteria: durability and visibility. Most researchers was construct their degradation model based on the variable of the retro-reflectivity value of pavement marking which is considering the visibility performance of pavement marking. But in this thesis deterioration model was developed based on the variable of durability value of pavement marking over time.

1.3 Research Objectives

The general objective of this study is to evaluate the durability performance and cost of white lane line pavement marking material in Addis Ababa City arterial streets.

The specific objectives of the thesis will be:

- To create durability degradation model for thermoplastics and traffic paint pavement markings.
- To predict the safe service life of pavement markings based on their deterioration rate.
- To determine the cost-effective pavement marking material in the city.

1.3.1 Research question

The major questions that the research tried to answer include the following:

1. What are the relationships between the service life and durability performance of pavement markings?
2. What is the safe service life of pavement marking? / At what time pavement marking materials should be replaced?
3. Which pavement marking material is best with respect to life-cycle cost?

1.4 The significance of the study

Through a review of the relevant literature, it was made clear that development of degradation models can greatly assist in the management of pavement markings. By developing a degradation model for thermoplastic and paint pavement markings, this research will add a tool to the field of pavement marking management. The degradation models presented in this thesis can readily be used by pavement marking managers to better allocate resources and manage pavement marking maintenance schedule. AACRA, ERA, or other organizations in Addis Ababa wishing to further their understanding of pavement marking degradation can quickly and easily gain insight into the analysis of the results presented here.

Each study examined in this thesis effort provided insight into the nature of pavement marking degradation and encouraged future research in this area. While the significance

of this research has yet to be fully realized, the application of this research in asset management programs specifically pavement marking maintenance department has tremendous potential.

1.5 Scope and limitation of the study

As the topic of pavement marking performance evaluation touches lots of areas and wide, it is necessary to define the scope of the study so that the untreated topics could be left to other researchers.

Generally, there are three line types of pavement markings at each road segment (see Figure 1-1). These are white edge line, white lane line and yellow center line pavement markings (MUTCD, 2009). But in this thesis only white lane line was considered to evaluate the durability performance of pavement marking. Because white lane line pavement marking has a high probability to tire contact relative to the white edge line and yellow center line. Hence, it has the performance determinant of pavement marking.

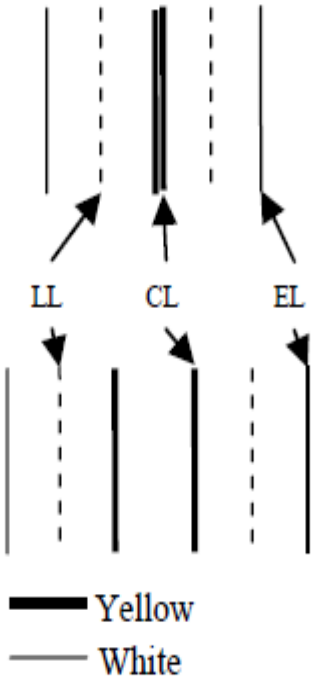

Figure 1-1: General pavement marking lines

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Pavement markings are traffic control lines that convey continuous information to the motorists and pedestrians about the roadway path and restrictions. 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, 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.

Pavement marking usage can be broadly classified as to how the markings are used (laid out) on the road. Possible marking uses would be longitudinal, transverse, symbols, words, and special markings (TSM, 2010). One major concern with degrading the performance of pavement markings arises in the case of longitudinal markings that are used for delineating the traffic in different directions or along the same direction. Poor visibility of longitudinal pavement markings can be a contributing factor in vehicular crashes.

Longitudinal pavement markings can be further classified as centerline markings, edge line markings, and lane line markings. Centerline markings are used to separate traffic flowing in opposing directions and are always yellow in color. Centerline markings can be either a lane line (also called skip or broken lines) or a double line with a combination of broken and solid lines. Edge lines are solid yellow or solid white line and are used to mark the edge of the travel lane. Lane lines are used to mark lanes along a single direction when multiple lanes exist. Lane lines are always white in color and are typically a broken line unless passing is not permitted. Also white dotted lane lines are sometimes used in merging areas to delineate merging lanes (MUTCD, 2009).

This chapter provides information through a review of the different kinds of literature from 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' performance (Retroreflectivity/ visibility and durability).

2.2 Pavement Marking Materials

A typical pavement marking material consists of binders, pigments, fillers, and glass beads (ASTM, 2005). Binders are responsible for the thickness of marking material and adhere to the road surface, pigments distribute color throughout the mix, and fillers impart durability to the mix. The retroreflective effect of pavement markings is made possible with the help of small glass beads which are added by dropping them on the marking during the application of the material in liquid form.

Pavement markings are sometimes defined by the type of marking material. There are 16 types of line marking materials available on the market (Migletz, et al., 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. Addis Ababa city road authority (AACRA) and Ethiopia road authority (ERA) primarily uses two pavement marking materials: traffic paint and thermoplastics. Traffic paints make up nearly 35 percent of the pavement marking inventory for the Addis Ababa while thermoplastics represent 65 percent.

Thomas and Schloz 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, et al., 2001).

Some of the commonly used pavement marking materials like traffic paints and thermoplastic are discussed in this section. Advantages and disadvantages of these pavement marking materials will also be discussed.

2.2.1 Traffic Paint

One of the most widely used pavements marking materials is waterborne traffic paint. Waterborne traffic paints are the least expensive pavement marking material available and are environmentally friendly, with less Volatile Organic Compound (less than the permissible limit of 150 g/L of VOC) and easily disposable. Conventional solvent paints, though more durable than waterborne traffic paints, have high VOC content and have seen diminishing use after the introduction of new regulations by the Environmental Protection Agency (EPA). Another advantage of waterborne traffic paints is that it can be applied with greater thickness when compared to solvent-based traffic paints. Waterborne traffic paints are most commonly installed using large mobile-truck mounted sprayers that apply paint striping at a rate of approximately 12 mph. Glass beads may be premixed with the paint or sprayed immediately on to the top of the paint to achieve a desired level of reflectivity. Traffic paints are normally applied in a thickness ranging between 15 and 20 mils. The higher thickness of waterborne paints can hold larger glass beads which can be more efficient in terms of visibility (retroreflectivity) during wet-night conditions (ASTM-D713, 2009).

Waterborne traffic paints perform similarly on asphalt and concrete pavements, but the durability of waterborne traffic paints has been a common complaint of many state agencies. Waterborne paints wear off quickly and lose their Retroreflectivity sooner than other pavement marking materials when exposed to high traffic conditions. For the above reason, waterborne traffic paints are typically used for temporary pavement markings or in areas with low traffic volumes, unless restriped at least annually. Also, due to the short service life of waterborne markings, several state agencies prefer to repaint the waterborne markings on a fixed schedule rather than restriping based on quantitative measures (TxDOT, 2004).

2.2.2 Thermoplastic

Thermoplastic is also another widely used pavement marking material due to its moderate cost and long durability. It's generally classified by the type of binder used: hydrocarbon-based or alkyd-based. Alkyd-based binders are more widely used because they are resistant to chemical decomposition from motor oil and other hydrocarbon contaminants. This issue is most relevant for transverse markings. Thus, alkyd-based

binders are used in transverse and longitudinal applications, while hydrocarbon-based binders are strictly used in longitudinal markings (Migletz, et al., 2002).

Thermoplastics are generally composed of four ingredients: binder, glass beads, titanium dioxide and calcium carbonate. The binder is used to hold the mixture together as a rigid mass, the glass beads are used to provide reflectivity, the titanium dioxide is used for reflectivity enhancement, and calcium carbonate or sand is used as an inert filler material. Typical thermoplastic markings are 15 to 33 percent binder, 14 to 33 percent glass beads, 8 to 12 percent titanium dioxide and 48 to 50 percent filler (Ahmad, et al., 2001).

Thermoplastics have significantly higher costs when compared to paints. Typically installed costs of thermoplastics marking material is range from $4.50 to $6.00 per square foot for inlaid thermoplastic pavement markings and $0.19 to $0.26 per linear foot for sprayed pavement markings. Costs of sprayed thermoplastics are based on a four-inch wide longitudinal stripe. But the costs are 1990 dollars (Henry, et al., 1990).

Thermoplastics are applied in a molten state (425º F) by extrusion or by spraying onto the roadway surface. Thermoplastics in a molten state form a chemical bond with the asphalt surface, resulting in a hard, durable product. Because a proper bond depends on this chemical reaction with the asphalt, bonding thermoplastics to concrete surfaces is recommended. Older roads with less asphalt binder may not provide sufficient asphalt material to form a chemical bond. When compared to alkyd, latex and epoxy paints, thermoplastics are the most sensitive to surface preparation and atmospheric conditions during installation. Typically the road surface is lightly ground before thermoplastics are applied so that a better bond is formed with the surface material. Bond performance is improved by up to 60 percent when this process is used compared to direct surface bonding (Martin, et al., 1996).

The right amount of material must be used at the right temperature and thickness to generate the proper heat transfer between the thermoplastic material and the roadway to produce a good bond. It is suggested that surface and air temperatures be at least 55 degrees Fahrenheit for proper heat transfer to occur. Typical thicknesses of sprayed thermoplastics range between 60 and 90 mils when applied at an average speed of approximately 12 mph. Extruded thermoplastics are generally 90 to 120 mils in

thickness when applied at an average speed of approximately three miles per hour (AASHTO-M249, 2008).

Thermoplastics perform well on asphalt pavements, but not as well on concrete pavements. It is reported that many state agencies have discontinued the use of thermoplastic pavement markings on concrete pavements. Thermoplastics tend to crack away from concrete resulting in reduced retro-reflectivity and durability of the marking.

2.3 Performance Evaluation of Pavement Marking

In general, pavement marking performance is judged by two criteria: durability and visibility. Durability refers to the amount of material remaining on the pavement surface over time (ASTM-D713, 2009). Durability affects both the daytime and nighttime appearance of markings. Durability performance is often measured either by determining the percentage of material remaining on the surface or by directly testing the bond strength of a material to the surface. Visibility relates to the brightness of the material. Visibility is particularly a nighttime performance measure when the retroreflective properties of the markings greatly influence their ability to be seen. Daytime visibility is related to the contrast of the marking with the pavement surface.

Pavement marking performance can be broken into two main categories: visibility factors and durability factors. Table 2-1 lists some of the major factors for each category (Ahmad, et al., 2001).

Table 2-1: Factors affecting pavement marking performance.

Visibility Factors	Durability Factors
• Contrast • Retroreflectivity • Presence • Pavement Texture • Pavement Color • Marking Color • Marking Type • Marking Size • Headlamp Type • Viewing Geometry • Ambient Lighting Conditions	• Marking Material • Marking Thickness • Pavement Type • Pavement Texture • Traffic Volume • Weather • Maintenance Activities • Marking Location (Edge line, Centerline, Lane line) • Roadway Geometry (Horizontal Curves, Weaving Areas, etc.)

Much of the research concerning marking visibility uses retroreflectivity as a proxy measure for visibility performance, but for this thesis, durability is the proxy measure for the general performance of the pavement marking. These criteria are discussed next in detail.

2.3.1 Durability

In general, pavement marking performance is judged by two criteria: durability and visibility. Durability refers to the amount of material remaining on the pavement surface over time. Durability affects both the daytime and nighttime appearance of markings. Durability performance is often measured either by determining the percentage of material remaining on the surface or by directly testing the bond strength of a material to the surface. So, this paper mainly focuses on the percentage of the marking material remaining to evaluate the durability of pavement marking in Addis Ababa city main roads.

The durability of a pavement marking is typically measured by assessing the amount of material remaining on the roadway on a scale of 0 to 10, where 0 indicates that the material has been completely lost and 10 means that 100% of the material is remaining**.** Figure 2-1 depicts the durability rating procedure used by the Ohio Department of Transportation (ODOT) (ODOT, 2002). As can be noticed in this figure, different durability ratings can be assigned to the marking material depending on the amount of material remaining on the surface. Several factors affect the durability of the pavement marking including material type, traffic volume, surface type, and environmental conditions.

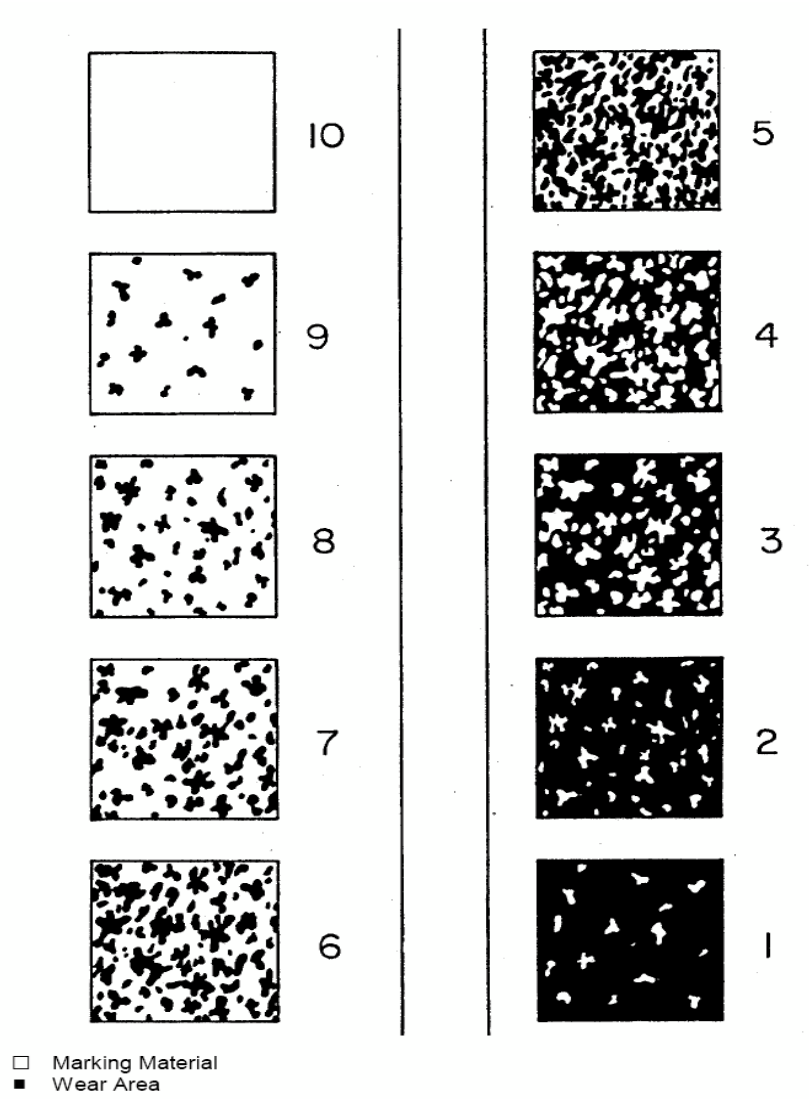

Figure 2-1: **Pavement Marking Durability Performance Rating**

Durability evaluation is performed by three trained evaluators. The evaluators separately rate markings on a subjective scale of 0-10, where a rating of 10 interprets, as 100% of the marking remains as it was originally installed. Averages of all evaluators' scores are to be the final score and also they conclude that the durability value is 5 (50%), it is the threshold value for pavement marking performance. But in this thesis to eliminating human entry error use, MATLAB image processing computer software to determine the amount of material remaining on the roadway by percent.

2.3.2 Retroreflectivity

Nighttime visibility of pavement markings is generally described using the marking retroreflectivity, which is defined as the portion of incident light from the vehicle headlight beams reflected the driver after striking the marking material (ASTM, 2005). Pavement marking Retroreflectivity is typically provided through the use of round transparent glass beads that are partially embedded in the marking material. To ensure that the retroreflection will happen effectively, the embedment depth of glass beads is critical. For optimum retroreflectivity performance, 50 to 60% of the glass beads diameter must be embedded in the marking material.

Pavement marking Retroreflectivity is quantified using the coefficient of retroreflected luminance, RL, represented in mill candelas per square meter per flux (McD/m^2/lux); (Transafety, 1998). This coefficient is calculated by dividing the luminance or the amount of light available for seeing or reflected in a particular direction, by the luminous flux defined as the rate of flow of light over time. It is commonly measured using hand-held and mobile reflectometers that vary in cost, required manpower, data accuracy, equipment reliability, and compliance with current standards (Migletz, et al., 2000). The American Standard for Testing and Materials (ASTM) specifies a minimum retroreflectivity value of 250 McD/m^2/lux and 175 McD/m^2/lux for new white and yellow markings respectively (ASTM, 2005). Some States have different requirements, while others do not have any requirements.

2.4 Pavement Marking Degradation Modeling

Through the different studies, it is revealed that Retroreflectivity and durability 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, et al., 2008). 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:

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

$$T100 = 10^{(Ro-100)/b}$$

Where:

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

Ro = 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/m2/lx. No goodness of fit measures has been published for this model and it has considered only the retroreflectivity value as a dependent variable.

Migletz and its friend's 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 and it was not considered the performance of the materials with respect to durability. 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, a 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, et al., 2000).

In a follow-up study, Migletz and its friend's 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:

- The average life of waterborne white paint markings was 10.4 months
- The average life of thermoplastics was 26.2 months (white) and 27.5 months (yellow).

Pavement marking degradation modeling for traffic paint and thermoplastic markings was developed by sitabee and its friends. 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 paint (Sitabee, et al., 2008).

Generally, most of the above study was evaluate the performance characteristics of pavement markings in terms of only the retroreflectivity value as the dependent variable and its degradation model was based on their factors affecting pavement marking performance. But in this thesis evaluate the performance characteristics of pavement markings in terms of durability value as the dependent variable because durability is one of the criteria to judge the performance of pavement marking.

2.5 Pavement marking service life

The service life of a longitudinal pavement marking is the time or number of traffic passages needed for its Retroreflectivity to decrease from the initial value to a minimum threshold value under which the marking needs to be refurbished or replaced (Migletz, et al., 2002). But in this thesis, the service life of a longitudinal pavement marking is the time needed for its durability to decrease from the initial value to a minimum threshold value under which the marking needs to be replaced. It is a function of the pavement marking material, pavement surface type, type and color of the line, traffic volume, the

climate, and the quality control when the markings are applied. Dale found that the increased speed and truckload can also reduce the service life (Dale, 1988). AC pavements have longer service lives than PCC pavements, and white lines have longer service lives than yellow lines.

The life of paint pavement marking is dependent on traffic levels; use of sand and abrasives; and the type of surface upon which they are used (i.e., asphalt or concrete). The life of paint pavement markings is normally ranged between three and thirty-six months, depending on traffic volume and weather conditions (Migletz, et al., 2002).

Thermoplastic markings provide excellent performance when applied properly, being the most durable of the commonly used pavement marking system. The life of thermoplastic markings, however, varies widely because of its dependence on installation procedures, the volume of traffic, atmospheric conditions when placed, and snowplow activity. Life expectancy typically ranges from four to seven years (KDOT, 1999). This relatively long service life can exceed the interval between pavement maintenance activities.

The life of pavement marking is typically determined using the following criteria: wear, Retroreflectivity levels, and discoloration. In terms of wear, it is assumed that the useful service life of sprayed thermoplastics is reached when only 10 to 15 mils of the marking are remaining. Another form of failure results from deterioration of the surrounding pavement, which can lead to pulling out of the material from the pavement structure.

The Utah Department of Transportation (UDOT) tried to conclude the relationship between pavement marking life expectancy and traffic levels, such as AADT (Martin, et al., 1996). The UDOT identified the main elements of pavement marking management system without developing such a system. Only AADT and age were considered to predict the reflectivity measurements and to calculate the service life of marking material. Other initiatives took place to evaluate the pavement markings in cold regions through rating existing marking, measuring retro-reflectivity and evaluating the overall performance of markings using subjective opinion survey (Fares, et al., 2009). These initiatives focused on the impact of pavement marking patterns on drivers, minimum reflectivity requirements, and performance of reflectivity and service lives of pavement markings. There are models to assess the condition of various pavement marking materials in different weather conditions.

2.6 Pavement Marking Economic Evaluation

The objective of a pavement marking economic evaluation is to identify the most economical pavement marking materials. Two major methods have been employed.

Lindly and its friends was used life-cycle cost analysis (LCCA) to compare different marking materials for Alabama DOT. LCCA assumes the alternatives yield the same level of service, provided the durability of the pavement markings meets the minimum value requirement. LCCA requires identification of pavement marking service life and total cost and then calculate the equivalent uniform annual cost (EUAC). The material with the lowest EUAC is selected (Lindly, et al., 2003).

2.6.1 Equivalent Uniform Annual Cost Analysis (EUAC)

In this method, all costs (initial and future costs) are combined into equal annual payments over the analysis period. A benefit of this method is the simplicity and ease of understanding that it offers for public officials. In order to perform the EUAC method, the suggested first step is to determine the net present value (NPV) which is the initial cost of pavement marking material and then use Equation 2-1 to convert the present costs into annual uniform costs.

$$EUAC = NPV * \left[\frac{i * (1+i)^{n}}{(1+i)^{n} - 1}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation 2.1$$

Where

n = number of years into the future

I = discount rate

NPV = net present value (initial cost of pavement marking)

KDOT (KDOT, 1999) applied benefit-cost analysis. They assume that higher values of Retroreflectivity produce higher user benefits and that the total benefit is the total Retroreflectivity produced during the service life of the marking material. The brightness benefit factor (BBF) is the ratio of the total Retroreflectivity and the total cost during the service life. As a result, the material with the highest BBF value is selected.

Cottrell and Hanson (Cottrell, et al., 2001) used cost-effectiveness analysis to select marking materials for Virginia DOT (VDOT). They found that there is not much benefit in using a marking with a retroreflectivity value greater than 600 McD/m^2/lux compared to one with a value of 300 McD/m^2/lux. As a result, their study did not use retroreflectivity as a benefit, only service life. The result of their economic analysis is a table of total cost per mile of pavement marking materials for different study periods.

The components of total cost vary from study to study. In a broad sense, total cost includes installation cost (including application cost and removal cost of old material if needed), user cost due to traffic delay, Retroreflectivity measurement cost if any, and safety cost due to pavement marking related accidents. Installation cost per unit length varies greatly according to the job site. The larger the contract, the lower the installation cost. The number of lanes to be remarked also impacts the cost. KDOT (KDOT, 1999) and VDOT (Cottrell, et al., 1996) included installation and user costs, Utah (Martin, et al., 1996) and Alabama (Lindly, et al., 2003) used installation cost only. Abboud and Bowman (Abboud, et al., 2002) used installation cost and crash cost to calculate total cost.

Because installation costs only occur once in a material's life cycle, the costs must be distributed throughout the life cycle. This distribution is done using a conversion method from the present value to annual value with the assumed interest rate. The annual cost of the pavement marking material will show its economic efficiency, but this estimation is not definite.

Generally, Literature has revealed that numerous factors affect pavement marking performance, such as traffic, marking age, geographical locations, nature and type of pavement surface and environmental conditions.

CHAPTER 3 METHODOLOGY

This section presents the methodology used for data collection and analysis in this study. One of the objectives of this study is to create a pavement marking degradation model for thermoplastics and traffic paint pavement marking in Addis Ababa arterial streets. To accomplish this, the durability of pavement marking in terms of service life is measured. Based on the durability and service life as a dependent and independent variable respectively, degradation model will be developed and used to estimate the safe service life (lifespan) of pavement markings. Linear regression analysis was employed as the modeling method. The monetary cost of providing such pavement markings will be estimated. The cost can be converted to annualized cost by taking the cost per kilometer and dividing by the lifespan of pavement marking. And the material with the lowest annualized cost is the preferred choice.

For the most results reported herein, the available dataset was reduced to roads that used thermoplastic and traffic paint pavement markings. A range of possible variables was evaluated for inclusion in the model, but only those variables with a significant impact on the degradation of pavement markings were kept in the model.

3.1 Research Design

The research methodology employed in this thesis outlines the steps used to answer research questions as described in section 1.3.1 above. A key data source used for the entire study was the durability which is the percentage of pavement marking remains on pavement surface and installation cost for one kilometer arterial streets in the city. The research relied mainly on primary data sources; however, some data was derived from secondary sources.

The main aim of this research is to find out the truth which is hidden and which has not been discovered as yet. Though the study has its own specific purpose, in this research some of the methodologies used are:

- Studies with this object in view are known as descriptive research studies. The descriptive research attempts to describe, explain and interpret conditions of something i.e. “what is’.

The purpose of a descriptive research is to examine a phenomenon that is occurring at a specific place and time. So, this research tries to evaluate the durability performance of pavement marking at a time.

- Regarding application, this research uses a method of applied research methodology in which it tries to find a solution or recommendation for the current problem in AACRA regarding the established proper pavement marking maintenance schedule.
- Regarding data, the collected data from the concerned body are analyzed using quantitative research methodology method to get some relation between them.

Following are some specific methods in this research.

- First of all analysis regarding the study area is made in which the current practice of pavement marking management in the city is reviewed
- Literature which discusses performance evaluation of pavement marking materials assessed deeply to understand what performance measure is and also how this performance evaluation was done using some performance indicators.

3.2 Data Collection

In this thesis literature studies, site observations, site selection, sampling and field measurements were carried out to collect necessary data for the research.

3.2.1 Literature Studies

In this thesis, different kinds of literature were studied as a source of information or secondary data. Among them, journals and reports prepared to focus on the performance of pavement marking materials were the major ones. Documents like the painted date (service life) of pavement marking data were collected from AACRA pavement marking department contract documents for each arterial street in the city is shown in Appendix A: Collected Data from AACRA. Besides the documents collected from the above mentioned governmental institution different documents relevant to the performance of marking materials and its deterioration rate with time were collected from pavement marking maintenance department committee in AACRA and from websites. All these documents were studied and analyzed accordingly to meet the objective of the thesis.

3.2.2 Site Selection

Before selected the representative site of roads, first the painted date (service life) of pavement marking data were collected from AACRA pavement marking department contract documents for each main road in the city and make a reconnaissance's survey by using a motorcycle conduct with 21.8 MP SONY video camera (see Appendix H: Photo Gallery). Then 37 arterial streets were selected based on the service life of pavement marking, high traffic volume, good pavement condition and good drainage condition. From those streets, 24 streets are painted by thermoplastic and the remaining 13 streets are painted by traffic paint pavement marking materials. The selected road name, its service life, and other information are shown in Appendix B: Selected Arterial streets.

3.2.3 Sampling Technique

The sample size was determined based on the basic principles of sampling, the level of accuracy planned, type of research design and the scope and limitations of the thesis work. In principle, there are different types of sampling techniques to be used during sample selection processes. Simple random sampling type was used for this thesis. This is because each strip or spot has an equal and independent chance of being included in the sample.

At each of the selected main road, at least 10 strip or spots were delineated on the pavement marking randomly. Therefore totally more than 740 strips or spot were delineated on the pavement marking using blind folded techniques. (See Appendix G: Durability Value). The average of the 10 durability measurements at a location represents the overall durability value for the selected road site at a given service life. For each strip/spots observation were done twice within fifteen days interval.

3.2.4 Durability Data Collection Method

A 21.8 MP SONY video is used to capture a current existing condition of pavement marking (percent remaining of pavement marking) for selected Addis Ababa arterial streets. The durability data was collected for six consecutive month week ends from September to March 2009 EC. The available data set was reduced to only those roads that used thermoplastic and traffic paint pavement marking materials. During data collection, the following criteria should be considered so as to get original and representative durability result.

- The strip is not around the intersection or accessing point (excessive braking or turning movements)
- If the selected road is deteriorated, select the strip with minimal cracking and/or pavement deterioration.
- The strip is at good drainage and with full exposure to the sun throughout daylight hours.
- The pictures were taken at a constant height which was 1.2m above from the pavement surface and before taking the picture clean the strip.

3.2.5 Durability Measuring Techniques

The durability of a pavement marking is typically measured by the amount of material remaining on the roadway. So the qualitative picture data was converted to the percent remaining of pavement marking (durability) quantitative data by using a combination of Adobe Photoshop CS6 and Matlab R2016a computer software. The MATLAB code which is used to convert a single marking strip picture to a durability value is shown in Appendix C: MATLAB R2016a Image Processing Code and Adobe Photoshop CS6 were used for detecting R-G-B value of a deferential element of a given picture. The MATLAB code was written based on R-G-B fundamental coloring system, which is the amount of marking remaining on the roadway is considered as white and quantify in terms of percent.

3.3 Methods of Data Processing and Analysis

The impact on durability values by placement activities and other variables such as traffic volume, inside/outside edge of highways, climatic condition and the adhesion of markings with pavement surfaces, to make it clear that a great deal of data processing and stratification would be necessary to produce a statistically strong model. After some preliminary analysis, it was decided that the best modeling approach was to divide the dataset into subgroups and develop separate models for each group. The selected road sites were thus grouped into categories based on combinations of the following characteristics:

- Pavement surface–ACC
- Marking material–thermoplastic and paint
- Marking color – white

- Traffic volume – almost similar to all selected streets, which is high traffic volume

Therefore data was available for only two possible combinations: White Thermoplastic on Asphalt and White paint on Asphalt. Simple linear regression was used to describe the relation between dependent and independent variables. As expected based on insight gained from the literature review, time was a significant independent variable.

3.3.1 Regression Analysis

Regression analysis is the main method for estimating the relationship between the output and inputs in this study. It involves a single dependent variable or response, *Y*, which is uncontrolled in this analysis. The response depends on one independent or regressor variable that are measured with negligible error and controlled. The relationship fits a set of observational data is characterized by a prediction equation called a regression equation.

In this thesis, the regression is a single variable regression and the dependent and independent variable are durability, which is the percentage of pavement marking remaining on the pavement surface, and age of pavement marking respectively.

The smaller the variability of the residual values around the regression line relative to the overall variability, the better our prediction. For example, if there is no relationship between the *X* and *Y* variables, then the ratio of the residual variability of the *Y* variable to the original variance is equal to 1.0. If *X* and *Y* are perfectly related, then there is no residual variance and the ratio of variance is zero. In most cases, the ratio would fall somewhere between 0 and 1.0. One minus this ratio is referred to as R-square or the coefficient of determination. The R-square value is an indicator of how well the model fits the data (i.e., an R-square close to 1.0 indicates that we have accounted for almost all of the variability with the variables specified in the model).

3.3.2 Pavement Marking Economic Evaluation

There are a number of variables that can affect the life of a given pavement marking material cost. The following are the major:-

- Analysis period
- Performance period (service life)
- Cost (construction, material, maintenance cost)
- Discount rate

- Salvage value
- User cost

But salvage value and user cost are not considered for this thesis. B/c pavement markings have no salvage value and user cost should be difficult to calculate in Addis Ababa.

3.3.2.1 Service Life Estimation

The service life of a longitudinal pavement marking is the time needed for its durability to decrease from the initial value to a minimum threshold value under which the marking needs to be replaced. The durability value is 5 (50%), it is the threshold value for pavement marking performance, which is the conclusion of ODoT, 2002. The proper regression equation and the threshold values will allow us to estimate the life cycles of the pavement marking materials.

3.3.2.2 Initial Cost Estimation

In order to estimate the total cost for the given one-kilometer of roadway segment that needs to be painted, it need to know how much it costs to install each product. The estimation of installation costs should incorporate all components of the application, including material, labor, and equipment. The material, labor and equipment cost was collected from AACRA pavement marking department contract documents for study purpose.

3.3.2.3 Equivalent Uniform Annual Cost (EUAC)

Because installation costs only occur once in a material's life cycle, the costs must be distributed throughout the life cycle. This distribution is done using a conversion method from the present value to annual value with the interest rate which was taken from Ministry Of Finance and Economic Development (MOFED). The annual cost of the pavement marking material will show its economic efficiency. The material with the lowest equivalent uniform annual cost is selected.

3.4 Summary of the Analysis Process

The analysis process for this project is summarized in Figure 3-2

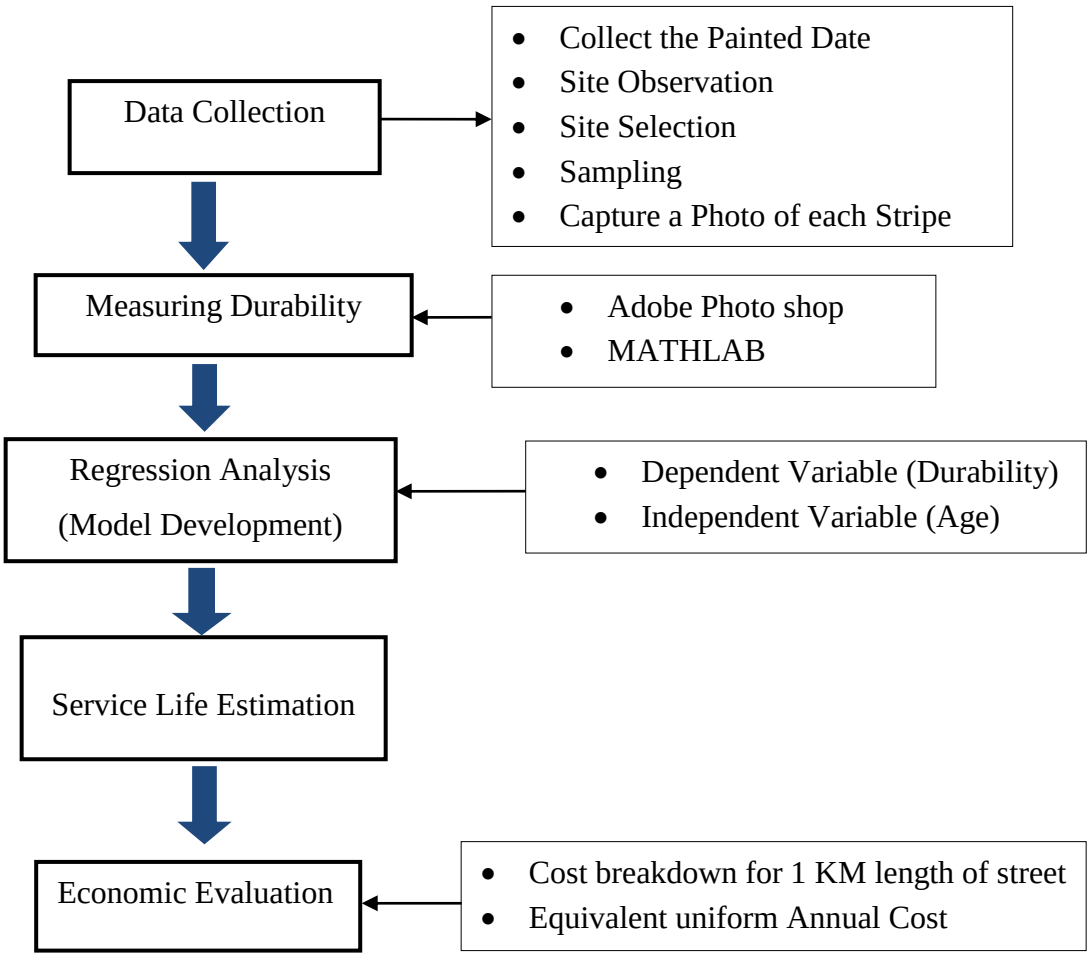

Figure 3-1: Summary of the Analysis Process

CHAPTER 4 RESULTS AND DISCUSSION

Durability data collection was performed on selected locations (sites) on highways in Addis Ababa city. As explained in section 3.2, the data collection was performed more than 10 marking stripe for each selected main streets twice within 15 days interval. Data analysis was performed using regression analysis method, using Microsoft Excel Data Analysis tool. A visual representation of the fitted regression model was shown by generating a response function surface plot (plane) also using Minitab 17.

In the regression analysis, the following factors were considered in generating predictive models: pavement marking age and pavement marking material type. Pavement age represents the age (in days) of the pavement marking from the pavement marking application date to the date of durability data was collection. Pavement marking types considered for analysis were thermoplastic and traffic paint, and colors are only white. The regression analysis was used for the data analysis and development of the pavement marking durability prediction models.

Several mathematical models were used to predict the future durability performance of material groups in different test decks by fitting these models to actual field durability data. These models were then used to predict the service life of the pavement markings. Pavement marking service life defined as the time required for its durability to drop below a preselected threshold value. Finally, based on the result provide information that will be useful in selecting cost-effective pavement marking system.

4.1 Modeling Pavement Marking Durability

Simple linear regression statistical analysis method was used for data analysis and model development. Three mathematical models were used to define the deterioration trend of pavement markings. These models include the linear model, the exponential model, and the polynomial model. The mathematical expressions for these three models are presented in Table (4-1) using both x-y and Durability, D_R, Versus Age forms. Durability, D_R, was represented in these models using present (%) and Age was represented by days.

Table 4-1: Pavement Marking Durability Models

Model Type	Mathematical Form	
Linear	$Y = a + b*X$	$D_R = a + b*Age$
Exponential	$Y = a*e^{b*X}$	$D_R = a*e^{b*Age}$
Polynomial	$Y = a*X^2 + b*X + c$	$D_R = a*Age^2 + b*Age + c$

A Microsoft Excel was developed to handle a large amount of data involved in the analysis. The developed Microsoft Excel employed the Ordinary Least Square (OLS) method in obtaining the regression model parameters. In brief, this method is based on minimizing the sum of the squared difference between the data points and the model predictions in obtaining the model parameters. This analysis method is briefly explained in Appendix D: Regression Analysis.

The sample analysis was performed on selected sites with traffic paint and thermoplastic pavement marking. Section 4.1.1 and 4.1.2 comprise of the analysis of traffic paint and thermoplastic pavement markings respectively.

4.1.1 White Traffic Paint Pavement Marking

This section presents the analysis performed on data collected from highways comprising white traffic paint pavement markings. Table 4-2 is present the collected durability values which are the output of MATLAB and figure 4.1 – 4.3 presents the collected data in the 2D scatterplot of durability values against age for white traffic paints in the model of linear, exponential and polynomial respectively. And also Table 4-3 is present its mathematical equations and coefficient of determination R^2.

Table 4-2: Collected durability values for traffic paint marking material

Code	Service life (Day)	Durability Value For Sample N0. (%)										
		Average	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten
A'	90	89.73	75.69	84.51	89.17	80.62	95.67	98.47	97.27	98.24	91.28	86.36
	105	88.44	74.40	83.22	87.88	79.33	94.38	97.18	95.98	96.95	89.99	85.07
B'	120	76.45	64.58	78.96	84.27	67.24	89.47	64.24	77.48	85.67	70.54	82.03
	135	73.83	61.96	76.34	81.65	64.62	86.85	61.62	74.86	83.05	67.92	79.41
C'	150	81.20	71.54	89.34	84.27	89.64	80.27	90.24	75.37	71.28	82.57	77.47
	165	78.50	68.84	86.64	81.57	86.94	77.57	87.54	72.67	68.58	79.87	74.77
D'	180	76.20	75.87	56.27	87.57	86.34	87.64	59.37	79.27	80.24	77.01	72.42
	195	73.02	72.69	53.09	84.39	83.16	84.46	56.19	76.09	77.06	73.83	69.24
E'	210	54.80	64.28	71.56	49.37	44.28	65.58	46.21	55.98	42.84	40.28	67.62
	225	51.69	61.17	68.45	46.26	41.17	62.47	43.10	52.87	39.73	37.17	64.51
F'	240	70.97	54.27	78.69	80.24	79.25	69.27	67.14	68.25	73.25	75.68	63.65
	255	69.54	52.84	77.26	78.81	77.82	67.84	65.71	66.82	71.82	74.25	62.22
G'	270	50.06	41.74	56.38	65.24	45.00	39.47	46.87	46.37	61.27	40.00	58.23
	285	46.51	38.30	52.94	61.80	42.00	36.03	43.43	42.93	57.83	35.00	54.79
H'	300	51.54	44.27	62.27	48.67	56.37	41.57	35.27	58.29	61.47	57.41	49.83
	315	47.99	40.72	58.72	45.12	52.82	38.02	31.72	54.74	57.92	53.86	46.28
I'	330	57.78	62.47	55.84	57.14	48.69	56.32	48.25	63.57	66.27	69.54	49.72
	345	54.79	59.48	52.85	54.15	45.70	53.33	45.26	60.58	63.28	66.55	46.73
J'	360	49.32	41.74	56.38	65.24	43.37	39.47	46.87	46.37	61.27	34.27	58.23
	375	45.88	38.30	52.94	61.80	39.93	36.03	43.43	42.93	57.83	30.83	54.79
K'	390	41.04	41.00	42.87	32.00	51.05	58.34	30.47	32.87	41.27	38.57	42.00
	405	38.69	35.62	40.25	30.00	48.43	55.72	27.85	37.00	38.65	35.95	37.40
L'	420	40.40	38.24	42.87	30.27	51.05	58.34	30.47	32.87	41.27	38.57	40.02
	435	37.78	35.62	40.25	27.65	48.43	55.72	27.85	30.25	38.65	35.95	37.40
M'	450	38.28	38.24	35.00	30.27	51.05	45.00	30.47	32.87	41.27	38.57	40.02
	465	35.64	30.00	40.25	27.65	48.43	40.00	27.85	30.25	38.65	35.95	37.40

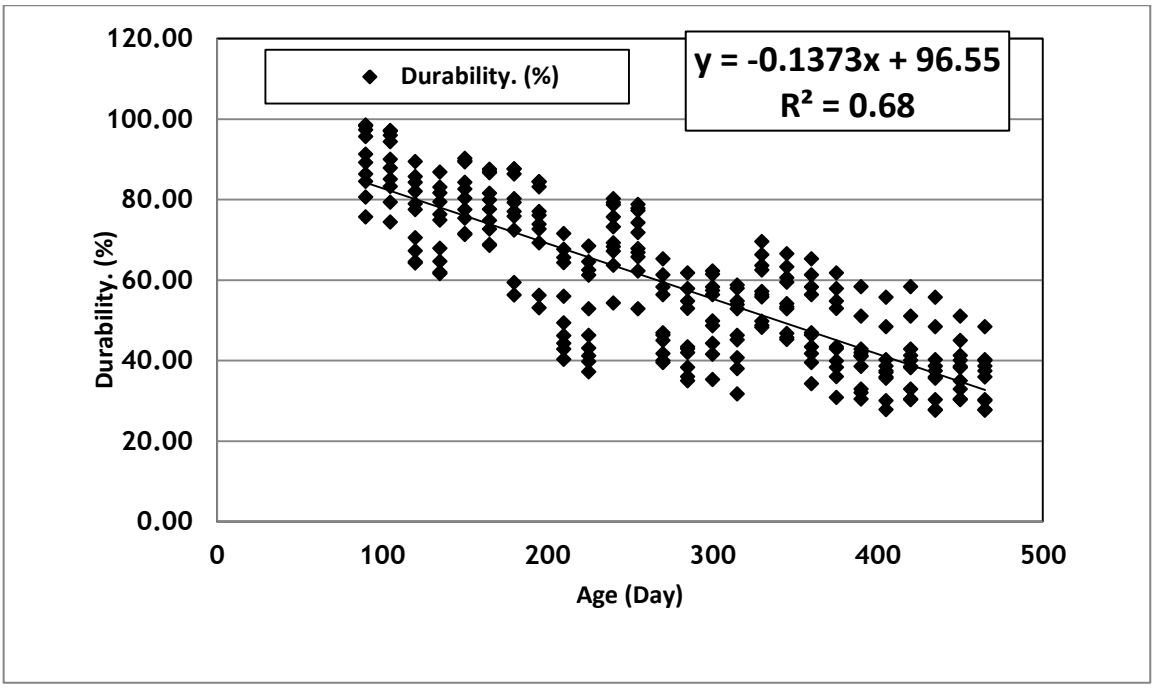

Figure 4-1: Scatter Plot, D_R vs Age for White Traffic Paints by a linear model

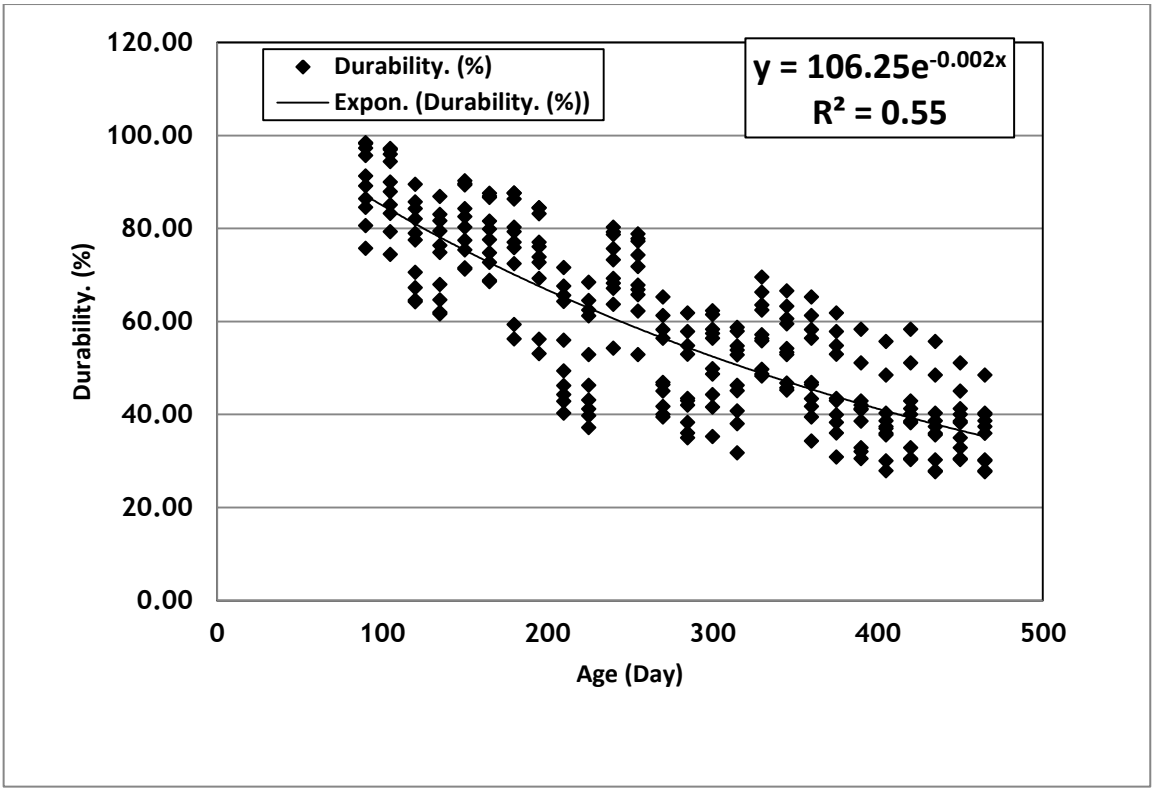

Figure 4-2: Scatter Plot, D_R vs Age for White Traffic Paints by an exponential model

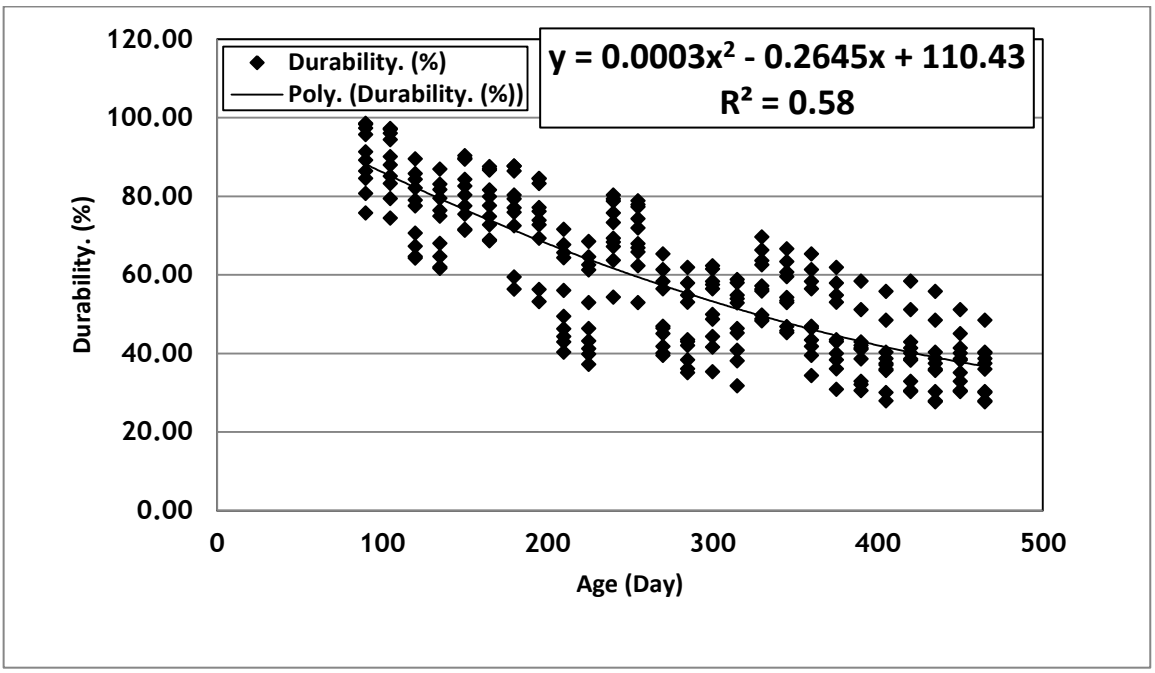

Figure 4-3: Scatter Plot, D_R vs Age for White Traffic Paints by a polynomial model

Table 4-3: Mathematical Equations and Coefficient of Determination R^2

Model Type	Mathematical Equation	The coefficient of Determination (R^2)
Linear	$D_R = 96.554 – 0.137*Age$	0.680
Exponential	$D_R = 106.25*e^{-0.002*Age}$	0.548
Polynomial	$D_R = 0.0003*Age^2 – 0.2645*Age + 110.43$	0.580

Where: - Age is the service life of pavement marking in day

D_R is Durability of pavement marking in percent (%)

From Figure 4-1 and Table 4-3, the data trend indicates a linear relationship with durability decreasing with increase in pavement marking age. And also the bar chart in Figure 4-4 shows that the durability value was decrease by average of 2.74% within two weeks. This influenced the decision of using a linear model, because it has high coefficient of determination. Hence a linear relationship model was considered as it is more likely to reflect the trend in pavement marking deterioration.

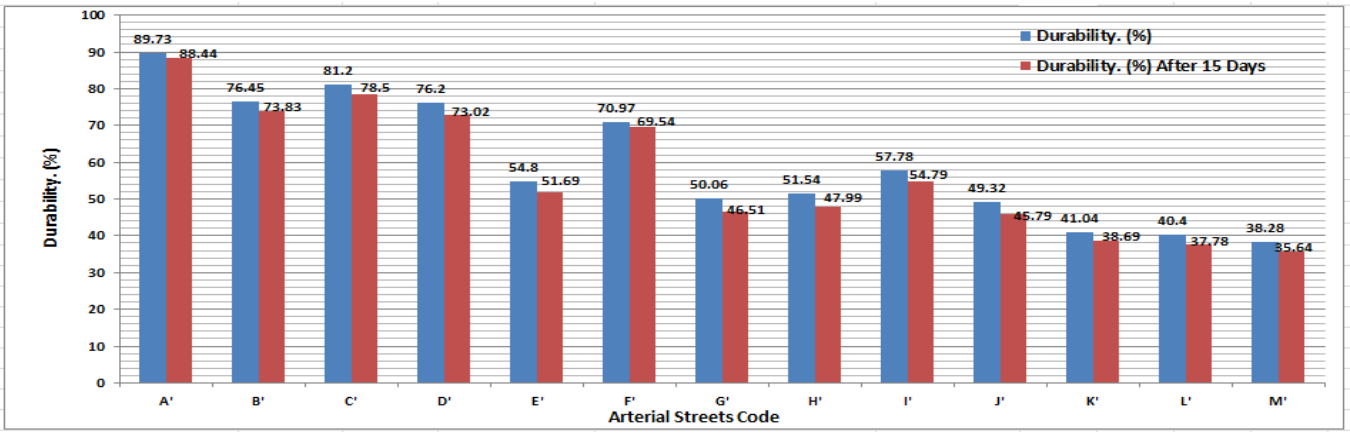

Figure 4-4: Durability value within two weeks interval for traffic paint

With this data, regression analysis was performed and the results obtained are presented in Table 4.4 – 4.6. As it can be seen in the table, this data had 260 observations with a coefficient of determination (R^2) of 0.6802 and adjusted R^2 of 0.6789. The regression analysis used a confidence level of 95%.

The output of the regression analysis from Minitab 17 (see Appendix E: Minitab 17 output for regression analysis) for white paints has three components:

- Regression statistics table for the determination of R^2 as shown in Table 4-4
- Table of analysis of variance (ANOVA) for null hypothesis analysis is depicted in Table 4-5; and
- Regression coefficients table (Table 4-6), which provides the model coefficients.

Table 4-4: Regression Statistics Output

Regression Statistics		Explanation
Multiple R	0.676	R = square root of R^2
R Square	0.680	R^2 known as coefficient of determination
Adjusted R Square	0.679	Adjusted R^2 used if more than one x variable
Standard Error	10.630	This is the sample estimate of the standard deviation of the error u
Observations	260	Number of times data was collected for number of sites (n)

Table 4-5: Analysis of Variance (ANOVA) Output

	df	*SS*	*MS*	*F*	*P*
Regression	**1**	**61998.2**	**61998.2**	**548.70**	**0.000**
Residual	**258**	**29151.8**	**113.0**		
Total	**259**	**91150.0**			

Table 4-6: Regression Coefficients Output

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*VIF*	*Lower 95%*	*Upper 95%*
Intercept	**96.55**	**1.75**	**55.03**	**0.000**		**93.120**	**99.980**
Age (Day)	**-0.13726**	**0.00586**	**-23.42**	**0.000**	**1.00**	**-0.149**	**-0.126**

If βj denotes the population coefficient of the jth regressor (intercept and age and), then a summary of the output in Tables 4.3 - 4.5, results in equation 4.1 which is the linear model for white paints:

$D_R = 96.554 – 0.137*(Age)$ …..……..……..……. (4.1)

Where: - Age is the service life of pavement marking in day

D_R is Durability of pavement marking in percent (%)

4.1.1.1 Test of Statistical Significance

From Table 4-5 it can be seen that the coefficient of age has a value of – 0.137 with an estimated standard error of 0.00586, t-statistic of -23.42 and p-value of 0.000 < 0.05. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05. Otherwise, it could be insignificant.

Assume that the null hypothesis is H_0: $\beta_1 = 0$ and the alternative hypothesis is H_a: $\beta_1 \neq 0$. From the ANOVA table, the F-test statistic is 548.70 with a p-value of 0.000. 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 is statistically significant at significance level 0.05. Otherwise, we could not reject the null hypothesis, and the parameters (age) could be statistically insignificant. Therefore age is contributing factors to the deterioration of pavement marking durability.

4.1.1.2 Test the Adequacy of Model

Two residual plots for durability (D_R) residuals against durability fitted values obtained from the model and age are also presented in 2D, so as to observe the adequacy of the generated model (Figures 4-5 and 4-6).

Residual (error or deviation) is the difference between the observed value y* of the dependent variable for the jth observational data point (x1j, x2j… xpj, yj*) and the corresponding value yj given by the regression function (model) $yj = b_0 + b_1*_{x1j} + b_2*_{x2j} + \ldots\ldots + b_p*_{xpj}$. (e. g $D_R = 96.554 – 0.137*(Age)$, 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, rj = yj* - yj.

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_2, for other factors to our model). A plot of residuals is very helpful in detecting such a correlation. Figure 4-5 presents durability residuals against durability fitted values obtained from the model. And also Figures 4-6 depict plots of durability residuals against age.

It can be observed from Figure 4-5 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.

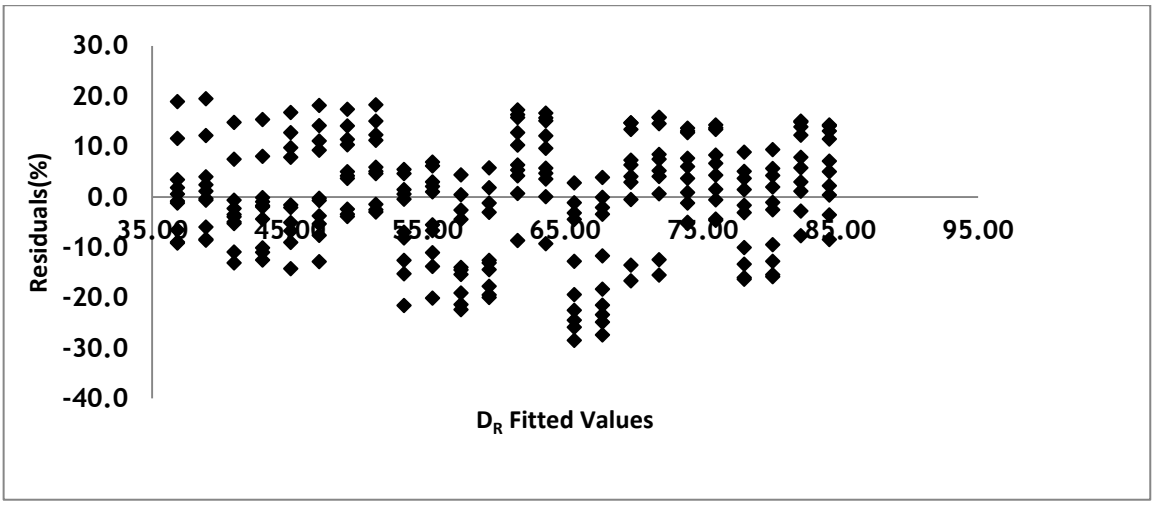

Figure 4-5: D_R-Residuals against Fitted Values for White Traffic Paints

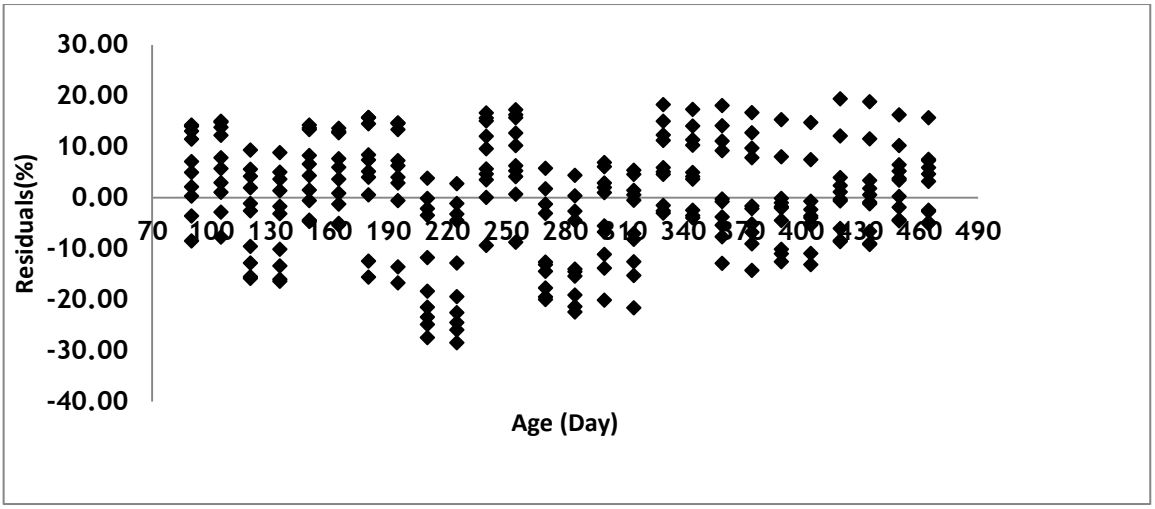

Figure 4-6: D_R-Residuals against Age for White Traffic Paints

Generally, the fact that all the residuals look like random and that there is no obvious correlation (pattern) with the fitted values and age, does not necessarily mean that by itself the model is adequate. This is considered with other parameters such as R^2, a p-value test, Normal probability plot and histogram was as shown in the Appendix E: Minitab 17 output for regression analysis. 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 the management of pavement markings.

4.1.1.3 The plot of the Regression model, Collected Data, and Residuals

This section presents plots and graphs generated after data analysis to include: predictive model line plot; and 2D plot of the residual. Figure 4-7 presents the line plot of durability values against age for the generated model (equation 4.1) of white traffic paints. The plot indicates that, in general, pavement marking durability decreases with increase in age.

The predictive surface plot in Figure 4-7 shows the graphic image of the generated model, equation 4.1. It presents the relationship between durability values and age of the white traffic paints pavement markings. It can be observed that at high traffic volume, the durability values decrease with the increase in pavement marking age. This means that, for the given asphalt highway, with high traffic volume, the deterioration of its white paint makings durability is proportional to the age of the markings.

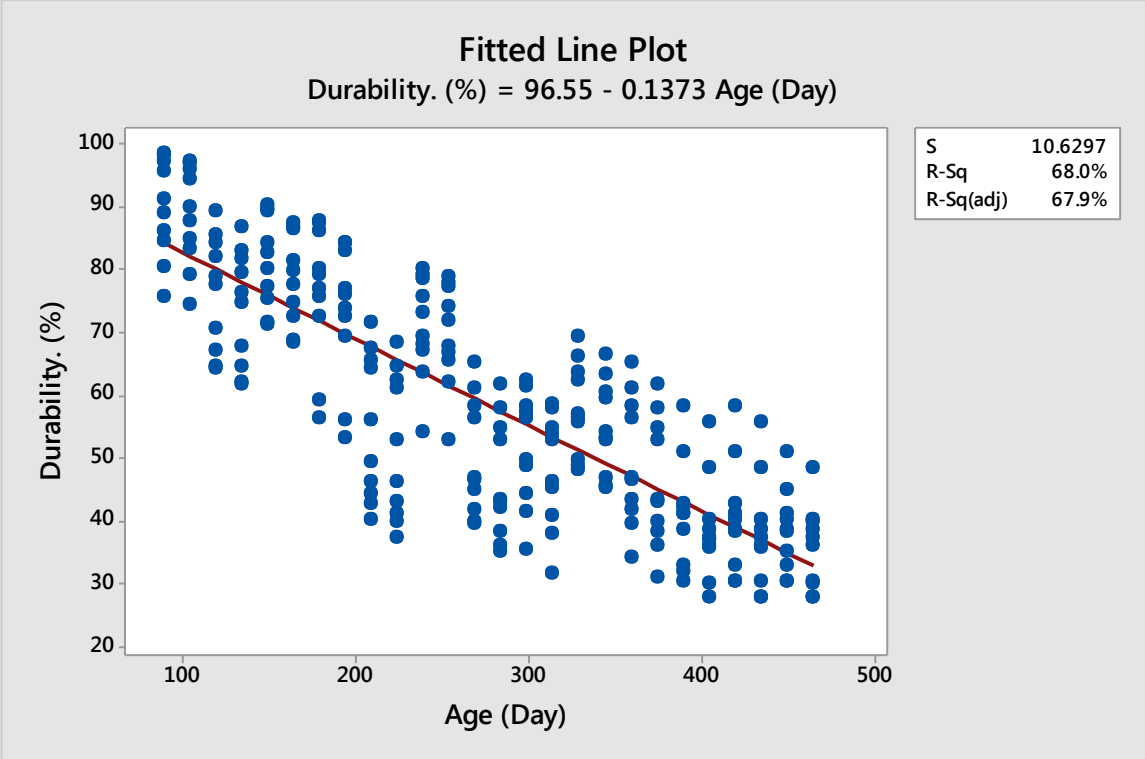

Figure 4-7: Fitted Line Plot for White Traffic Paints

Generally, it can be observed in Figure 4-7 that Durability is inversely proportional to age. That is, there is a decrease in durability values as age increase. But this is true for the pavement marking age is from 90 days to 465 days of traffic paint marking material.

4.1.2 White Thermoplastic Pavement Marking

The analysis for thermoplastic pavement marking is performed in the same way as in section 4.1.1. The analysis performed on data collected from selected road comprising white thermoplastic pavement markings. Table 4-7 is present the collected durability values which are the output of MATLAB and figure 4.8 – 4.10 are presents the collected data in the 2D scatterplot of durability values against age for white thermoplastic in the model of linear, exponential and polynomial respectively and Table 4.8 are present it's mathematical equations and coefficient of determination R^2.

Table 4-7: Collected durability values for thermoplastic marking material

Code	Service life (Day)	Durability Value For Sample N0. (%)										
		Average	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten
A	180	95.23	88.26	97.36	87.29	98.26	92.57	98.97	97.54	96.84	98.24	96.97
	195	94.25	87.15	96.18	86.21	97.21	91.13	97.69	96.36	98.26	97.06	95.29
B	210	87.59	92.67	90.25	80.47	94.27	89.36	79.48	87.54	91.57	85.69	84.57
	225	85.61	91.69	87.27	78.49	91.29	87.38	78.50	85.56	88.59	83.71	83.59
C	240	87.69	92.67	90.25	80.47	94.27	89.36	80.48	87.54	91.57	85.69	84.57
	255	86.02	91.69	88.27	78.49	92.29	87.38	79.59	85.56	89.59	83.71	83.59
D	270	67.28	60.03	69.37	61.48	73.52	78.74	59.83	66.32	60.33	67.42	75.73
	285	65.93	58.68	68.02	60.13	72.17	77.39	58.48	64.97	58.98	66.07	74.38
E	300	68.84	82.44	79.02	74.23	78.00	80.79	79.63	55.32	53.91	52.01	53.03
	315	68.50	65.98	51.13	84.83	53.35	86.77	74.48	60.00	76.98	63.40	68.12
F	330	79.65	82.44	79.02	74.23	76.43	80.79	79.63	84.02	82.61	79.06	78.23
	345	77.03	79.82	76.40	71.61	73.81	78.17	77.01	81.40	79.99	76.44	75.61
G	360	70.04	83.44	80.02	75.23	78.00	88.79	79.63	56.32	53.91	52.01	53.03
	375	68.68	82.44	79.02	74.23	76.43	80.79	79.63	55.32	53.91	52.01	53.03
H	390	67.98	65.98	51.13	84.83	53.35	86.77	74.48	54.80	76.98	63.40	68.12
	405	65.93	58.68	68.02	60.13	72.17	77.39	58.48	64.97	58.98	66.07	74.38
I	420	52.49	40.18	54.70	59.29	45.60	49.07	53.11	57.49	56.08	54.18	55.20
	435	50.32	38.01	52.53	57.12	43.43	46.90	50.94	55.32	53.91	52.01	53.03
J	450	69.45	67.45	52.60	86.30	54.82	88.24	75.95	56.27	78.45	64.87	69.59
	465	67.98	65.98	51.13	84.83	53.35	86.77	74.48	54.80	76.98	63.40	68.12
K	480	51.35	74.63	48.95	56.87	48.37	57.34	38.45	56.78	61.58	34.57	35.94
	495	50.00	73.13	47.62	55.54	47.04	56.01	37.12	55.45	60.25	33.24	34.61
L	510	49.70	50.24	38.97	31.75	48.68	69.24	56.27	48.25	45.67	39.47	68.42
	525	47.33	47.87	36.60	29.38	46.31	66.87	53.90	45.88	43.30	37.10	66.05
M	540	52.49	40.18	54.70	59.29	45.60	49.07	53.11	57.49	56.08	54.18	55.20
	555	51.35	74.63	48.95	56.87	48.37	57.34	38.45	56.78	61.58	34.57	35.94
N	570	53.56	38.25	67.58	76.24	34.27	40.90	71.35	64.27	31.47	50.01	61.27
	585	52.28	36.97	66.30	74.96	32.99	39.62	70.07	62.99	30.19	48.73	59.99
O	600	62.68	61.00	66.30	68.29	65.00	65.59	64.19	57.54	58.00	66.55	54.30
	615	61.77	52.00	67.43	52.00	70.56	66.72	65.32	48.00	72.54	67.68	55.43
P	630	50.75	74.63	49.00	56.87	48.37	57.34	37.00	56.78	61.58	30.00	35.94
	645	48.27	73.13	47.62	55.54	35.00	56.01	37.12	55.45	55.00	33.24	34.61
Q	660	62.59	51.18	64.70	69.29	55.60	59.07	63.11	67.49	66.08	64.18	65.20
	675	61.32	49.91	63.43	68.02	54.33	57.80	61.84	66.22	64.81	62.91	63.93
R	690	51.55	74.63	52.00	56.87	48.37	57.34	40.00	56.78	61.58	32.00	35.94
	705	47.76	68.00	47.62	55.54	35.00	56.01	37.12	55.45	55.00	33.24	34.61
S	720	55.66	42.25	68.58	76.24	34.27	40.90	71.35	64.27	47.47	50.01	61.27
	735	54.90	49.91	63.43	45	54.33	57.8	61.84	47	64.81	62.91	42
T	750	48.27	73.13	47.62	55.54	35.00	56.01	37.12	55.45	55.00	33.24	34.61
	765	45.36	68.00	47.62	45.00	35.00	56.01	37.12	42.00	55.00	33.24	34.61
U	780	46.17	50.14	69.34	70.24	40.00	36.84	29.84	64.27	35.00	31.74	34.27
	795	44.58	50.14	69.34	70.24	30.47	36.84	29.84	64.27	28.67	31.74	34.27
V	810	43.66	50.14	54.00	65.00	30.47	36.84	29.84	64.27	40.00	31.74	34.27
	825	42.25	47.81	67.01	67.91	28.14	34.51	27.51	61.94	26.34	29.41	31.94
W	840	42.54	45.97	51.37	62.48	27.94	25.71	20.76	54.27	34.17	38.47	64.21
	855	40.97	44.40	49.80	60.91	26.37	24.14	19.19	52.70	32.60	36.90	62.64
X	870	30.92	24.87	26.35	38.84	32.72	31.76	22.42	28.63	36.19	34.58	32.83
	885	29.37	23.32	24.80	37.29	31.17	30.21	20.87	27.08	34.64	33.03	31.28

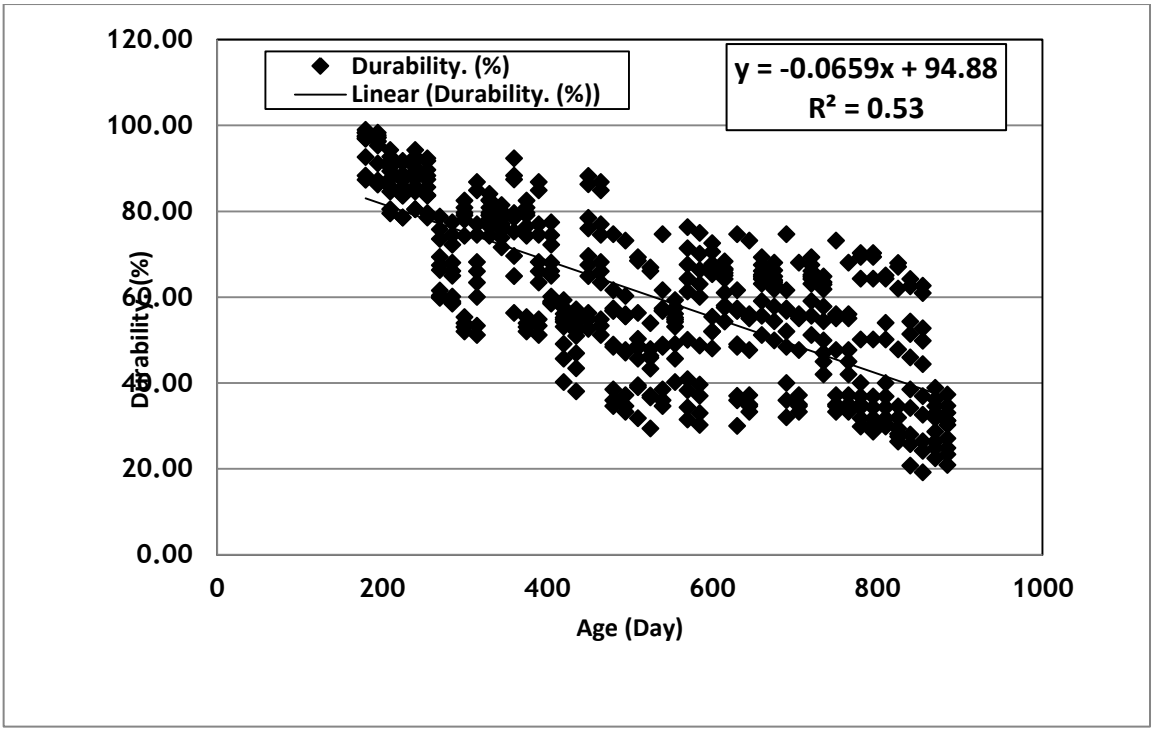

Figure 4-8: Scatter Plot, D_R vs Age for White Thermoplastic by a linear model

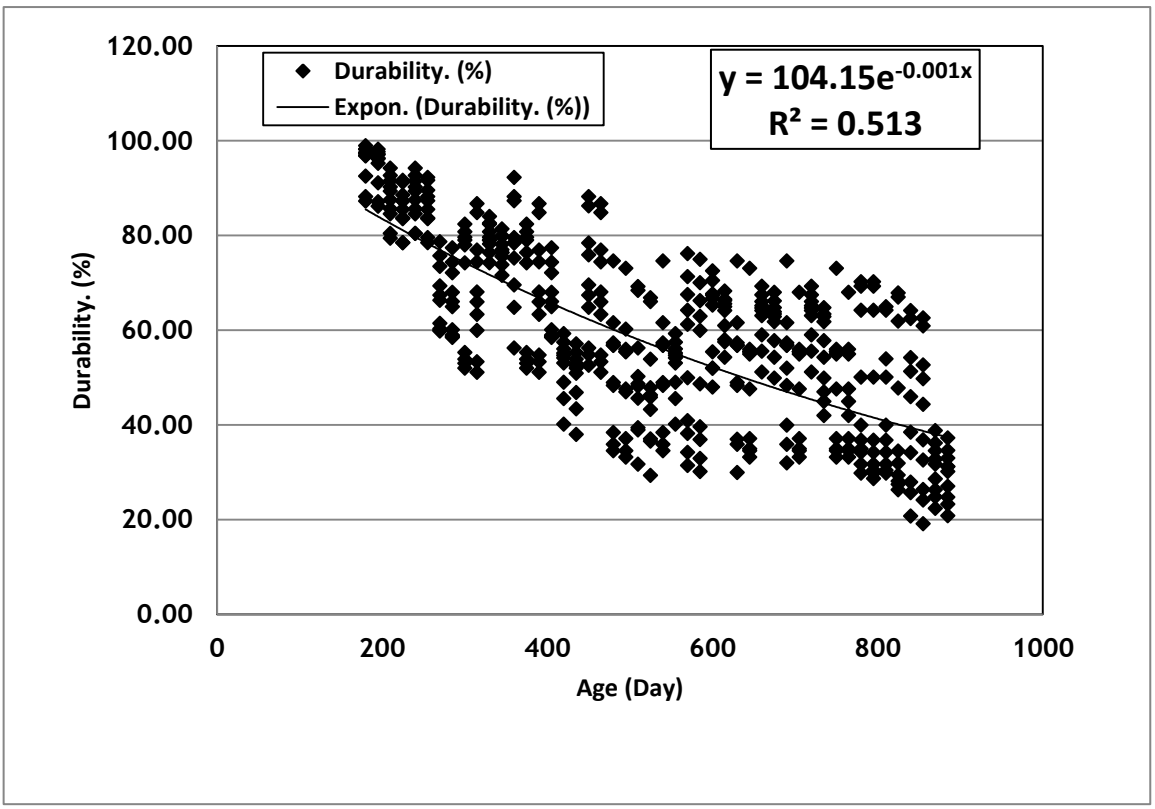

Figure 4-9: Scatter Plot, D_R vs Age for White Thermoplastic by an exponential model

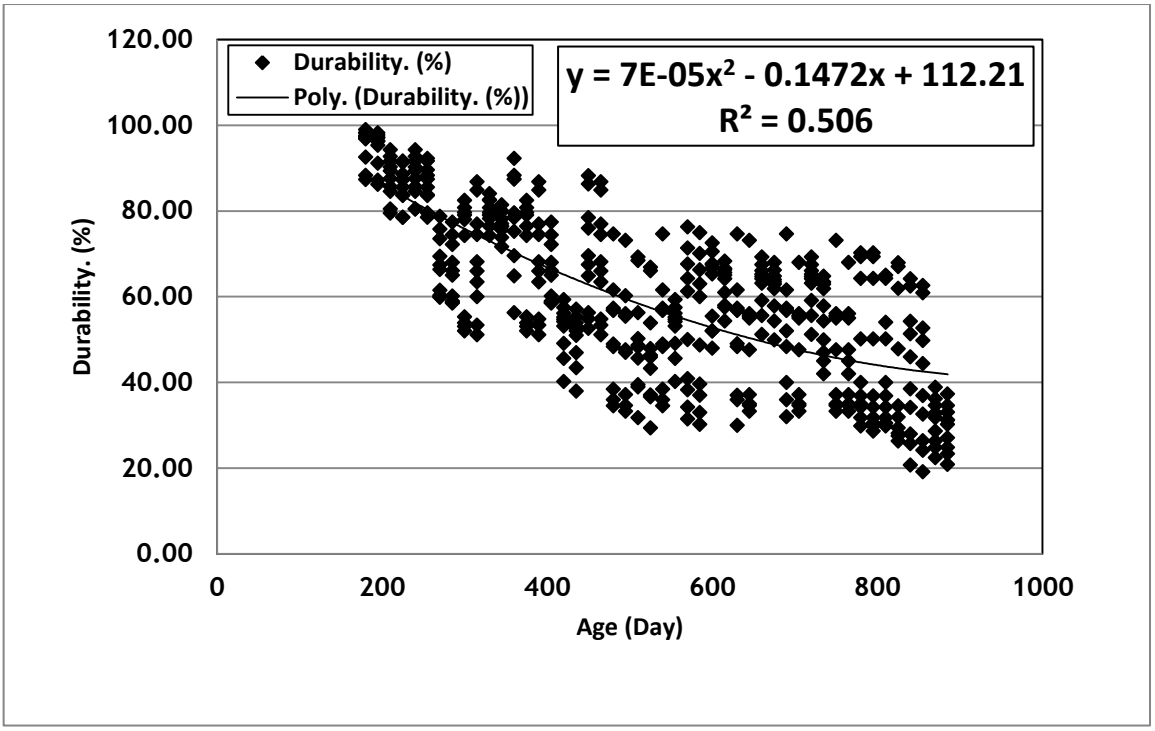

Figure 4-10: Scatter Plot, D_R vs Age for White Thermoplastic by a polynomial model

Table 4-8: Mathematical Equations and Coefficient of Determination R^2

Model Type	Mathematical Equation	The coefficient of Determination (R^2)
Linear	$D_R = 94.88 – 0.0659*Age$	0.5290
Exponential	$D_R = 104.15*e^{-0.001*Age}$	0.5132
Polynomial	$D_R = 7E\text{-}05*Age^2 – 0.1472*Age + 112.21$	0.5061

Where: - Age is the service life of pavement marking in day

D_R is Durability of pavement marking in percent (%)

From Figure 4-8 and Table 4-8, the data trend indicates a linear relationship with durability decreasing with increase in pavement marking age. And also the bar chart in Figure 4-11 shows that the durability value was decrease by average of 1.68% within two weeks. This influenced the decision of using a linear model. Hence a linear relationship model was considered as it is more likely to reflect the trend in pavement marking deterioration.

Under this category, there are 480 observations with a coefficient of determination (R^2) of 0.5290 that means 52.9% of Durability (D_R) is explained by the regressor (age).

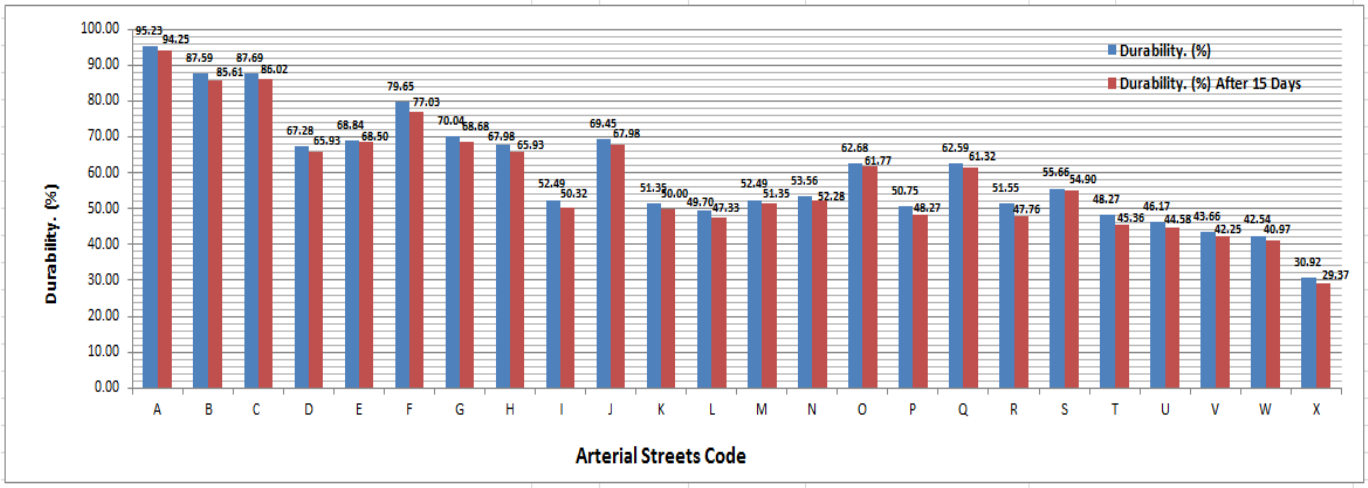

Figure 4-11: Durability value within two weeks interval for thermoplastic

Table 4-9: Regression Statistics Output

Regression Statistics		Explanation
Multiple R	0.525	R = square root of R^2
R Square	0.529	R^2 known as coefficient of determination
Adjusted R Square	0.528	Adjusted R^2 used if more than one x variable
Standard Error	12.952	This is the sample estimate of the standard deviation of the error u
Observations	480	Number of times data was collected for number of sites (n)

Table 4-10: Analysis of Variance (ANOVA) Output

	df	*SS*	*MS*	*F*	*P*
Regression	1	90027.0	90026.8	536.66	0.000
Residual	478	80187.0	167.8		
Total	479	170214.0			

Table 4-11: Regression Coefficients Output

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*VIF*	*Lower 95%*	*Upper 95%*
Intercept	94.88	1.63	58.35	0.000		-112.736	115.996
Age (Date)	-0.06590	0.00284	-23.17	0.000	1.00	45.416	-45.410

If βj denotes the population coefficient of the j_{th} regressor (intercept and age and), then a summary of the output in Tables 4.9 - 4.10, results in equation 4.2 which is the linear model for white thermoplastic:

$D_R = 94.88 – 0.0659*(Age)$ …..……..……..……. (4.2)

Where: - Age is the service life of pavement marking in day

D_R is Durability of pavement marking in present (%)

4.1.2.1 Test of Statistical Significance

From Table 4-11 it can be seen that the coefficient of age has a value of – 0.0659 with an estimated standard error of 0.0028, t-statistic of -23.17 and p-value of 0.000 < 0.05. It is therefore statistically significant at significance level $\alpha = 0.05$ as p-value < 0.05. Otherwise, it could be insignificant.

Test H0: $\beta_1 = 0$ versus Ha: β_1 does not equal zero. From the ANOVA table, the F-test statistic is 536.66 with a p-value of 0.000. 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 is statistically significant at significance level 0.05. Otherwise, we could not reject the null hypothesis, and the parameters (age) could be statistically insignificant. Therefore age is contributing factors to the deterioration of thermoplastic pavement marking durability.

4.1.2.2 Test the Adequacy of Model

Two residual plots for durability (D_R) residuals against durability fitted values obtained from the model and age are also presented in 2D, so as to observe the adequacy of the generated model (Figures 4-12 and 4-14). The residual is given by, rj= yj* - yj.

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_2, for other factors to our model). A plot of residuals is very helpful in detecting such a correlation. Figure 4-12 presents durability residuals against durability fitted values obtained from the model. Figures 4-13 depict plots of durability residuals against age.

It can be observed from Figure 4-12 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.

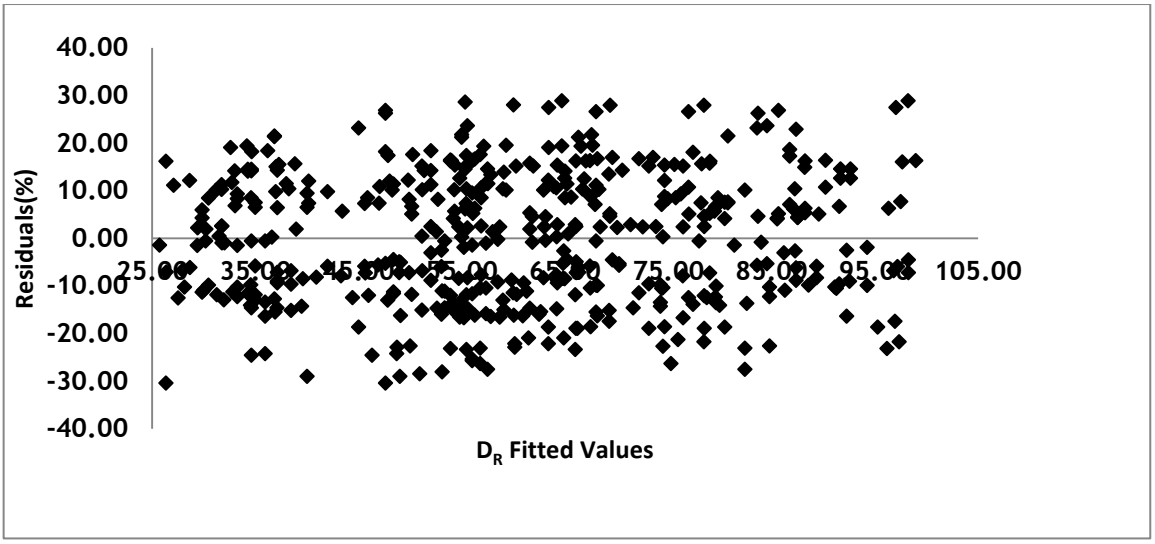

Figure 4-12: D_R-Residuals against Fitted Values for White Thermoplastic

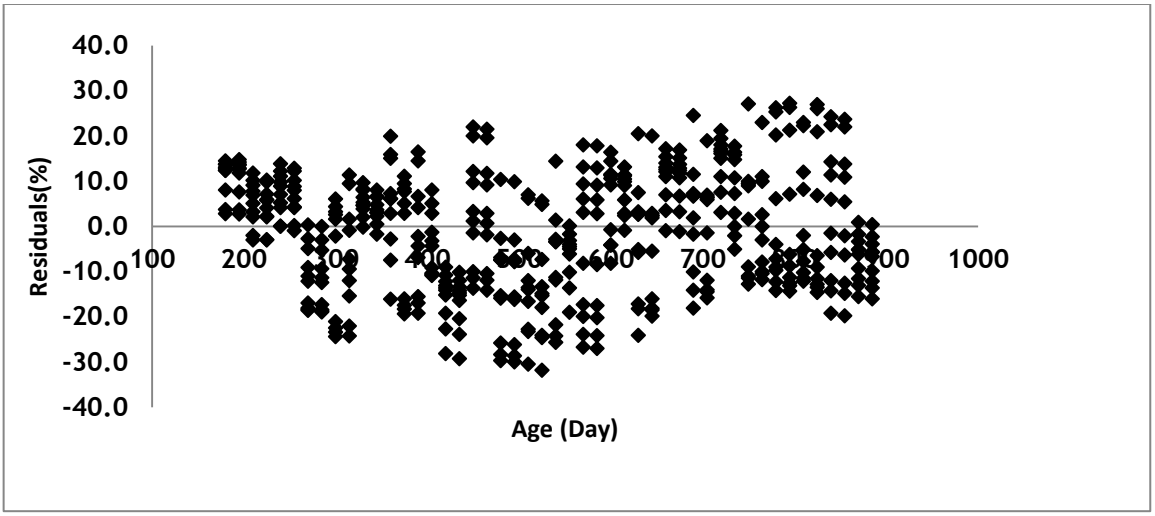

Figure 4-13: D_R-Residuals against Age for White Thermoplastic

Generally, the fact that all the residuals look random and that there is no obvious correlation (pattern) with the fitted values and age, does not necessarily mean that by itself the model is adequate. This is considered with other parameters such as R^2, a p-value test, Normal probability plot and histogram was as shown in the Appendix E: Minitab 17 output for regression analysis. Since these have already been considered, it can be concluded that the model is adequate. Therefore, the model (Equation 4.2) generated under thermoplastic pavement marking, can be used in the management of pavement markings.

4.1.2.3 The plot of the Regression model, Collected Data, and Residuals

This section presents plots and graphs generated after data analysis to include: predictive model line plot; and 2D plot of the residual. Figure 4-14 presents the line plot of durability values against age for the generated model (equation 4.2) of white Thermoplastic. The plot indicates that, in general, pavement marking durability decreases with increase in age.

The predictive surface plot in Figure 4-14 shows the graphic image of the generated model, equation 4.2. It presents the relationship between durability values and age of the white thermoplastic pavement markings. It can be observed that at moderate traffic volume, the durability values decrease with the increase in pavement marking age. This means that for the given asphalt highway the deterioration of its white thermoplastic makings durability is proportional to the age of the markings.

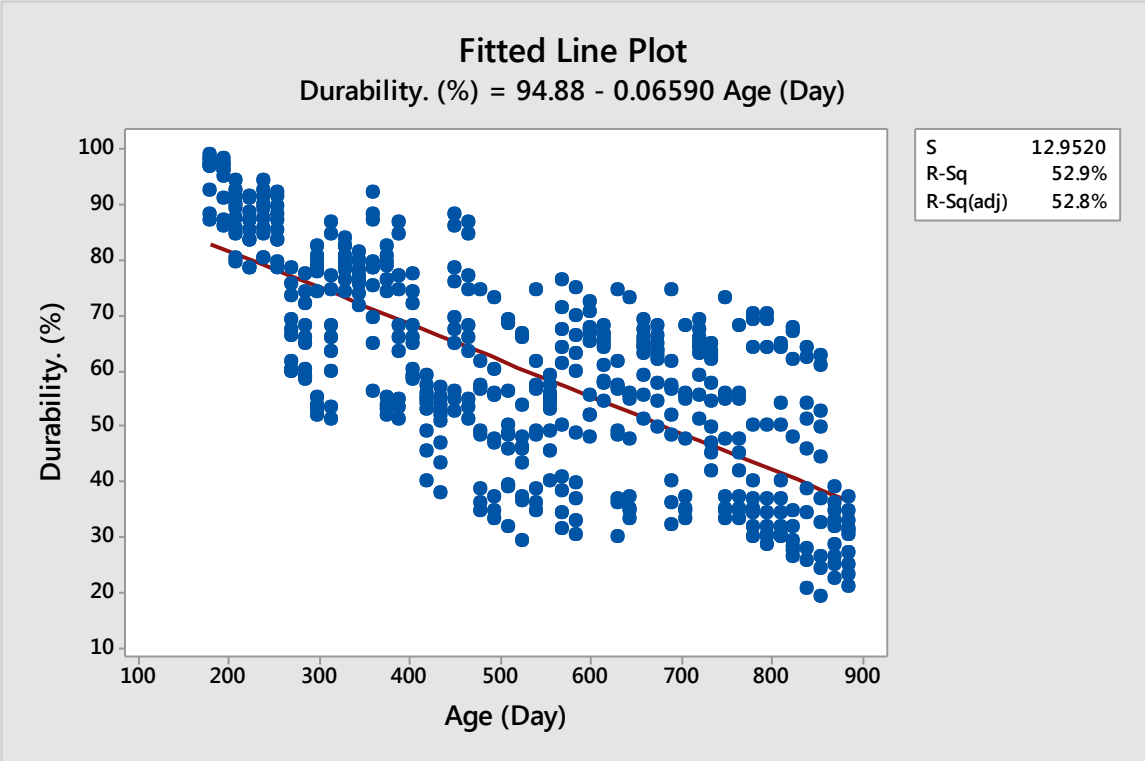

Figure 4-14: Fitted Line Plot for White Thermoplastic

Generally, it can be observed in Figure 4-14 that Durability is inversely proportional to age. That is, there is a decrease in durability values as age increase. But this is true for the pavement marking age is from 180 days to 885 days of thermoplastic marking material.

4.2 Prediction of Pavement Marking Service Life

In this subtopic, several mathematical models were used to predict the future durability performance of paint and thermoplastic pavement marking by fitting these models to actual field durability data. These models were then used to predict the service life of the pavement markings. Pavement marking service life defined as the time required for its durability to drop below a preselected threshold value. In this study, a durability value of 50% was used for white paint and thermoplastic pavement markings. AACRA pavement marking maintenance department also accept these durability threshold value, to plan the maintenance schedule.

4.2.1 Pavement Marking Service Life

Table (4-12) present predicted service life for paint and thermoplastic pavement marking, as shown in the table, in general, the linear and exponential model produced the most conservative service life predictions which are around one year for traffic paint pavement marking and around two years for thermoplastic pavement marking. This is based on the durability value is 5 (50%), it is the threshold value for pavement marking performance, which is the conclusion of ODoT, 2002The service life predictions using polynomial models were unrealistic (no solution). Therefore, only results for the linear and the exponential models are presented in this section.

Table 4-12: Estimated Pavement Marking Service Life

Material	Model Type	Mathematical Form	Service Life (Month)
Traffic Paint	Linear	$D_R = 96.554 – 0.137*Age$	11.327
	Exponential	$D_R = 106.25*e^{-0.002*Age}$	12.548
	Polynomial	$D_R = 0.0003*Age^2 – 0.2645*Age + 110.43$	---
Thermoplastic	Linear	$D_R = 94.88 – 0.0659*Age$	22.701
	Exponential	$D_R = 104.15*e^{-0.001*Age}$	24.466
	Polynomial	$D_R = 7E\text{-}05*Age^2 – 0.1472*Age + 112.21$	---

The estimated service life values presented in this table were obtained by equating the predicted durability using the linear or the exponential models to minimum acceptable durability criterion depending on the type of pavement marking. This procedure estimates the time required for average durability to drop to that threshold criterion. As expected, some of the individual durability readings will fail (drop below threshold) before reaching these service lives.

4.3 Economic Evaluation of Pavement Markings

The economic study of pavement marking was based on a deterministic LCCA of the agency costs following ADOE LCCA guidelines (ADOE 1999). These guidelines provide the reader with the steps necessary to conduct their own life cycle analysis given their experience with a particular marking material and the information that is provided in this report. The life cycle calculations would have different results given the differences in expected life. So, the following steps are shows a cost comparison between paint and thermoplastic pavement marking materials.

Step 1: Estimate the service life of pavement marking materials.

Performance period (service life) is the expected lifetime, in a month, of the alternative pavement marking before the minimum durability value of materials. From research conclusion (Table 4-10) performance period is 12 month for traffic Paint pavement marking and 24 month for thermoplastic pavement marking. Table 4-13 shows the work schedule used in the LCCA for this study.

Table 4-13: Work schedule for pavement marking material alternatives

Year	Material Type	
	Traffic Paint	Thermoplastic
Zero	Initial panted cost	Initial panted cost
One	Re-painted cost	---
Two	Salvage value	Salvage value

Step 2: For the given 1-kilometer of roadway segment that needs to be painted, estimate the life cycle cost (LCC) of pavement marking materials per linear kilometer.

There are a number of variables that can affect the life of a given pavement marking material costs such as analysis period, performance period (service life), cost (construction, material, maintenance cost), discount rate, salvage value and user cost. But salvage value and user cost are not considered for this thesis. Pavement markings have no salvage value and user cost should be difficult to calculate and the same for both pavement marking materials.

Analysis period is the time horizon over which the alternatives are evaluated in the LCCA. So the analysis period is 24 month (2 years). B/c it's long enough to include at least one complete life cycle for thermoplastic pavement marking material.

The discount rate is the interest rate by which future costs will be converted to present value. Real discount rates (as opposed to nominal discount rates) reflect only the true time value of money without including the general rate of inflation. According to Ministry of Finance and Economic Development (MoFED), the discount rate is 10.23%.

For each project alternative, Initial construction cost and maintenance cost should be estimated. But the only maintenance activity in AACRA for pavement marking is clearing. This activity is common for both alternatives, so maintenance cost should be avoided for the LCCA. Initial construction costs include material and application cost per linear kilometer. In order to obtain accurate initial costs for each of the pavement marking materials, for the given one-kilometer of roadway segment that needs to be painted area had to be computed. The geometric characteristics of all pavement markings used are shown in Fig. 4-15. It's 4-meter module, which is the default lane guidance marking for all roads (IDOT 2010). Therefore, the total painted area for the given one-kilometer road section is 10 m^2.

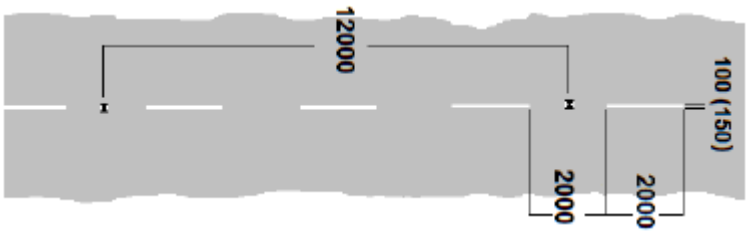

Figure 4-15: Geometric characteristics of the 4-meter module

The unit prices of varies item were obtained using the average AACRA bid documents and surveying the market prices in the city. All costs computed were based on one-kilometer road section and detailed cost break down for each pavement marking material alternatives are as shown in the Appendix F: Cost Break Down. This detailed cost break down analysis is based on the following assumptions:

- Total painted area for the given one-kilometer of roadway segment 10m^2 (For two way two lanes =2*(2m*0.01m)*250=10m^2)
- Ordinary road marking paint shall be applied at a nominal rate of 0.42 liter/sq. meter. (For the given one-kilometer road section 4.2Lit. of paint is required)

- The rate of application of the beads shall be 0.8 kg/liter paint. (For the given one-kilometer road section 3.36Kg. the bead is required)

Therefore the results of the initial cost of pavement marking material alternatives are summarized in table 4-14.

Table 4-14: the Initial painted cost of the alternatives

Material Type	Initial Cost (Birr/km)
Traffic Paint	17,957.23
Thermoplastic	29,246.73

Step 3: Convert costs.

The equivalent uniform annual cost (EUAC) approach is used for this research. It produces the yearly costs of an alternative as if they occurred uniformly throughout the analysis period. The present value (PV) of this stream of EUAC is the same as the PV of the actual cost stream. Whether PV or EUAC is used, the decision supported by the analysis will be same.

In order to perform the EUAC method, the suggested first step is to determine the net present value (NPV) which is the initial cost of pavement marking material and then use Equation 2-1 to convert the present costs into annual uniform costs.

$$EUAC = NPV * \left[\frac{i * (1+i)^{n}}{(1+i)^{n} - 1}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation 2.1$$

Where

n = number of years into the future

I = discount rate

NPV = net present value (initial cost of pavement marking)

Comparisons between all the computed costs, including initial and equivalent uniform annual cost (EUAC) are shown in Table 4-15. Therefore, the least expensive pavement marking material alternative was the thermoplastic pavement marking material.

Table 4-15: Computed Costs Analysis for the Different Pavement Marking Materials

Material Type	Initial Cost (Birr/km)	EUAC (Birr/km)
Traffic Paint	17,957.23	19,794.25
Thermoplastic	29,246.73	16,862.76

Estimated life cycles and total installation costs were used to determine the materials' equivalent uniform annual costs (EUAC). The estimated equivalent uniform annual costs were 19,794.25 birrs per kilometer for traffic paint marking material and 16,862.76 birrs per kilometer for thermoplastic marking material. So thermoplastic was more economical under most conditions because of traffic paint marking material's higher equivalent uniform annual costs.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From this study, it can be concluded that the deterioration of the pavement marking durability is influenced by pavement marking age. Generally, it can be revealed from the developed models that there is a decrease in durability values as age increase. A result for the linear model is more reasonable than the polynomial and exponential models. The durability performance was decrease by average of 2.74% and 1.68% within two weeks for traffic paint and thermoplastic respectively.

For a given asphalt highway having paint markings, repainting and/or restriping period of the pavement marking can be designed, provided there is a known durability threshold value which is fifty percent. It will take about 340 days (approximately 1 year) for white traffic paint lane line markings, and 681 days (approximately 2 years) for white thermoplastic lane line markings, to reach the threshold values, hence need maintenance. Both materials investigated in this study are non-durable pavement markings. As such, the durability of most materials drops below a durability rating of fifty percent. For paint pavement marking materials, the highest deterioration took place in the six months.

Estimated life cycles and total installation costs were used to determine the materials' equivalent uniform annual costs (EUAC). The estimated equivalent uniform annual costs were 19,794.25 birrs per kilometer for traffic paint marking material and 16,862.76 birrs per kilometer for thermoplastic marking material. So thermoplastic was more economical under most conditions because of traffic paint marking material's higher equivalent uniform annual costs.

5.2 Recommendations

Based on the results of the study and literature review made on the subject matter, the following recommendations have been drawn:

- The degradation models presented in this thesis can readily be used to better allocate resources and manage pavement marking maintenance schedule in AACRA.
- Highways having pavement markings, repainting and/or restripe period are one year for traffic paint marking material and two years for thermoplastic marking material.
- In AACRA pavement marking department, there is a public doubt on which pavement marking material is cost effective. Thermoplastic marking material is cost-effective relative to traffic paint marking material.
- Further studies are recommended in pavement marking management by the consideration of more factors rather than only durability value and age, so as to investigate how other factors affect/contribute to the deterioration of pavement markings. The deterioration of the pavement marking can be contributed to by other factors such as: Retroreflectivity as dependent variable and traffic volume, thickness, position, weathering condition, method of application of pavment marking and Pavement Distresses.

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APPENDIX A. COLLECTED DATA FROM AACRA

Data Collection Format			
Location (From - To)	Type of PM. Material	Application Date	Code
ኮተቤ ኪዳነ ምህረት አዲስ የተሰራው መንገድ	W. Thermoplastic	1/7/2008	A
ዲያስፖራ አደባባይ - ቀበና አደባባይ	W. Thermoplastic	9/7/2008	A
እግሊዝ ኤምባሲ - ዲያስፖራ አደባባይ	W. Thermoplastic	19/7/2008	A
ብሄራዊ ትራፊክ መብራት - ለገሀር	W. Thermoplastic	26/7/2008	A
ብሄራዊ ትራፊክ መብራት - ፖሰታ ቤት - ቴድሮስ አደባባይ	W. Thermoplastic	27/7/2008	A
ዊንጌት አቡነ ጴጥሮስ አደባባይ	W. Thermoplastic	7/6/2008	B
ምንሊክ ሆስፒታል - ቀበና አደባባይ	W. Thermoplastic	26/6/2008	B
አያት ኮንዶሚኒየም በሳይክል መሄጃ	W. Thermoplastic	24/6/2008	B
ሸራተን - ፍል ውሀ - ቤተ መንግስት	W. Cold mix (paint)	15/10/2008	A'
ሰሜን ሆቴል - ጊዮርዚስ - ኒውኤራ ቤ/ት	W. Cold mix (paint)	21/10/2008	A'
ሜክሲኮ - ብሄራዊ ትያትር ቤት - በድሉ ህንጻ	W. Cold mix (paint)	16/10/2008	B'
በድሉ ህንጻ - ቤተ መንግስት	W. Cold mix (paint)	16/9/2008	C'
ሰሜን ሆቴል - ትራፊክ መብራት - ሰሜን ማዘጋጃ	W. Cold mix (paint)	23/8/2008	D'
አዲሲ ገበያ - ድል ካር	W. Cold mix (paint)	23/8/2008	D'
ኢፕሪያል ሆቴል - ገርጂ	W. Cold mix (paint)	23/5/2008	E'
4-ኪሎ - ስላሴ - ቤልኤር - እግሊዝ ኤምባሲ	W. Cold mix (paint)	30/5/2008	F'
እስጢፋኖስ ቤተ ክርስቲያን - ከተማ ልማት (ኢ. ሲ. ኤ)	W. Thermoplastic	3/5/2008	C
ፍል ውሀ - ቤተ መንግስት	W. Thermoplastic	4/5/2008	C
ሜክሲኮ አደባባይ - ሲጋራ ፋብሪካ	W. Thermoplastic	8/5/2008	C
አፍሪካ ህብረት አደባባይ አካባቢ	W. Thermoplastic	9/5/2008	C
6-ኪሎ - 3ተኛ ሻለቃ - ጉራራ አዲስ መንገድ	W. Cold mix (paint)	11/4/2008	G'
ቦሌ አየር መንገድ መግቢ ውስጥ	W. Cold mix (paint)	25/4/2008	G'
ኡራኤል ድልድይ - አትላስ - ኤድናሞል አደባባይ	W. Cold mix (paint)	20/4/2008	G'
6-ኪሎ - ጉራራ አዲስ መንገድ	W. Thermoplastic	8/4/2008	D
4-ኪሎ - ቀበና አደባባይ	W. Thermoplastic	22/4/2008	D
ቤሌኤር መታጠፊያ - ቀበና አደባባይ	W. Thermoplastic	23/4/2008	D
ሜክሲኮ አደባባይ - አፍሪካ ህብረት አደባባይ	W. Thermoplastic	29/4/2008	D
ቤሌኤር - 4-ኪሎ አደባባይ	W. Thermoplastic	21/4/2008	D
አፍሪካ ኢኮኖሚ ኮሚሺን ግቢ ውስጥ	W. Cold mix (paint)	17/3/2008	H'
ጎፋ ገብርኤል አደባባይ - ጎፋ ማዞሪያ መስቀለኛ	W. Cold mix (paint)	16/3/2008	H'
ጎፋ ገብርኤል አደባባይ - ጎፋ ማዞሪያ መስቀለኛ	W. Cold mix (paint)	15/3/2008	H'
ቆሬ መታጠፊያ - ጀርመን አደባባይ	W. Thermoplastic	2/3/2008	E
ቆሬ መታጠፊያ - ጀርመን አደባባይ	W. Thermoplastic	2/3/2008	E
ሳር ቤት - ካርል አደባባይ	W. Thermoplastic	3/3/2008	E
ብስራተ ገብርኤል - 3 ቁጥር ማዞሪያ	W. Thermoplastic	18/3/2008	E
ብስራተ ገብርኤል - ካርል አደባባይ - ደሴ ሆቴል	W. Thermoplastic	24/3/2008	E
6-ኪሎ - 3ተኛ ሻለቃ - ፈረንሳይ ሌጋሲዮን	W. Thermoplastic	27/3/2008	E
አሮጌ ፖሰታ ቤት - ጥኩር አንበሳ	W. Cold mix (paint)	4/2/2008	I'
አሮጌ ፖሰታ ቤት - ጥኩር አንበሳ	W. Cold mix (paint)	7/2/2008	I'

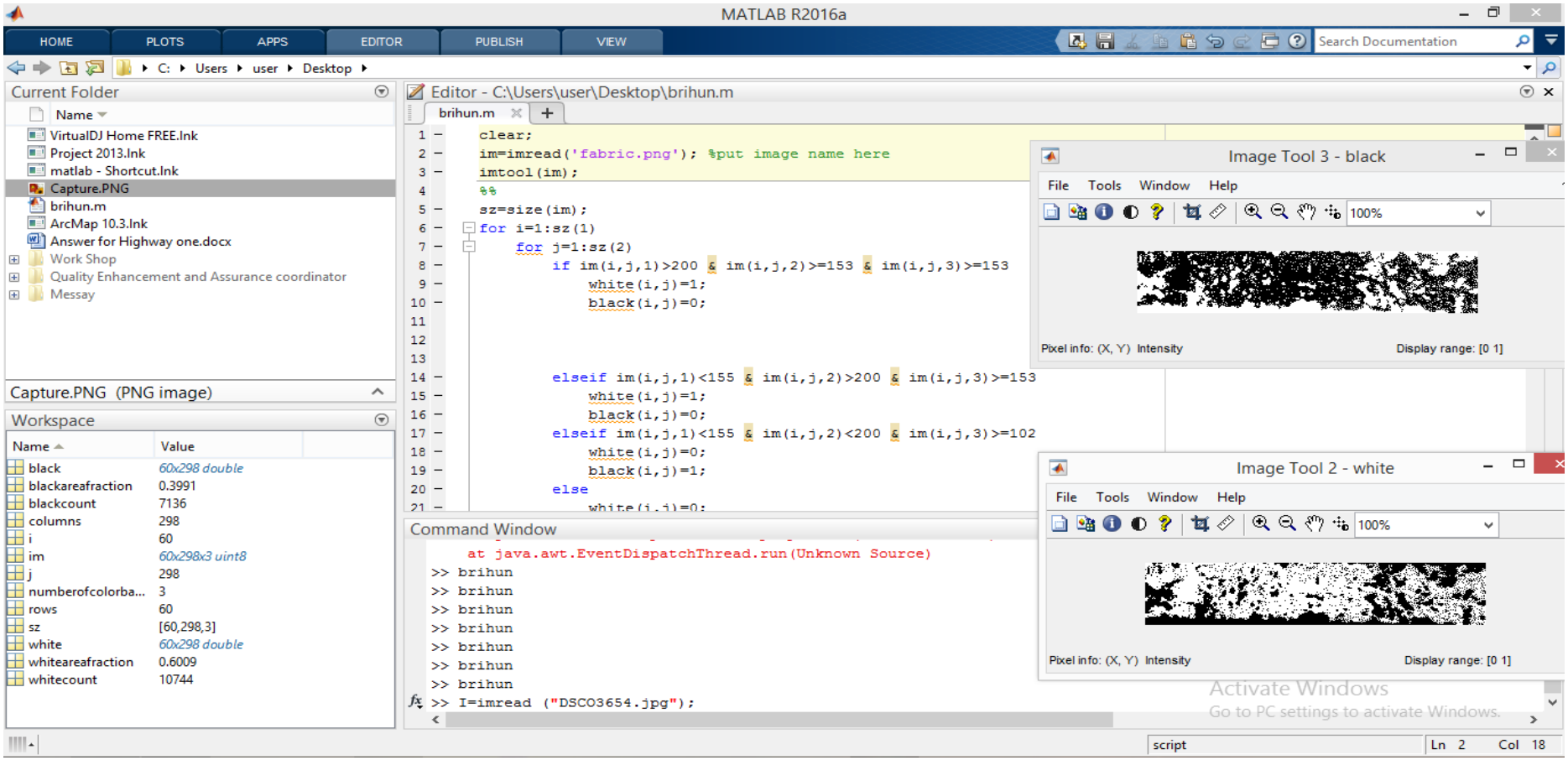
አፍሪካ ህብረት አደባባይ - ቫቲካን ኤምባሲ	W. Cold mix (paint)	14/2/2008	I'
ቫቲካን ኤምባሲ - አፍሪካ ህብረት	W. Cold mix (paint)	23/2/2008	I'
አፍሪካ ህብረት አደባባይ - ቫቲካን ኤምባሲ	W. Thermoplastic	14/2/2008	F
ሳር ቤት - ቄራ መውጫ መንገድ	W. Thermoplastic	18/2/2008	F
አቦ መታጠፊያ - ቆሬ መታጠፊያ	W. Thermoplastic	28/2/2008	F
ቫቲካነ - አቦ መታጠፊያ	W. Thermoplastic	28/2/2008	F
መሻለኪያ - ጎተራ መድረሻ	W. Cold mix (paint)	19/1/2008	K'
ብሄራዊ ትያትር ቤት አካባቢ	W. Cold mix (paint)	30/1/2008	K'
ካሳንቺስ ኢ. ሲ. ኤ አካባቢ	W. Thermoplastic	1/11/2007	I
ካሳንቺስ ዮርዳኖስ ሆቴል - እስጢፋኖስ ሆቴል	W&Y. Thermoplastic	18/10/2007	J
ካሳንቺስ ኢሊሌ ሆቴል አካባቢ	W. Thermoplastic	15/10/2007	J
ሀራምኔ ትራፊክ መብራተ መስቀለኛ አካባቢ	W. Thermoplastic	8/10/2007	J
ባንኮ ዲሮማ ትራፊክ መብራት - አራዳ ህንጻ - ጊዮን ሆቴል	W. Thermoplastic	10/10/2007	J
ቤተ መንግስት - ሱፐር ማርኬት - ካሳንቺስ ትራፊክ መብራት	W. Thermoplastic	11/10/2007	J
ቃሊቲ የአሽከርካሪዎች ማሰልጠኛ ግቢ ውስጥ	W. Thermoplastic	13/10/2007	J
ደጃች ወቤ - አፍንጮ በር	Y. Thermoplastic	3/10/2007	J
አትላስ አደባባይ - 17 ጤና ጣቢያ	Y. Thermoplastic	1/10/2007	J
አለም ባንክ - ኪዳነ ምህለት አደባባይ	W. Thermoplastic	3/9/2007	K
ብስራተ ገብርኤል - ቆሬ መንገድ	W. Thermoplastic	4/9/2007	K
6-ኪሎ - ፈረንሳይ እና ሩአንዳ - ሚካኤል	W. Thermoplastic	7/9/2007	K
ጎጃም በር - እንጦጦ ማርያም	Y. Thermoplastic	27/9/2007	K
አየር ጤና - ካራ ቆሬ	Y. Thermoplastic	30/9/2007	K
እንጦጦ ፍተሻ ጣቢያ - እራጉኤል	Y. Thermoplastic	15/9/2007	K
አየር ጤና - አለም ባንክ - ኪዳነ ምህለት	W. Thermoplastic	30/8/2007	L
ጀሞ ኮነዶሚኒየም አካባቢ አዲስ የተሰራ መንግድ	W. Thermoplastic	26/8/2007	L
አለም ባንክ - አንፎ አደባባይ	W. Thermoplastic	24/8/2007	L
ቴድሮስ አደባባይ - ባንኮዲሮማ ትራፊክ መብራት	W. Thermoplastic	15/8/2007	L
ጥኩር አንበሳ ትራፊክ መብራት - ቴሌቪዥን ትራፊክ መብራት	W. Thermoplastic	7/8/2007	L
ቃሊቲ ማረሚያ ቤት - ሳለ ጊዮርጊስ መታጠፊያ	W. Cold mix (paint)	22/7/2007	P'
ሸበሌ - ብሄራዊ ትያትር	W. Cold mix (paint)	15/7/2007	P'
ጃክሮስ አደባባይ አካባቢ	W. Cold mix (paint)	10/7/2007	P'
የካቲት ወረኪት ፋብሪካ - ቦሌ ክፍለ ከተማ ወ.5 ጽፈት ቤት	W. Cold mix (paint)	3/7/2007	P'
ጦር ሀይሎች - ቤቴል በሚወስደው መንገድ	W. Cold mix (paint)	24/6/2007	Q'
4-ኪሎ አደባባይ - 6-ኪሎ አደባባይ	W. Thermoplastic	13/6/2007	N
ጎፋ ኮንዶሚኒየም መግቢያ	Y. Thermoplastic	10/6/2007	N
6-ኪሎ - መዳኒያለም ቤተ ክርስቲያን	Y. Thermoplastic	2/6/2007	N
መድሀኒያለም ቤተ ክርስቲያን - አሜሪካን ኤምባሲ	Y. Thermoplastic	5/6/2007	N
ሲኒማ ኤፓየር - እራስ መኮኒን -ቂዲስት ማሪያም መታጠፊያ	W. Cold mix (paint)	25/5/2007	R'
ፓርላማ -አባፊ አደባባይ	W. Cold mix (paint)	24/4/2007	R'
አፍሪካ ህብረት አደባባይ - ሜክሲኮ አደባባይ	W. Thermoplastic	12/5/2007	O
ዋቢሸበሌ - ተግባረድ - ብሄራዊ ቲያትር	W. Thermoplastic	4/5/2007	O
ሸራተን - ዘውዲቱ ሆስፒታል	W. Thermoplastic	7/5/2007	O
ሜክሲኮ - ጮራ ጋዝ - አፍሪካ ህብረት	W. Thermoplastic	9/5/2007	O
ገብርኤል መሳለሚያ - ሂልተን ኢ. ሲ. ኤ መታጠፊያ	W. Thermoplastic	1/5/2007	O
ቴድሮስ አደባባይ - አራዳ ህንጻ	Y. Thermoplastic	18/5/2007	O

ወሎ ሰፈር - ጎተራ	W. Cold mix (paint)	22/4/2007	S'
ጎፋ መብራት - ገብርኤል ጎፋ ማዞሪያ - ጀርመን አደባባይ	W. Cold mix (paint)	2/4/2007	S'
ዊንጌት ቀለበት መንገድ አደባባይ - 19 ቁጥር ማዞሪያ	W. Cold mix (paint)	27/3/2007	T'
ጀርመን አደባባይ - ቫቲካን ኤምባሲ	W. Cold mix (paint)	17/2/2007	X'
ዊንጌት - አስኮ	W. Cold mix (paint)	21/8/2006	Z'
ካሳንቺስ መብራት ሀይል - አደዋ ድልድይ	W. Thermoplastic	3/8/2006	X
ኦራል አደባባይ - ደሴ ሆቴል መውጫ	W. Thermoplastic	6//7/2006	Y
ዲያስፖራ አደባባይ - ሰምን አውቶቢስ መናህሪያ	W. Thermoplastic	8/7/2006	Y
ዊንጌት ቀለበት መንገድ - ብርጪቆ ሩብሪካ	W. Thermoplastic	9/7/2006	Y
ገንዘብ ሚንስተር አካባቢ	Y. Thermoplastic	19/7/2006	Y
ጎፋ መማዞሪያ - ጎፋ ገብርኤል	Y. Thermoplastic	13/7/2006	Y
5-ቁጥር ማዞሪያ - አቡነ አረጋዊ ቤተክርስቲያን	W. Thermoplastic	11/8/2006	Z
ቀበና ድልድይ - ዲያስፖራ አደባባይ	W. Thermoplastic	24/6/2006	Z
መገናኛ አደባባይ - ሚካኤል - ጎበና አደባባይ	W. Thermoplastic	24/6//2006	Z
እንግሊዝ ኤምባሲ -ቀበና አደባባይ	W. Thermoplastic	25/6/2006	Z
አዲስ አበባ ማዘጋጃ ውስጥ ፓርኪንግ	W. Thermoplastic	27/6/2006	Z
ወሎ ሰፈር - ጎተራ ማሳለጫ	W. Thermoplastic	13/6/2006	Z
4-ኪሎ አደባባይ - አባሬ መታጠፊያ	W. Thermoplastic	18/6/2006	Z

APPENDIX B. SELECTED ARTERIAL STREETS

Arterial Streets Name	Type	Code	Car.W+ WW(M)	Length (M)	Pavment Type	Surface Drinage Type	Project Hand Over	Traffic Volume	Road Conditions	Application Date E.C	Observation Date E.C	Age (Day)
Painted With Thermoplastic Pavmenet Marking												
From Legahare toTeodros Sq	PAS3	A	28	1837	Asphalt	Fair	Before 1983	High	Good	26/7/2008	21/01/2009	180
From Popurale to cherkos church to meskerem mazoria	CS-2	B	14	847	Asphalt	Fair	Before 1983	High	Good	17/04/2008	12/1/2009	210
From Banko di Roma Jun to Eribekentu Jun.	SAS2	C	20	715	Asphalt	Good	Before 1983	High	Fair	29/6/2008	24/02/2009	240
From Bisrate gabriel (191 road) to Lafto Moll	CS-2	D	20	1133	Asphalt	Good	_	High	Good	22/03/2008	17/01/2009	270
From Winget to Asko Bridge	PAS4	E	30	2856	Asphalt	Good	__	High	Good	8/5/2008	3/3/2009	300
From Dan Techno office through no 108 to Bole Printing Junction	CS-2	F	7	1560	Asphalt	Fair	Before 2000	High	Fair	4/3/2008	29/01/2009	330
From Entoto street junction to Raguel	SAS2	G	10	4445	Asphalt	Good	__	High	Fair	23/4/2008	18/04/2009	360
From Bole Shewa dabo (Bole Garad) through Aster Buna to USA Aid office	CS-2	H	10	1056	Asphalt	Fair	Before 1983	High	Fair	25/04/2008	20/05/2009	390
From Megenana to Minilik hospital	PAS3	I	40	3695	Asphalt	Good	__	High	Good	18/3/2008	13/05/2009	420
From queens college junction (road 59) to Mesalemia junction Road 60	CS-4	J	8	1529	Asphalt	Good	Befor 2000	High	Good	20/01/2008	15/04/2009	450
From Kebena bridge through Germen embacy to Bella	SAS2	K	9	1200	Asphalt	Fair	Before 1983	High	Fair	18/01/2008	8/5/2009	480
From asfawe tekle hotel to ehel berenda	CS-2	L	12	12339	Asphalt	Good	1995EC	High	faire	20/11/2007	11/4/2009	510
From Lipzing Sq (German School) to Megenana Adwa Sq	SAS1	M	25	3026	Asphalt	Good	1997EC	High	Good	1/11/2007	22/04/2009	540
From water work construction office through Worku sefer to no 153 PAS	CS-2	N	10	1000	Asphalt	Fair	2002EC	High	Fair	8/9/2007	29/05/2009	570
From National palace (Gabrel Jun.) to Hilton hotel	PAS0	O	52	546	Asphalt	Fair	Before 1983	High	Good	10/9/2007	1/5/2009	600
From K/Meheret church (no 201 PAS) through new setelment to Alfa universty	CS-2	P	13	1385	Asphalt	Good	__	High	Fair	15/06/2007	6/2/2099	630
From Yordanos hotel to Kazanchiz meberat	PAS3	Q	22	760	Asphalt	Fair	Before 1983	High	Fair	27/6/2007	18/04/2009	660
From Japan Embacy to RR	PAS1	R	10	867	Asphalt	Good	Before 1983	High	Fair	15/06/2007	6/5/2009	690
From Megenana Sq through CMC to Ayat Sq	PAS2	S	50	7700	Asphalt	Good	__	High	Good	7/8/2007	27/07/2009	720
From Pushikin Sq through Kera to Gotera	PAS4	T	26	2274	Asphalt	Fair	Before 1983	High	Fair	2/5/2007	17/05/2009	750
From Mexico Sq to Tinbajo Monopol Sq	PAS4	U	30	1180	Asphalt	Good	Before 1983	High	Good	1/4/2007	16/05/2009	780
From T junction of stree (no 31) to bisrate gebriel	CS-2	V	8	522	Asphalt	Fair	Before 2000	High	Fair	30/8/2006	15/11/2008	810
From CPU college to grand palace tewdros road	CS-2	W	7	999	Asphalt	Fair	Before1983	High	Poor	9/10/2006	30/12/2008	840
From Afincho-Ber - to behaind Ketchene church	CS 1	X	10	850	Asphalt	Fair	__	High	Good	24/7/2006	9/1/2009	870
Painted With Traffic Paint Pavmenet Marking												
From Ethiopia hotel to national palace	PAS4	A'	26	1048	Asphalt	Good	Before 1983	High	Good	15/10/2008	10/1/2009	90
From Sheraton Hotel to National Palace	PAS3	B'	12	169	Asphalt	Fair	1985EC	High	Good	16/10/2008	11/2/2009	120
From Post Office to Tikur anbesa hospital	PAS4	C'	20	463	Asphalt	Good	Before 1983	High	Fair	20/9/2008	15/02/2009	150
From Mexico Sq to Beherawi theater	PAS3	D'	30	1075	Asphalt	Fair	Before 1983	High	Fair	23/8/2008	18/02/2009	180
From Giorgis through Semen Mazegaga Adisu gebeya	PAS4	E'	30	3298	Asphalt	Fair	Before 1983	High	Good	25/5/2008	20/01/2009	210
From Arat Kilo to Kebena bridge	PAS4	F'	28	1750	Asphalt	Good	20/04/2010	High	Good	30/5/2008	25/01/2009	240
From Meskel Sq to Gotera inter-change	PAS3	G'	40	3430	Asphalt	Fair	13/05/2012	High	Good	22/5/2008	27/02/2009	270
From S/t Urael church to Bole brass clinic	PAS4	H'	30	2981	Asphalt	Good	18/03/2004	High	Good	13/3/2008	7/1/2009	300
From Wereda 17 health center to Gergi RA	PAS4	I'	30	1200	Asphalt	Fair	2003EC	High	Good	7/2/2008	2/1/2009	330
From Teodros Sq through Mega book shop to Grand Palace	SAS1	J'	8	1161	Asphalt	Good	__	High	Fair	1/3/2008	26/02/2009	360
From S/t Urael church to Bole brass clinic	PAS4	K'	30	2981	Asphalt	Fair	18/03/2004	High	Good	13/3/2008	8/4/2009	390
From Mexico Sq to Di Afrique (no 41 PAS Jun.)	PAS4	L'	18	600	Asphalt	Good	Before 1983	High	Good	15/4/2008	10/6/2009	420
From Abo mekanisa to DagimMilinieum Hotel	PAS4	M'	10	1446	Asphalt	Fair	__	High	Fair	27/01/2008	22/03/2009	450
Note: Data was observed two times whith in two weeks intervals for each streets												

APPENDIX C. MATLAB R2016a Image Processing Code



MATLAB R2016a Image Processing Coding Samples

```
clear;
im=imread('Captures.png'); %put image name here
imtool(im);
%%
sz=size(im);
for i=1:sz(1)
    for j=1:sz(2)
        if im(i,j,1)>=195 & im(i,j,2)>=195 & im(i,j,3)>=195
            white(i,j)=1;
            black(i,j)=0;
        elseif im(i,j,1)<195 & im(i,j,2)<195 & im(i,j,3)<195
            white(i,j)=0;
            black(i,j)=1;
        elseif im(i,j,1)<150 & im(i,j,2)<150 & im(i,j,3)<150
            white(i,j)=0;
            black(i,j)=1;
        else
            white(i,j)=0;
            black(i,j)=0;
        end
             end
end
imtool(white);
imtool(black);

[rows,columns,numberofcolorbands]=size(im);
whitecount=sum(white(:)>0);
blackcount=sum(black(:)>0);
whiteareafraction=whitecount/(rows*columns);
blackareafraction=blackcount/(rows*columns);
```

```
clear;
im=imread('Capture-2.png'); %put image name here
imtool(im);
%%
sz=size(im);
for i=1:sz(1)
    for j=1:sz(2)
        if im(i,j,1)>=195 & im(i,j,2)>=195 & im(i,j,3)>=195
            white(i,j)=1;
            black(i,j)=0;
        elseif im(i,j,1)<195 & im(i,j,2)<195 & im(i,j,3)<195
            white(i,j)=0;
            black(i,j)=1;
        else
            white(i,j)=0;
            black(i,j)=0;
       end
             end
end
imtool(white);
imtool(black);

[rows,columns,numberofcolorbands]=size(im);
whitecount=sum(white(:)>0);
blackcount=sum(black(:)>0);
whiteareafraction=whitecount/(rows*columns);
blackareafraction=blackcount/(rows*columns);
```

APPENDIX D. REGRESSION ANALYSIS

Regression analysis is a statistical tool used to investigate the relationships between two or more variables. For this case, the durability measurement is investigated against the age of the pavement marking for locations with a moderate traffic range in vehicles per day. 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 age and pavement marking durability readings form MATLAB, 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 $R^2 = 0.5833$, it means that 58.33% of the variation of y_{ou} (durability) around y-bar ($\bar{y}$ is its mean) is explained by the regressor x_{2i} (age). 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 y_{ou} predicted from the regression line.

3. Adjusted R squared is calculated from: adjusted $R^2 = R^2 - (1 - R^2)*(k-1)/(n-k) = 0.44$. k is the number of regressor 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 the total.

- The value of SS is used in the 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 (H_o: the parameters all are zero: i.e $\beta_o = 0$ and $\beta_1 = 0$) versus Ha: at least one of β_o and β_1 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 at with (n-k) degrees of freedom.

7. P-value gives the value for test of the null hypothesis, H_0: $\beta_j = 0$, against H_a: $\beta_j \neq 0$.

8. The population linear regression model is given in the form: $y = \beta 1 + \beta 2\ x2 + \beta 3\ x3 + u$ It is assumed that the error *u* is independent with constant variance. 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 homoscedastic. Due to that, the error *u* is neglected and the model will be in the form of regression line: y = b1 + b2 x2 + b3 x3

APPENDIX E. MINITAB 17 OUTPUT FOR REGRESSION ANALYSIS

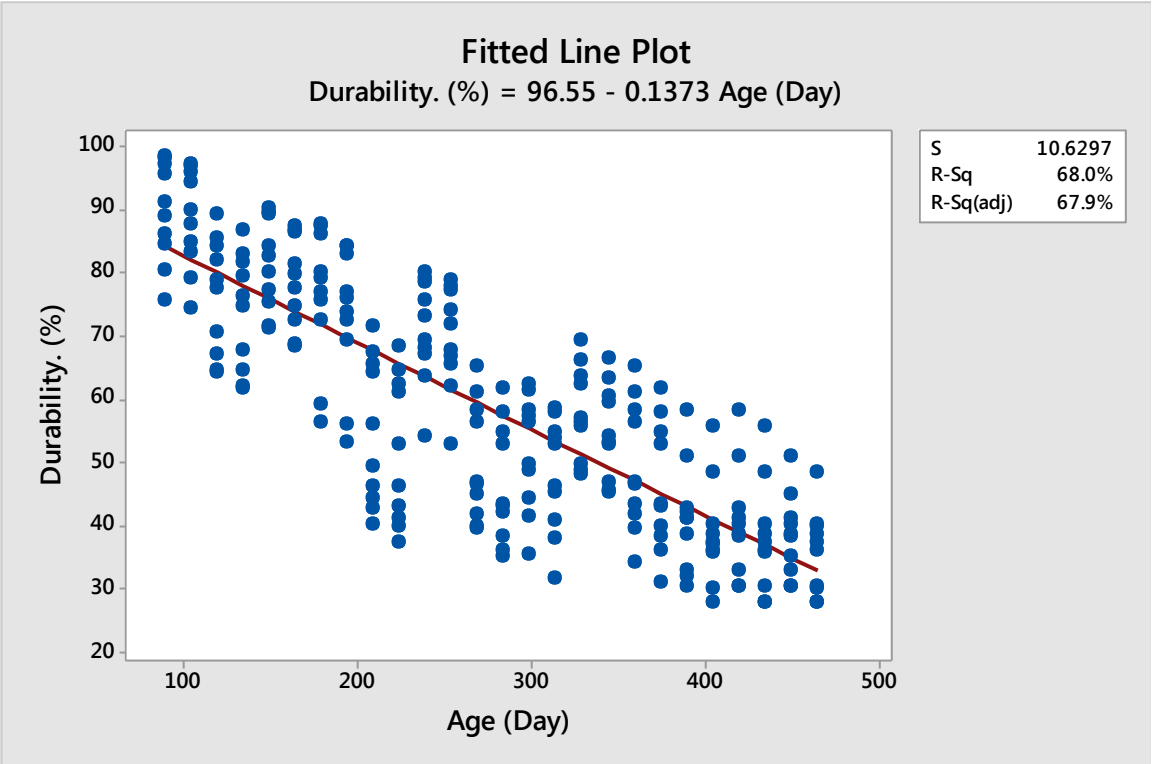
Regression Analysis: Durability. (%) versus Age (Day) For Traffic Paint

```
The regression equation is
Durability. (%) = 96.55 - 0.1373 Age (Day)


S = 10.6297   R-Sq = 68.0%   R-Sq(adj) = 67.9%


Analysis of Variance

Source        DF       SS        MS        F      P
Regression     1  61998.2  61998.2  548.70  0.000
Error        258  29151.8    113.0
Total        259  91150.0
```



Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	61998	61998.2	548.70	0.000
Age (Day)	1	61998	61998.2	548.70	0.000
Error	258	29152	113.0		
Lack-of-Fit	24	10231	426.3	5.27	0.000
Pure Error	234	18921	80.9		
Total	259	91150			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
10.6297	68.02%	67.89%	67.58%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	96.55	1.75	55.03	0.000	
Age (Day)	-0.13726	0.00586	-23.42	0.000	1.00

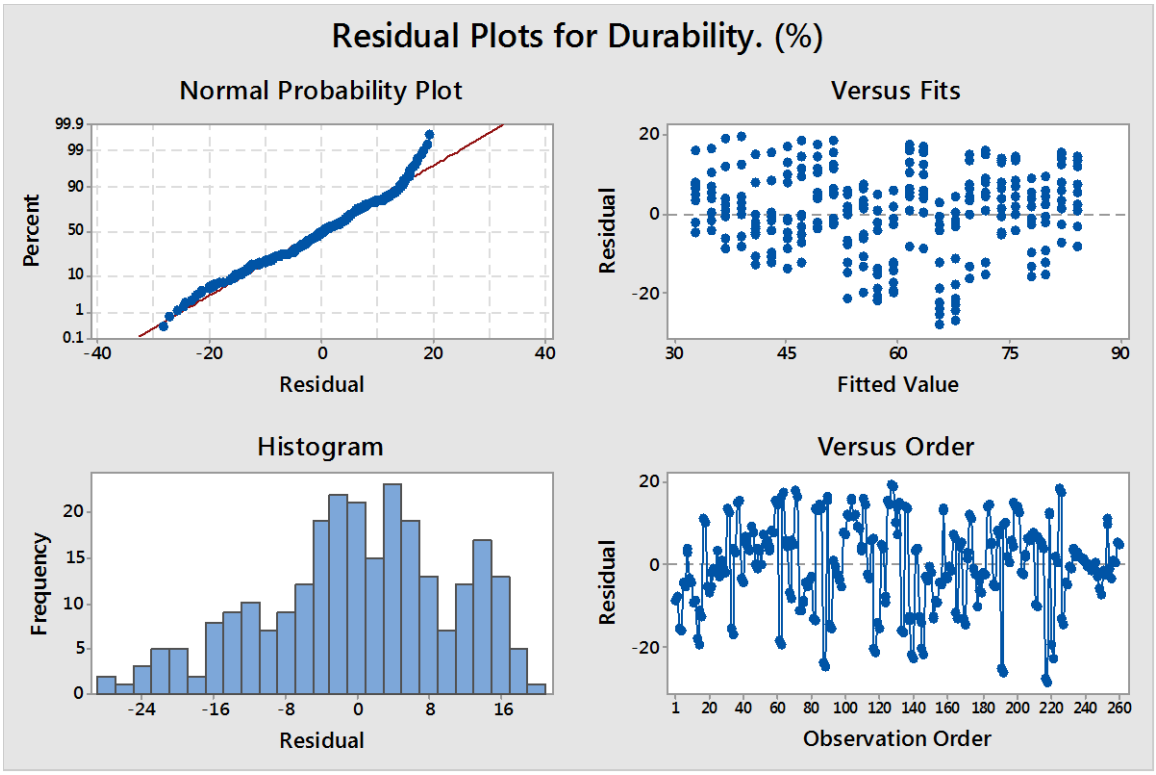
Regression Equation

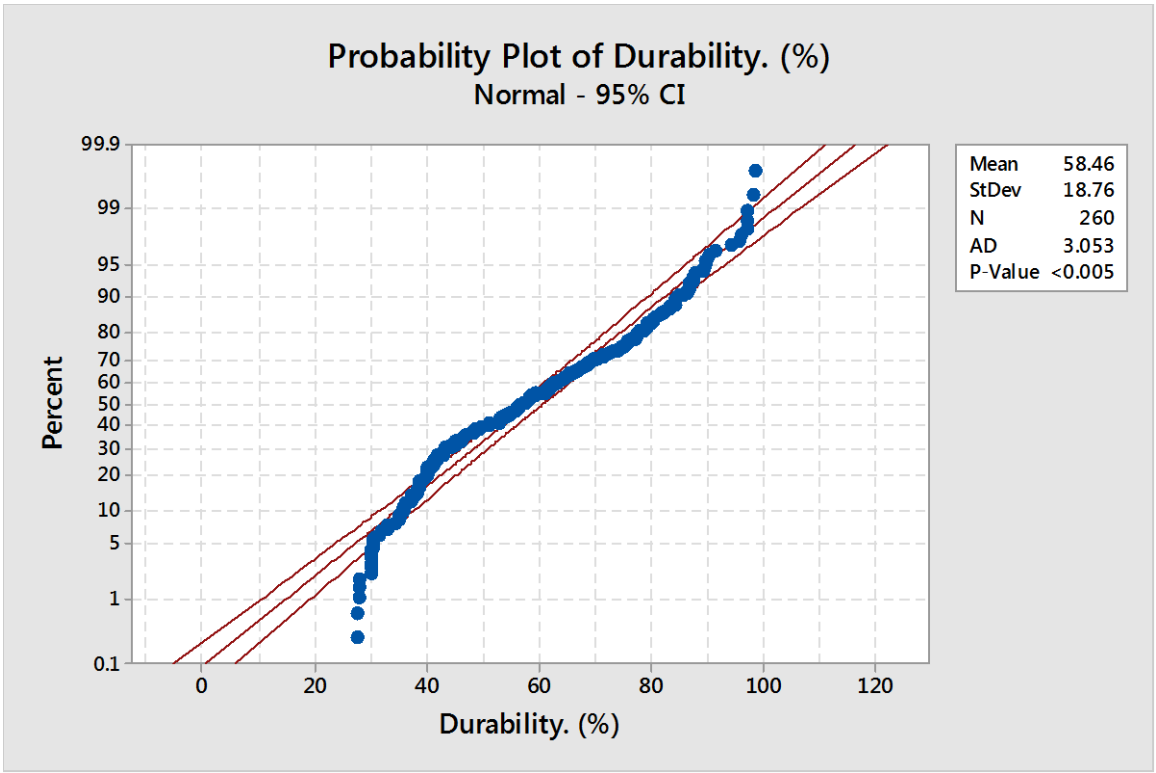
Durability. (%) = 96.55 - 0.13726 Age (Day)

Fits and Diagnostics for Unusual Observations

Obs	Durability. (%)	Fit	Resid	Std Resid	
87	44.280	67.729	-23.449	-2.21	R
88	41.170	65.670	-24.500	-2.31	R
118	36.030	57.434	-21.404	-2.02	R
139	46.210	67.729	-21.519	-2.03	R
140	43.100	65.670	-22.570	-2.13	R
146	31.720	53.316	-21.596	-2.04	R
191	42.840	67.729	-24.889	-2.35	R
192	39.730	65.670	-25.940	-2.45	R
217	40.280	67.729	-27.449	-2.59	R
218	37.170	65.670	-28.500	-2.69	R
222	35.000	57.434	-22.434	-2.11	R

R Large residual


Residual Plots for Durability. (%)
Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order


Probability Plot of Durability. (%)
Normal - 95% CI
Mean 58.46
StDev 18.76
N 260
AD 3.053
P-Value <0.005
Percent
Durability. (%)

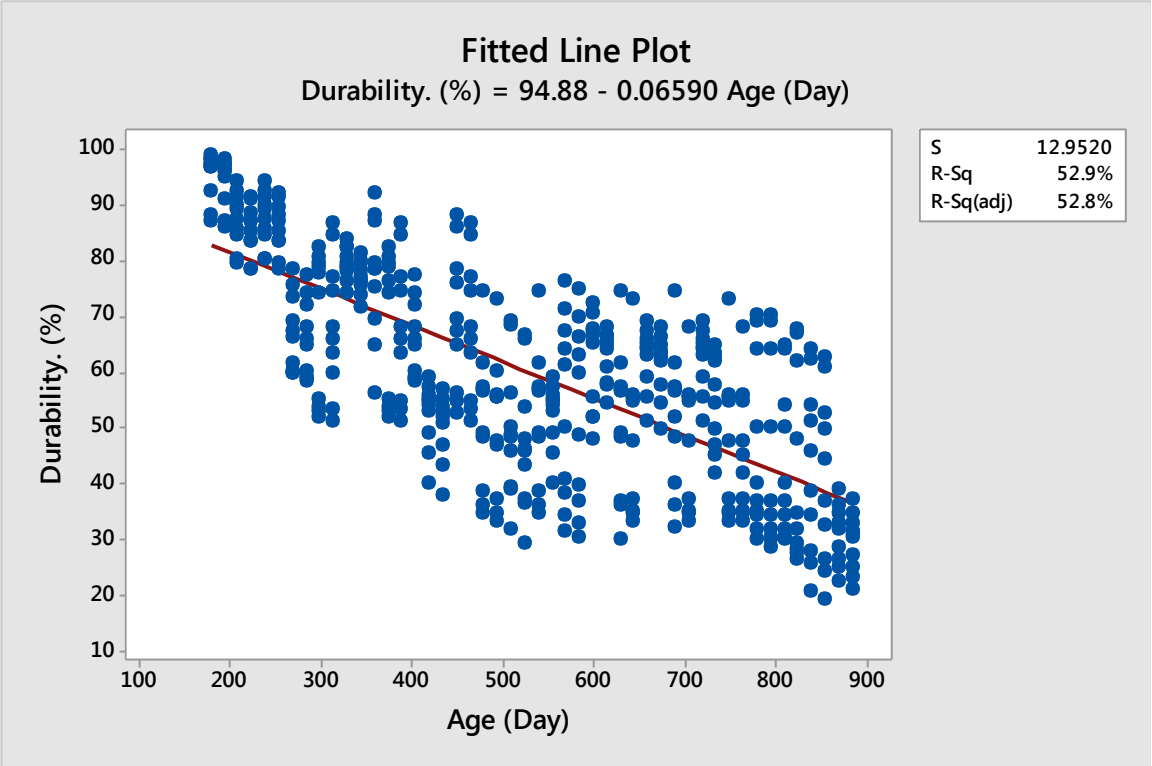
Regression Analysis: Durability. (%) versus Age (Day) For Thermoplastic

```
The regression equation is
Durability. (%) = 94.88 - 0.06590 Age (Day)


S = 12.9520   R-Sq = 52.9%   R-Sq(adj) = 52.8%


Analysis of Variance

Source        DF       SS        MS        F       P
Regression     1    90027   90026.8   536.66   0.000
Error        478    80187     167.8
Total        479   170214
```



Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	90027	90026.8	536.66	0.000
Age (Day)	1	90027	90026.8	536.66	0.000
Error	478	80187	167.8		
Lack-of-Fit	46	29362	638.3	5.43	0.000
Pure Error	432	50825	117.7		
Total	479	170214			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
12.9520	52.89%	52.79%	52.52%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	94.88	1.63	58.35	0.000	
Age (Day)	-0.06590	0.00284	-23.17	0.000	1.00

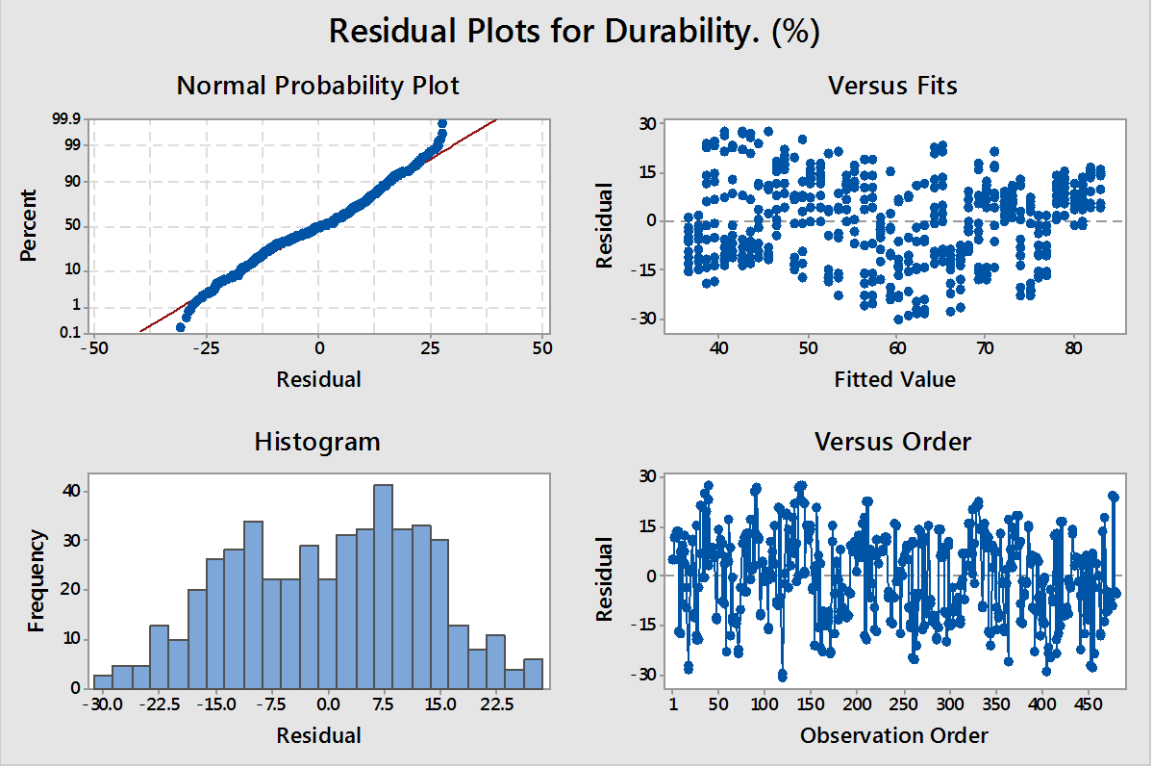
Regression Equation

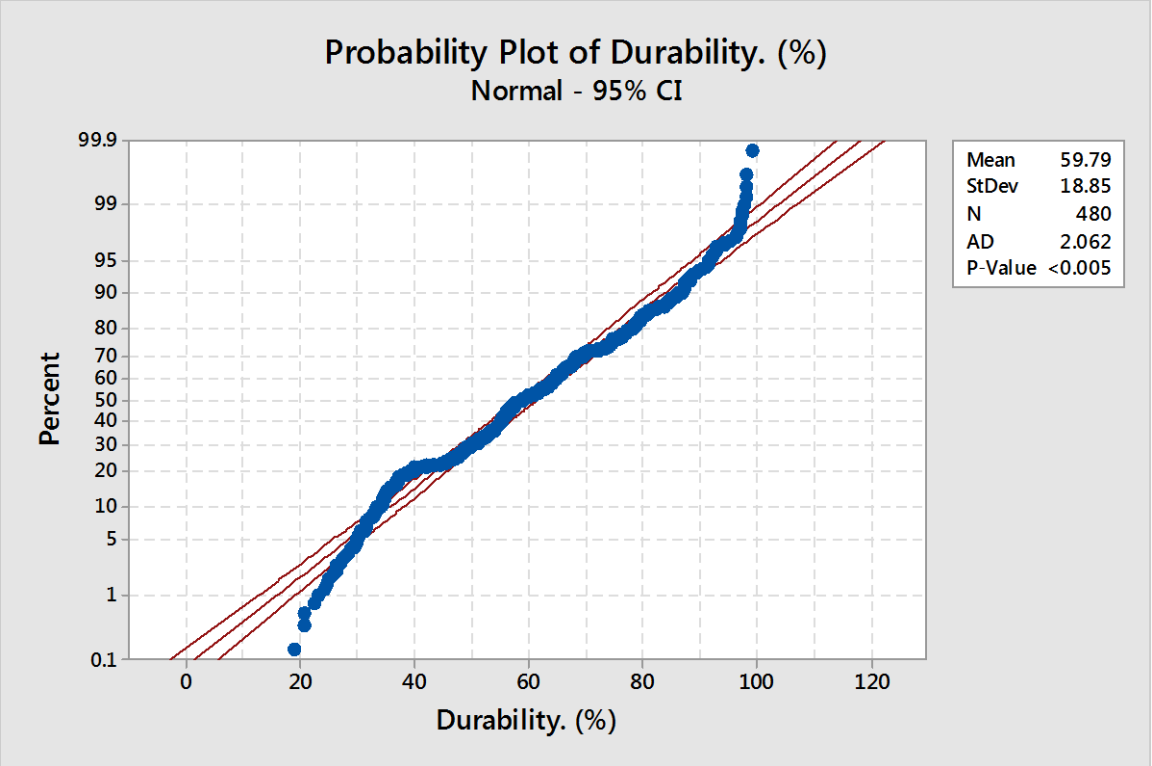
Durability. (%) = 94.88 - 0.06590 Age (Day)

Fits and Diagnostics for Unusual Observations

Obs	Durability. (%)	Fit	Resid	Std Resid	
17	40.180	67.202	-27.022	-2.09	R
18	38.010	66.213	-28.203	-2.18	R
39	73.130	45.453	27.677	2.14	R
89	69.340	43.476	25.864	2.00	R
90	69.340	42.487	26.853	2.08	R
92	67.010	40.510	26.500	2.05	R
119	31.750	61.270	-29.520	-2.28	R
120	29.380	60.282	-30.902	-2.39	R
137	70.240	43.476	26.764	2.07	R
138	70.240	42.487	27.753	2.15	R
140	67.910	40.510	27.400	2.12	R
364	30.190	56.327	-26.137	-2.02	R
405	34.570	63.247	-28.677	-2.22	R
406	33.240	62.259	-29.019	-2.24	R
453	35.940	63.247	-27.307	-2.11	R
454	34.610	62.259	-27.649	-2.14	R

R Large residual


Residual Plots for Durability. (%)
Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order


Probability Plot of Durability. (%)
Normal - 95% CI
Mean 59.79
StDev 18.85
N 480
AD 2.062
P-Value <0.005
Percent
Durability. (%)

APPENDIX F. COST BREAK DOWN

Basic Assumption		
1.Social Charge		**Percentage**
Annual leave		7
Holiday		4
Compensation payment		5
Mouring leave		3
Insurance(Workmen Collective)		4
Idle time payment(3 months)		25
Training		2
	Sum	**50**
2.Labour index factor		**Percentage**
Social charge		50
Displacement allowance		70
Desesrt allowance		
Other expenses		10
	Sum	**130**
Basic Salary		100
	Indexed salary	**230**

Indexed Labor Rate											
Item No.	Classification	Salary Range			Monthly Salary [Birr]	Yearly Salary [Birr]	Working Days per Year	Daily Rate	Working Hours per day	ourly Ra	Indexed Hourly Rate: Index*Cost
											2.3
	Labor Foreman	4500	-	5700	5100	61200	251	243.82	8	30.48	70.10
	Equipment Operator I	4500	-	4400	4450	53400	251	212.75	8	26.59	61.17
	Laborer	2400	-	3000	2700	32400	251	129.08	8	16.14	37.11

Average Material Cost				
Item No.	**Material**	**Unit**	**Material Cost at Addis Ababa**	**Total Cost**
	Thermoplastic Road Marking	Lit.	150	150.00

1 Gallon = 3.8 Liter

EQUIPMENT RENTAL RATE		
Item No.	**Equipment Type**	**Hourly Cost (Birr/hr.)**
	Road Marking Machine	141.07
	Hand tools (set)	15.00

Detailed break down of work item

unit prices

Project : **Cost Estimate- Any Road in Addis Ababa City** 1.25

Work Item : Paint, white broken line for lane line, width 100mm (Traffic Paint), 2m painted and 2m gap according to 4 meter module

Total quantity of work item : **Performance rate : 0.02 km/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate	
													hrly	Total
Road Marking paint	Lit.	4.20	22.00	92.40	Loubor Forman	1	0.5	70.10	35.05	Hand tools (set)	2	1	15.00	30.00
Glass/retro-flective beads	kg	3.36	12.00	40.32	Labourer I	4	1	37.11	148.45					
Total				132.72	**Total**				183.50	**Total**				30.00

A = Material Unit Cost 132.72 Birr/km B = Manpower Unit Cost : 12233.07 Birr/km C = Equipment Unit Cost : 2000 Birr/km

Direct cost of work item =A+B+C= **14365.79** Birr/km

Assuming 10 % project overhead, 10 % profit margin and 5% for others, the total surcharge adopted is 25% of direct cost. Thus :

Total cost = **17,957.23** Birr/km

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Assumption

Total Area/Km= 10m^2 (For two way two lane =2*2m*0.01m*250)

Ordinary road marking paint shall be applied at a nominal rate of 0.42 liter/sq. m, (For the given 1Km road 4.2Lit.)

The rate of application of the beads shall be 0.8 kg/liter paint. (For the given 1Km road 3.36Kg.)

Detailed break down of work item

unit prices

Project : **Cost Estimate- Any Road in Addis Ababa City** 1.25

Work Item : Paint, white broken line for lane line, width 100mm (Thermoplastic), 2m painted and 2m gap according to 4 meter module

Total quantity of work item : **Performance rate : 0.02 km/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Thermoplastic Road Marking	Lit.	4.20	150.00	630.00	Loubor Forman	1	0.5	70.10	35.05	Road Marking Machine	1	1	141.07	141.07
					Equip. Operator I	1	1	61.17	61.17	Hand tools (set)	2	1	15.00	30.00
					Labourer I	2	1	37.11	74.22					
Total				630.00	**Total**				170.44	**Total**				171.07

A = Material Unit Cost 630.00 Birr/km B = Manpower Unit Cost : 11362.55 Birr/km C = Equipment Unit Cost : 11405 Birr/km

Direct cost of work item =A+B+C= **23397.38** Birr/km

Assuming 10 % project overhead, 10 % profit margin and 5% for others, the total surcharge adopted is 25% of direct cost. Thus :

Total cost = **29,246.73** Birr/km

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

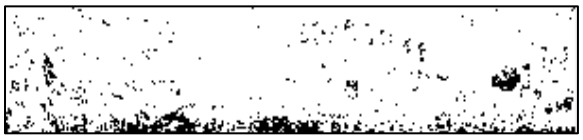
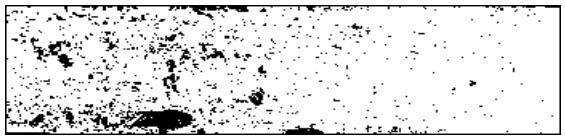
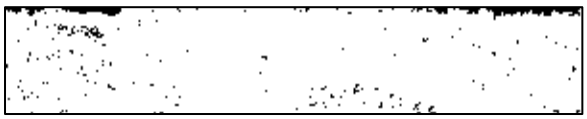
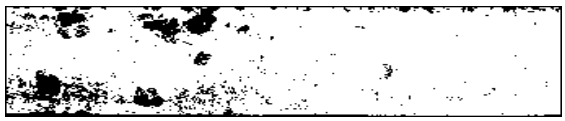
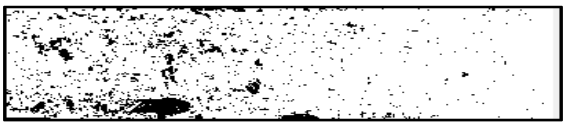
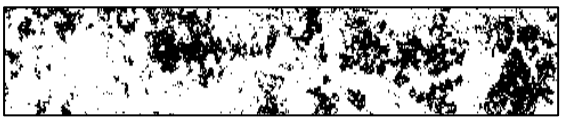
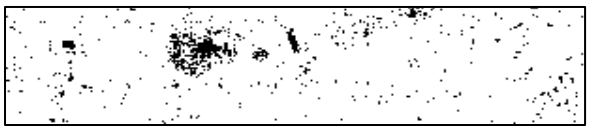
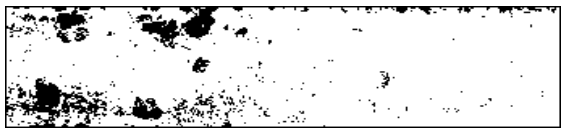
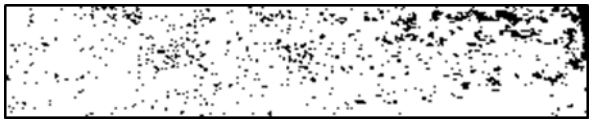
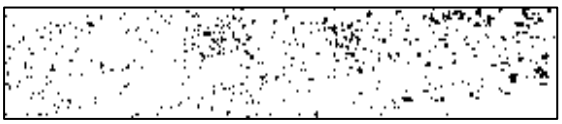
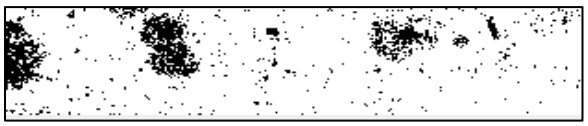
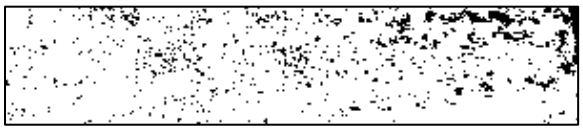
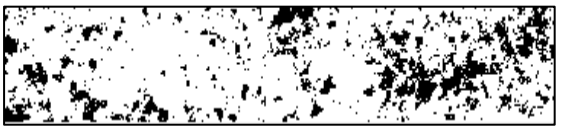
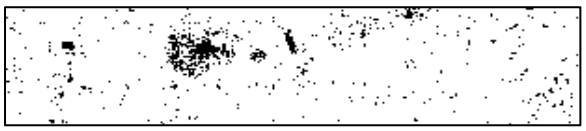
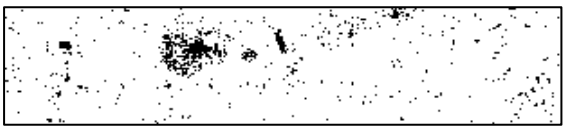
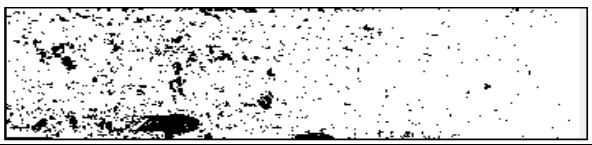
Assumption

Total Area/Km= 10m^2 (For two way two lane =2*2m*0.01m*250)

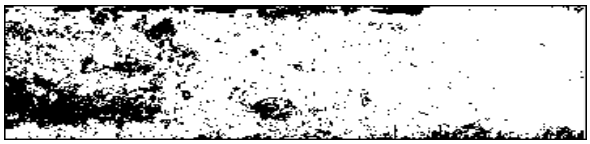
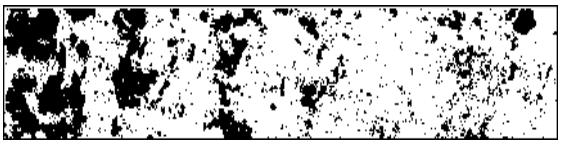
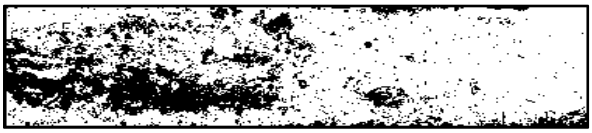
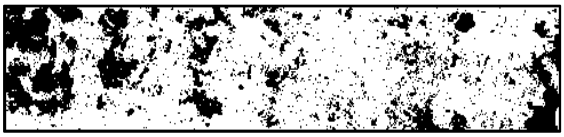
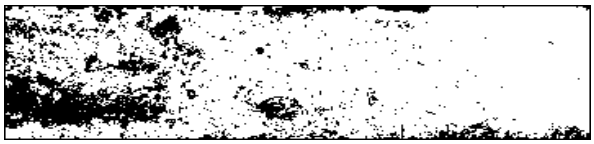
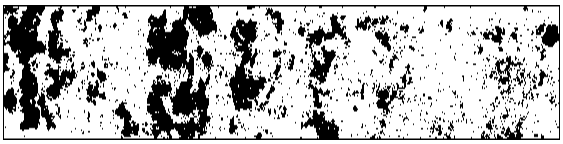
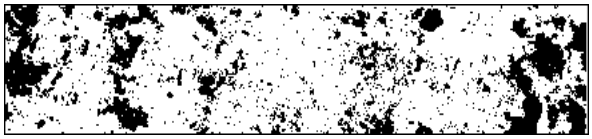
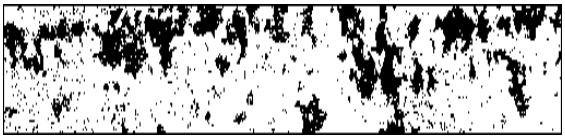
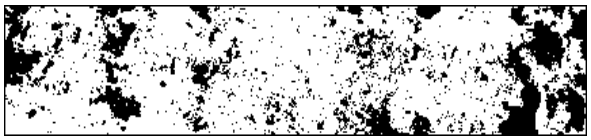
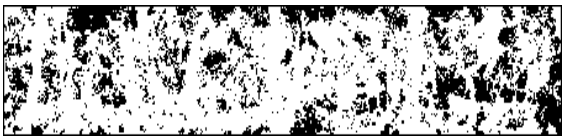
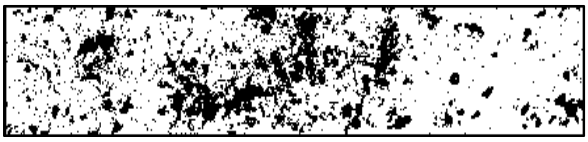
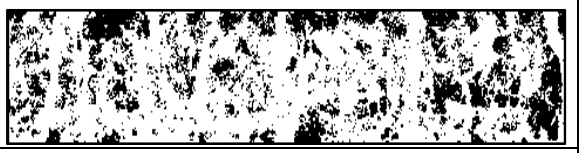
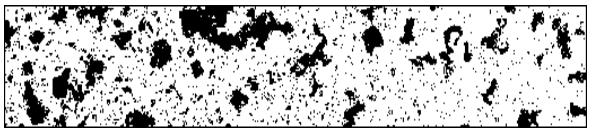
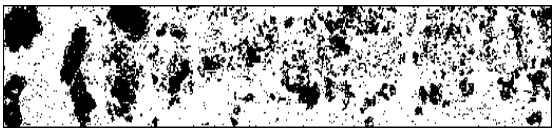
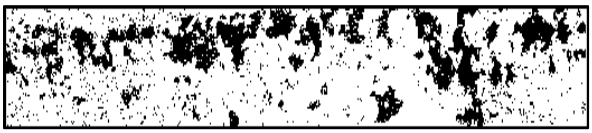
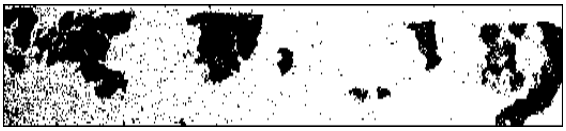
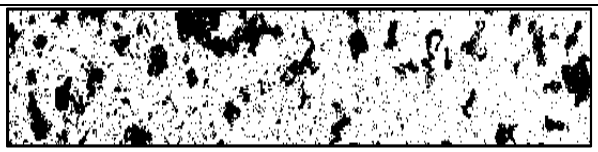
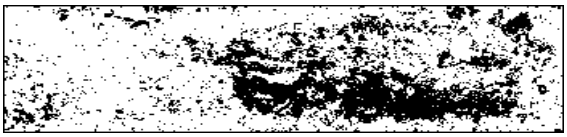
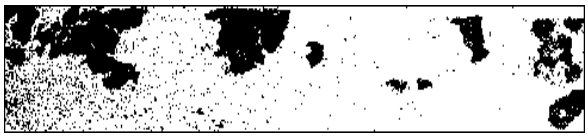
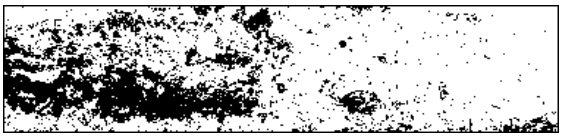
Ordinary road marking paint shall be applied at a nominal rate of 0.42 liter/sq. m, (For the given 1Km road 4.2Lit.)

APPENDIX G. DURABILITY VALU

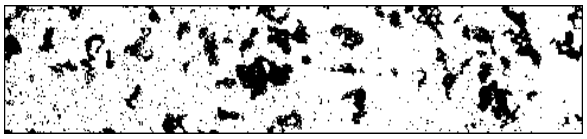
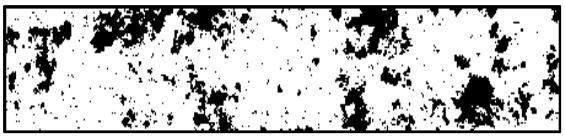
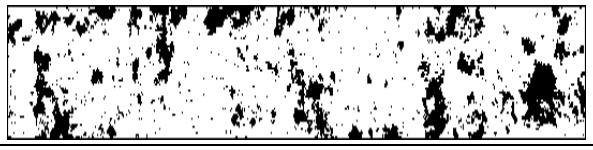
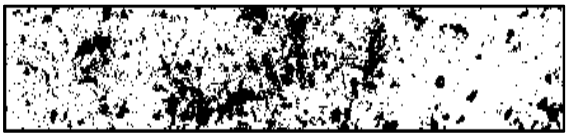
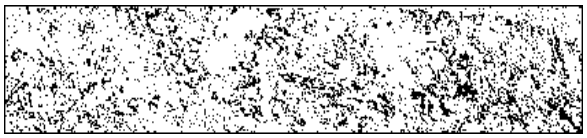
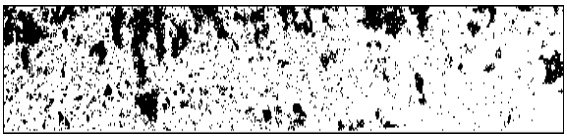
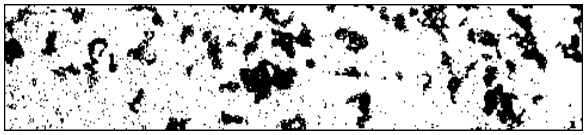
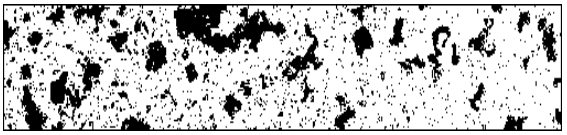
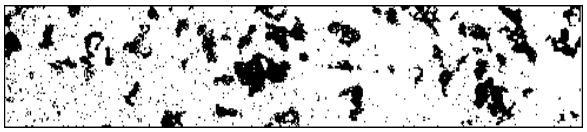
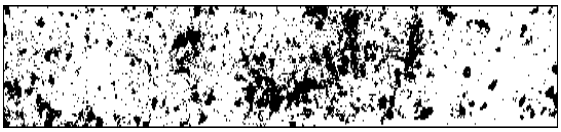
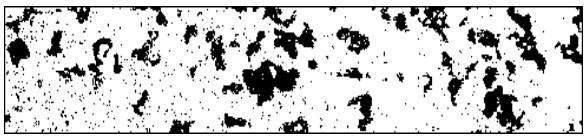
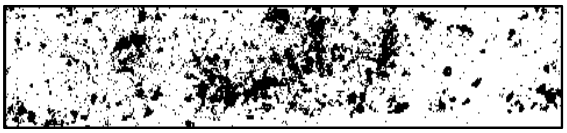
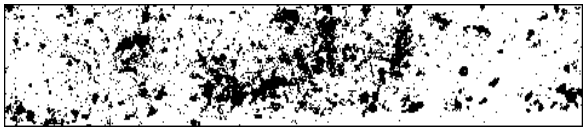
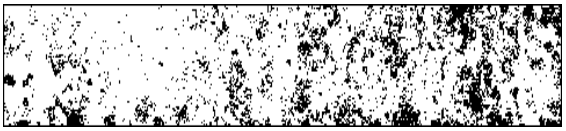
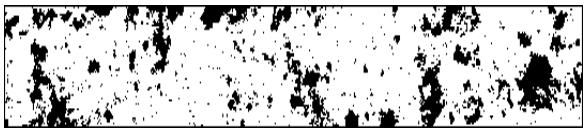
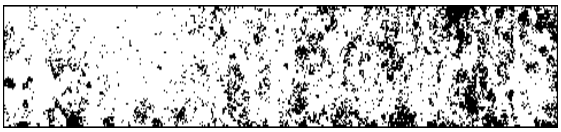
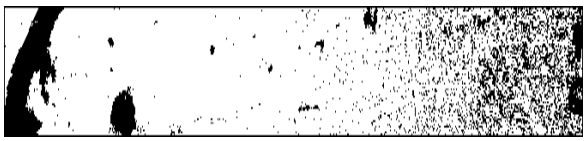
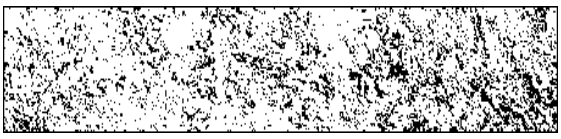
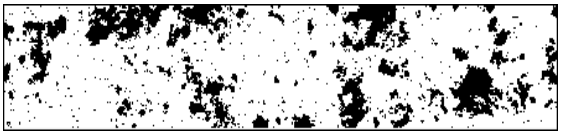
For Arterial streets: From Ethiopia hotel to national palace. (A) – Traffic Paint

No. of Samples	After 90 days	After 105 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**89.728%**	**88.438%**

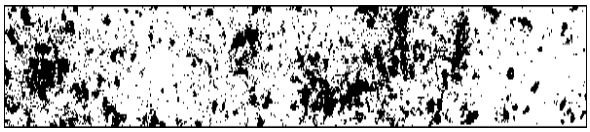
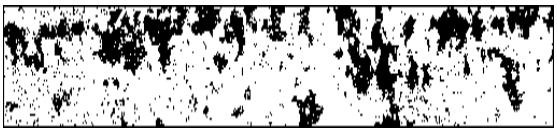
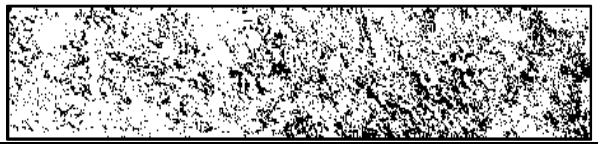
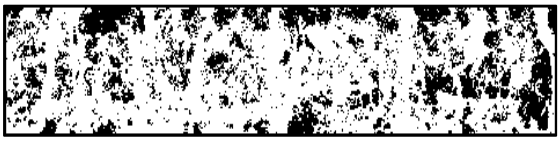
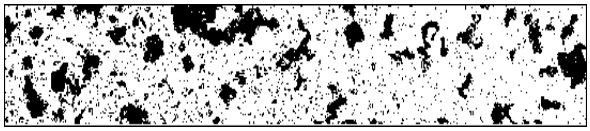
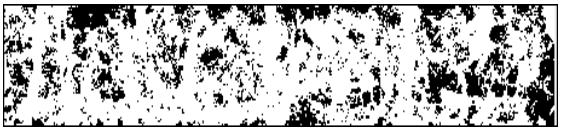
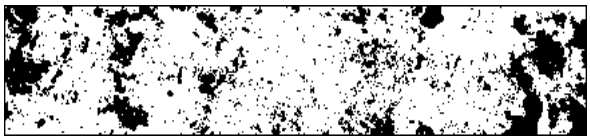
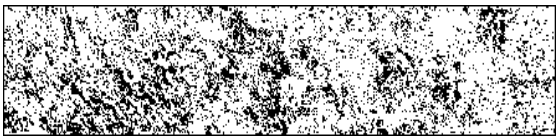
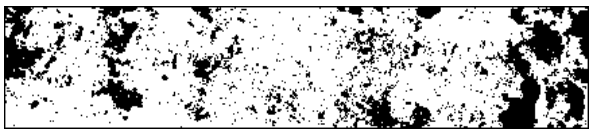
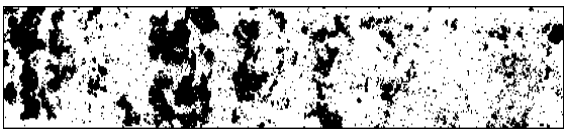
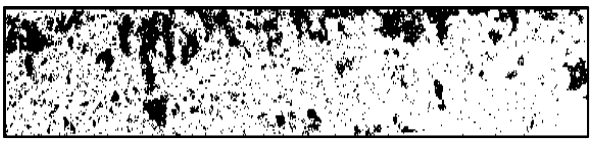
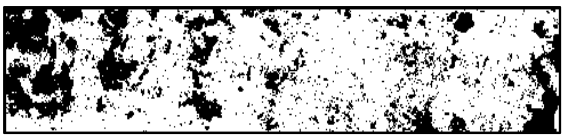
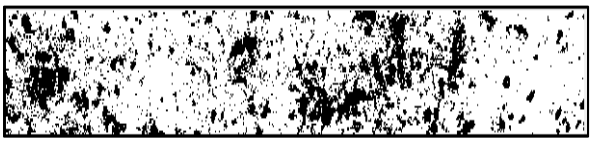
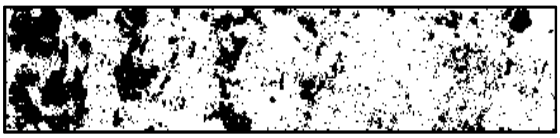
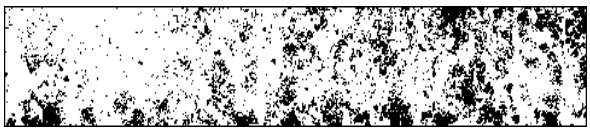
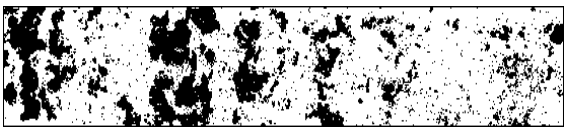
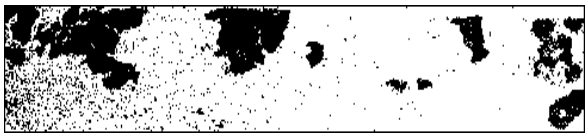
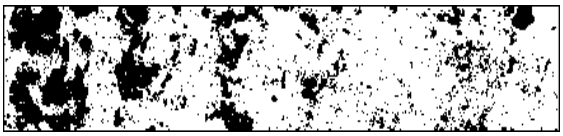
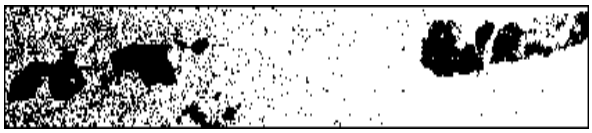
For Arterial streets: From Sheraton Hotel to National Palace. (B') – Traffic Paint

No. of Samples	After 210 days	After 135 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**76.447%**	**73.827%**

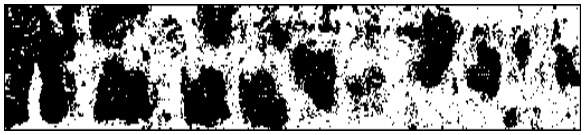
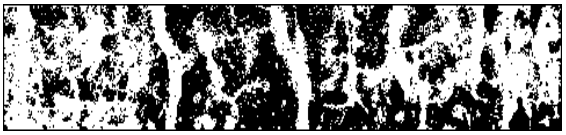
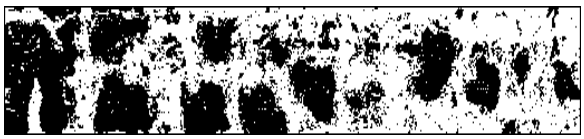
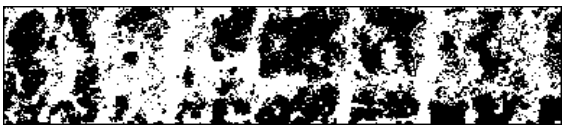
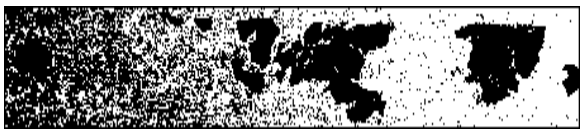
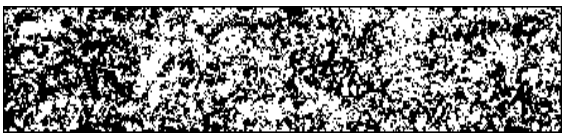
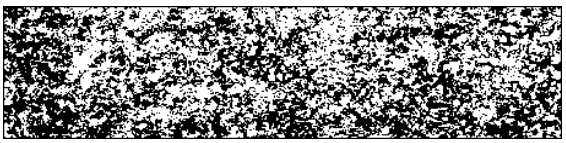
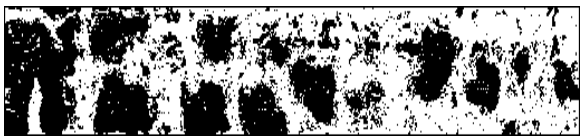
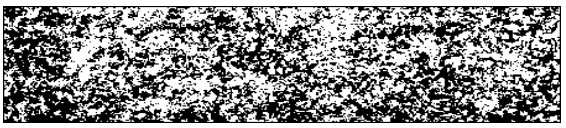
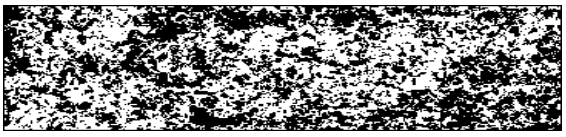
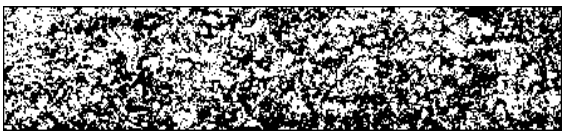
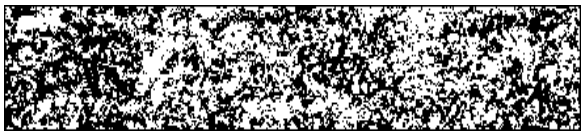
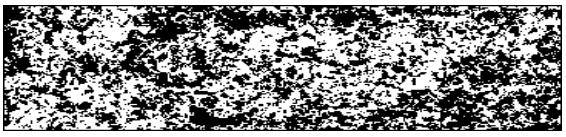
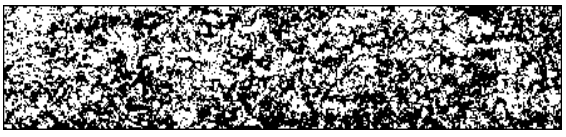
For Arterial streets: From Post Office to Tikur anbesa hospital. (C') – Traffic Paint

No. of Samples	After 150 days	After 165 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**81.20%**	**78.50%**

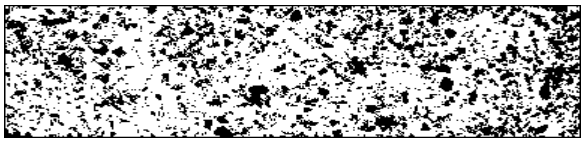
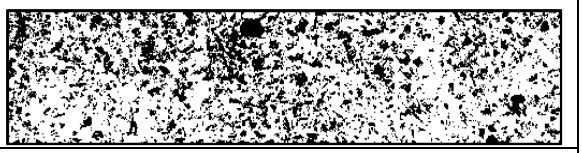
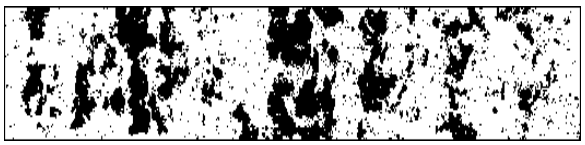
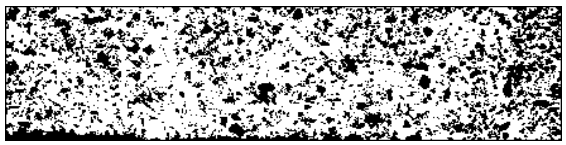
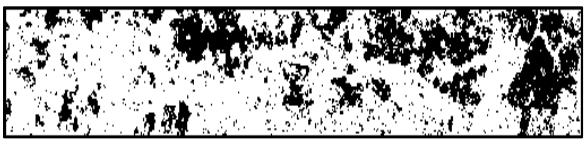
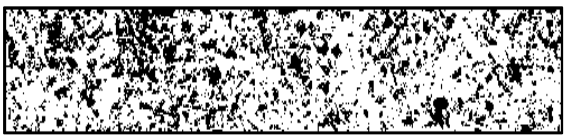
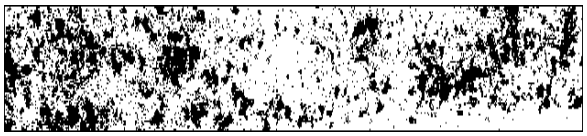
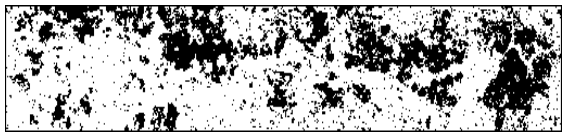
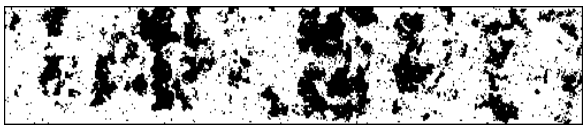
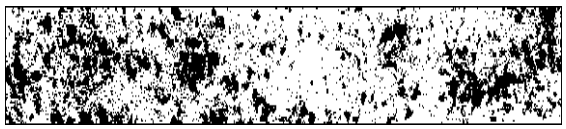
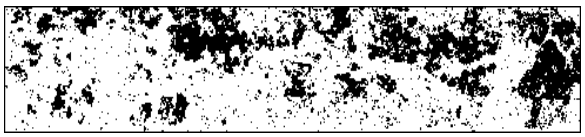
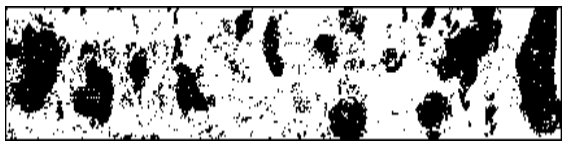
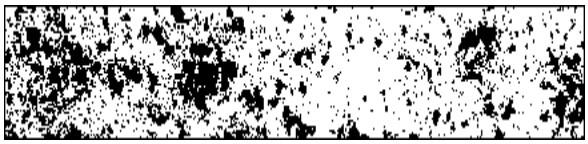
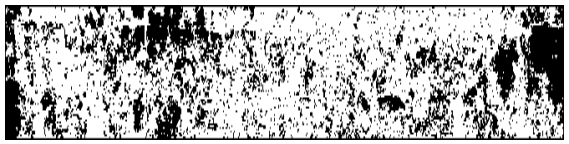
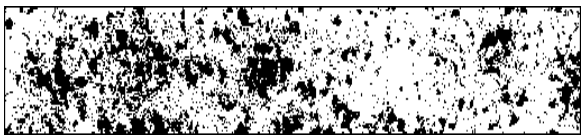
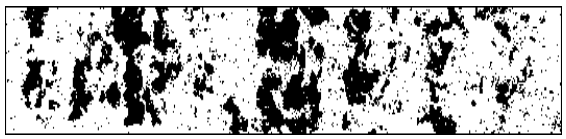
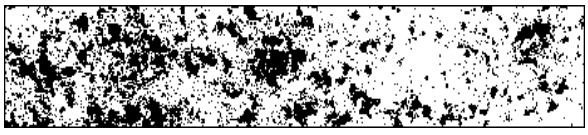
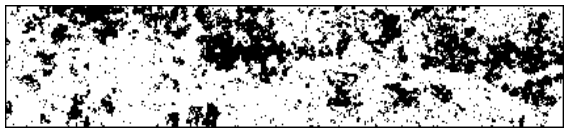
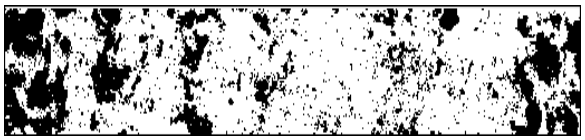
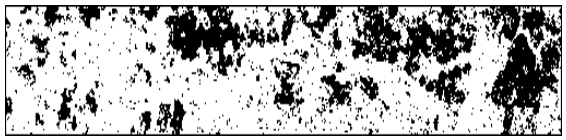
For Arterial streets: From Mexico Sq to Beherawi theater. (D') – Traffic Paint

No. of Samples	After 180 days	After 195 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**76.20%**	**73.02%**

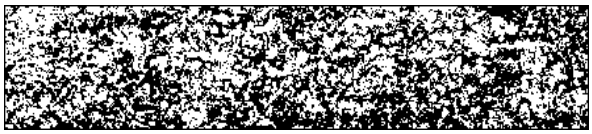
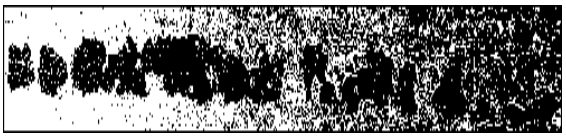
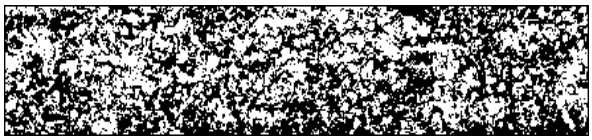
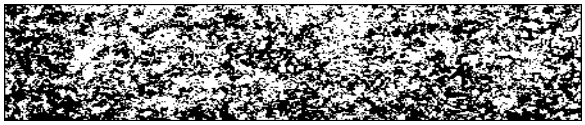
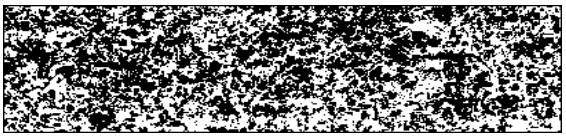
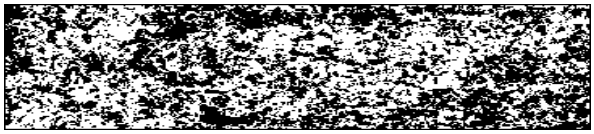
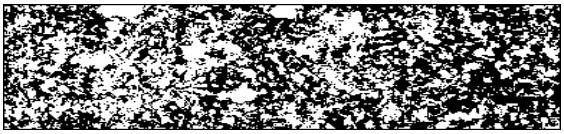
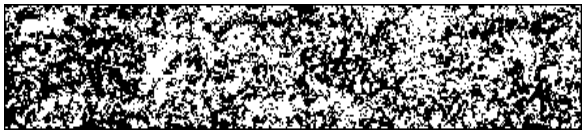
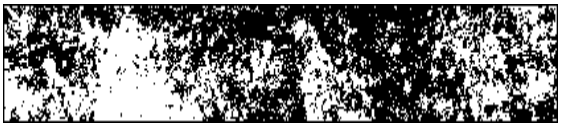
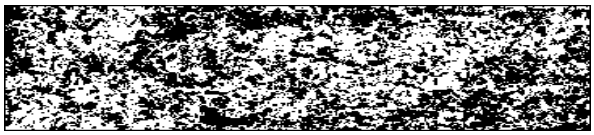
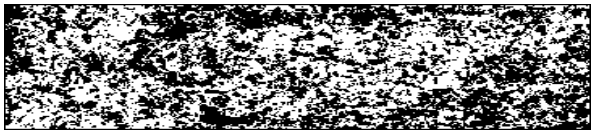
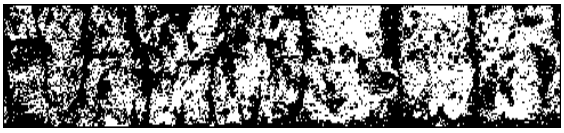
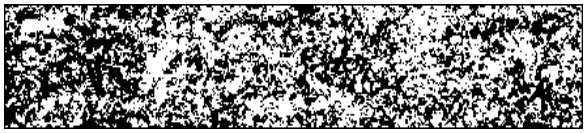
For Arterial streets: From Giorgis through Semen Mazegaja to Adisu gebeya. (E') – Traffic Paint

No. of Samples	After 210 days	After 225 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**54.80%**	**51.69%**

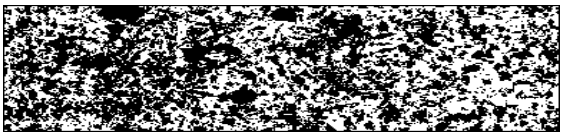
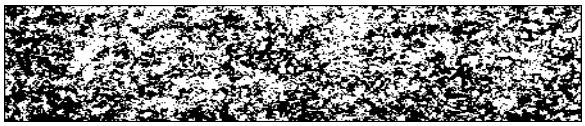
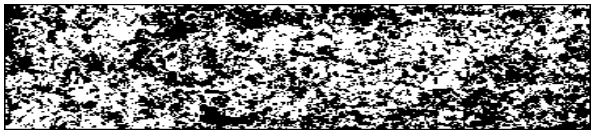
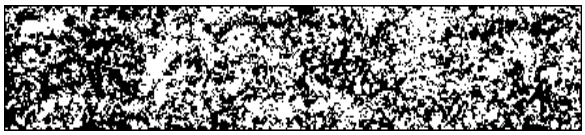
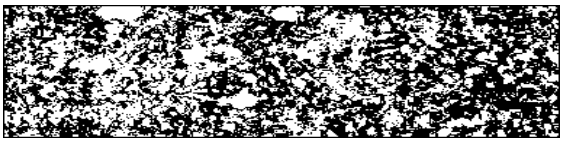
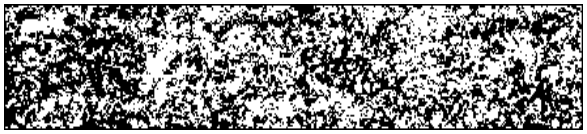
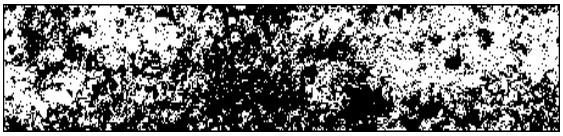
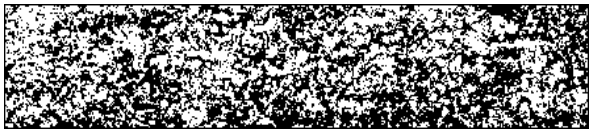
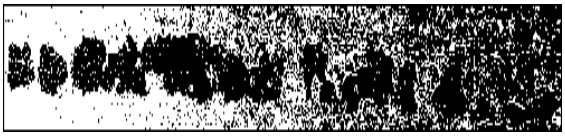
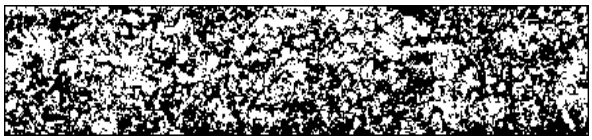
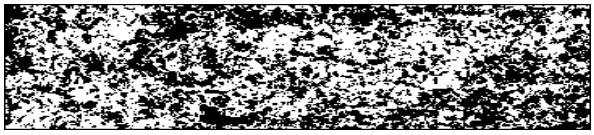
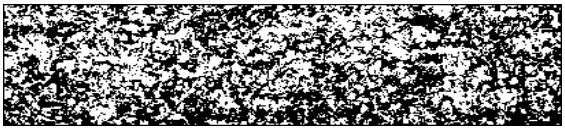
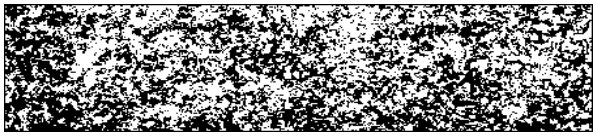
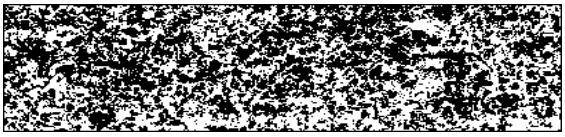
For Arterial streets: From Arat Kilo to Kebena bridge. (F') – Traffic Paint

No. of Samples	After 240 days	After 255 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**70.97%**	**69.54%**

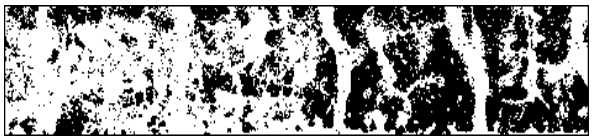
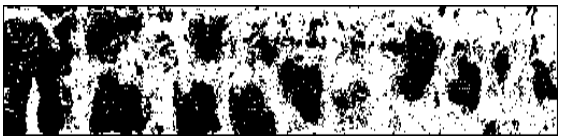
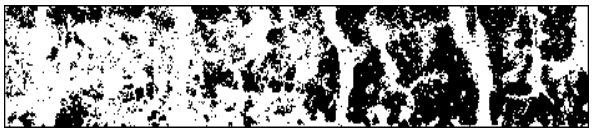
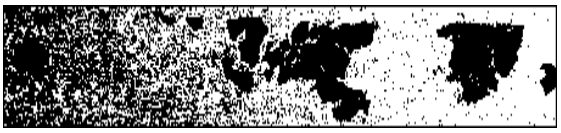
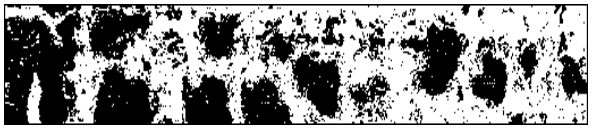
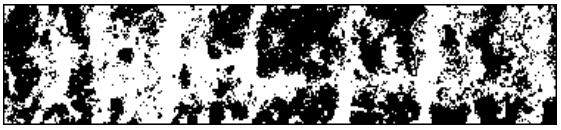
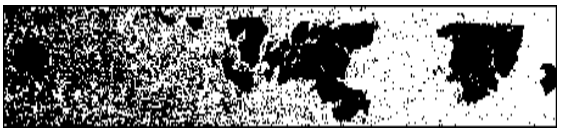
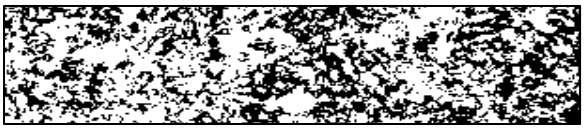
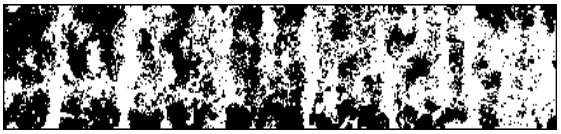
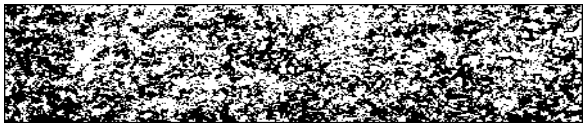
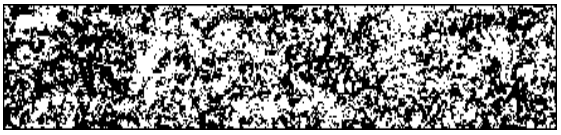
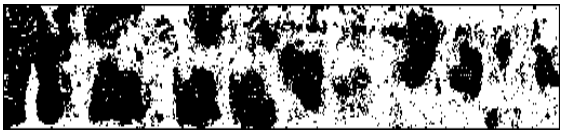
For Arterial streets: From Meskel Sq to Gotera inter-change. (G') – Traffic Paint

No. of Samples	After 270 days	After 285 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**50.06%**	**45.51%**

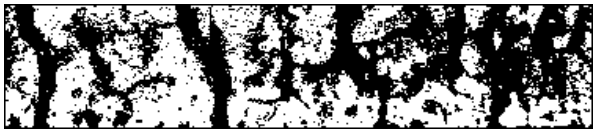
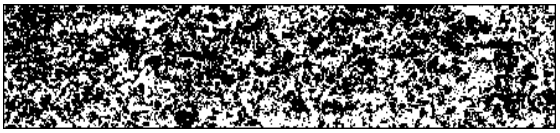
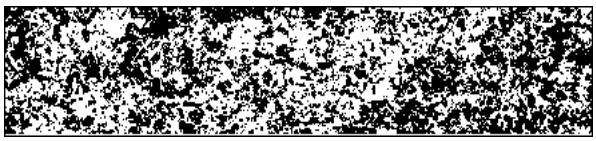
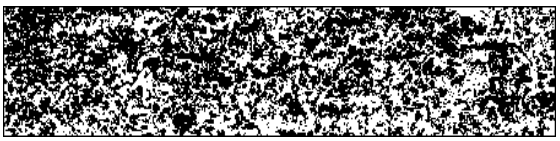
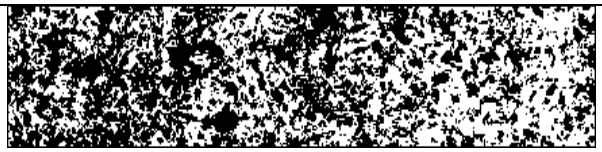
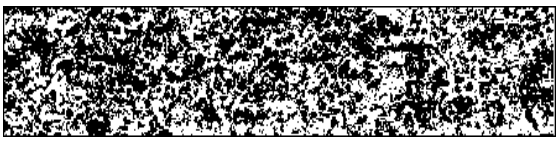
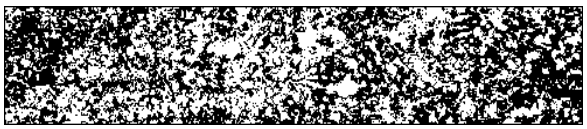
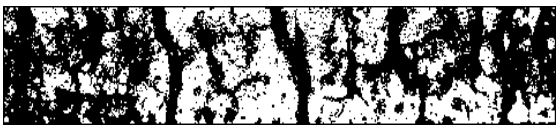
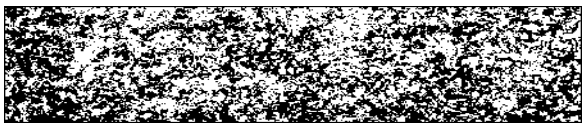
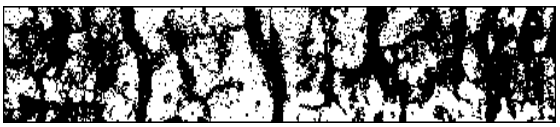
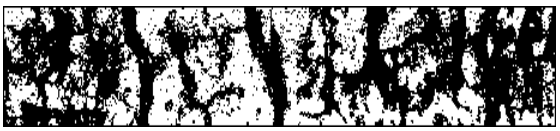
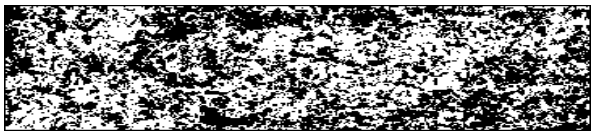
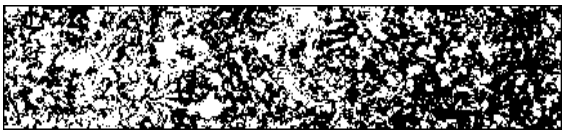
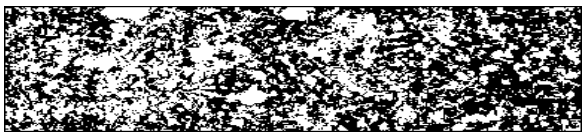
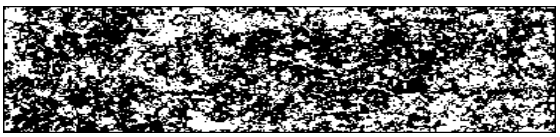
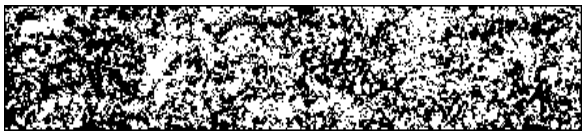
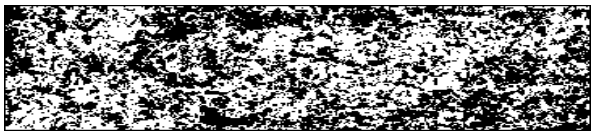
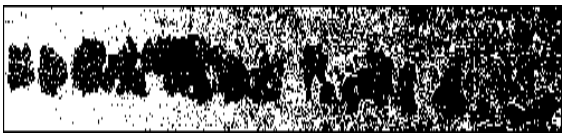
For Arterial streets: From S/t Urael church to Bole brass clinic. (H') – Traffic Paint

No. of Samples	After 300 days	After 315 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**51.54%**	**47.99%**

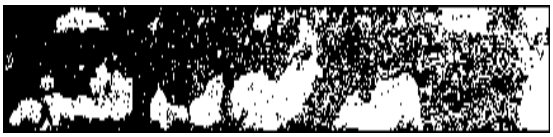
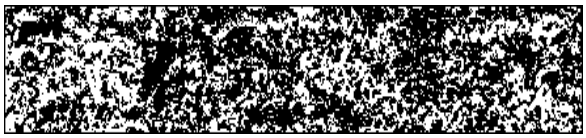
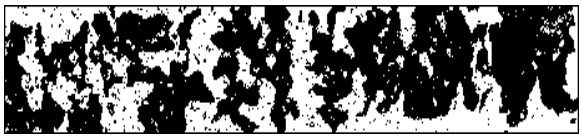
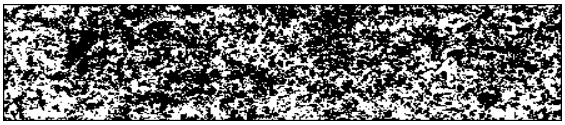
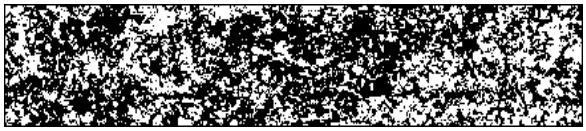
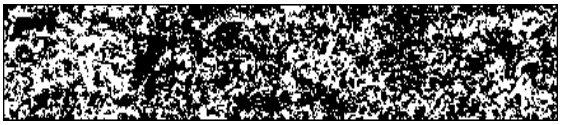
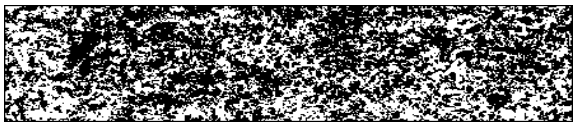
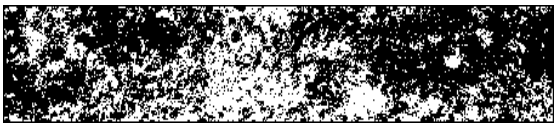
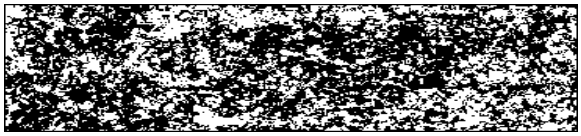
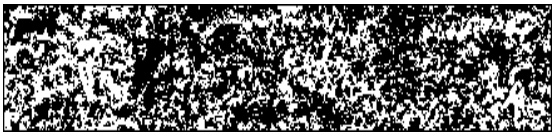
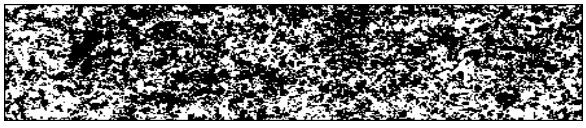
For Arterial streets: From Wereda 17 health center to Gergi RA. (I') – Traffic Paint

No. of Samples	After 330 days	After 345 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**57.78%**	**54.79%**

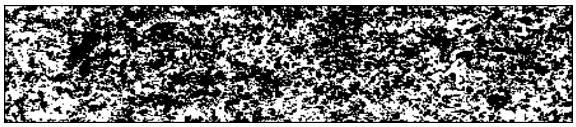
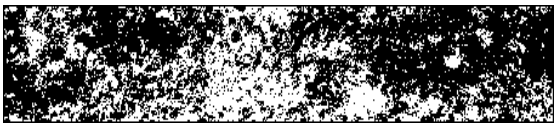
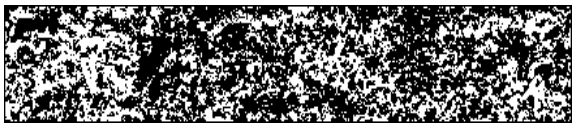
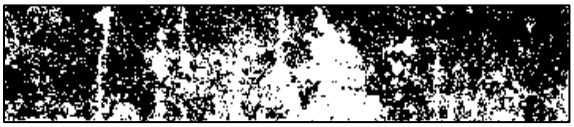
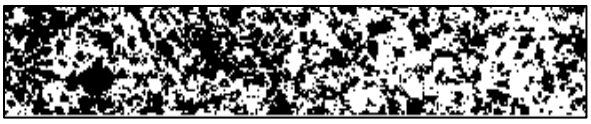
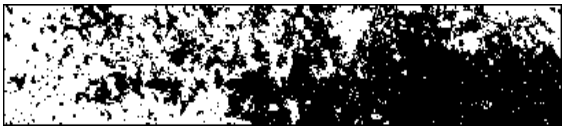
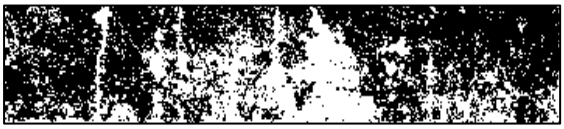
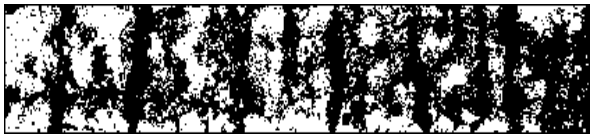
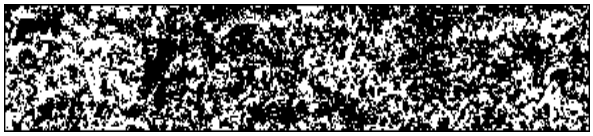
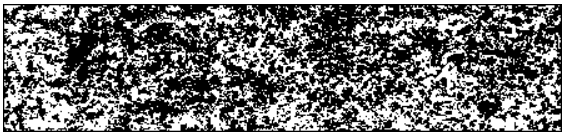
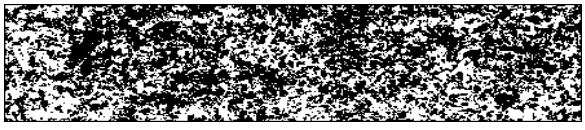
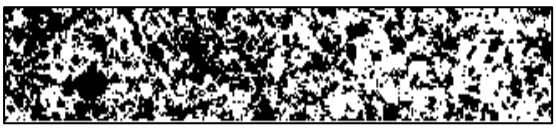
For Arterial streets: From Teodros Sq through Mega book shop to Grand Palace. (J') – Traffic Paint

No. of Samples	After 360 days	After 375 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**49.32%**	**45.88%**

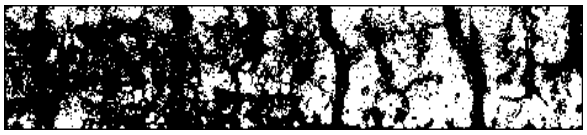
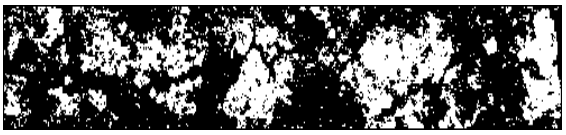
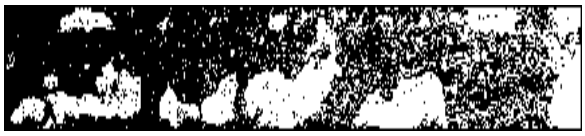
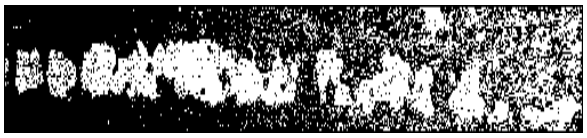
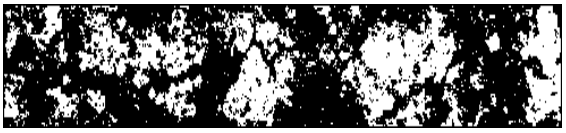
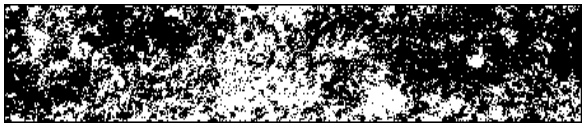
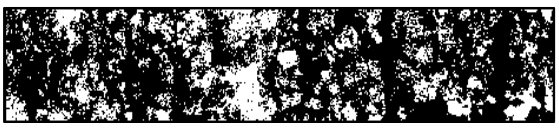
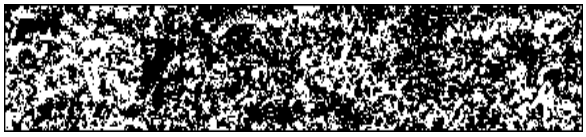
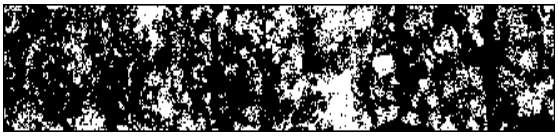
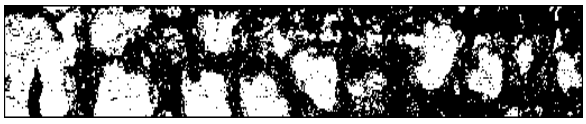
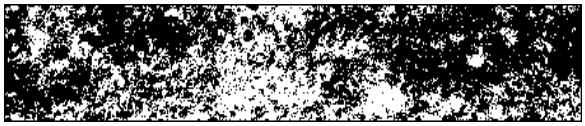
For Arterial streets: From S/t Urael church to Bole brass clinic. (K') – Traffic Paint

No. of Samples	After 390 days	After 405 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**41.04%**	**38.69%**

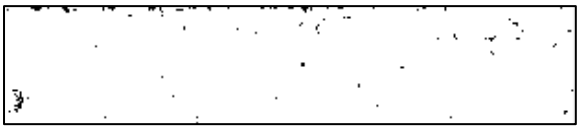
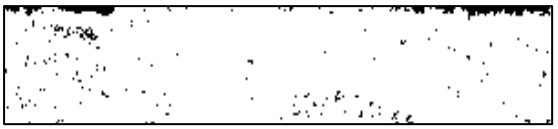
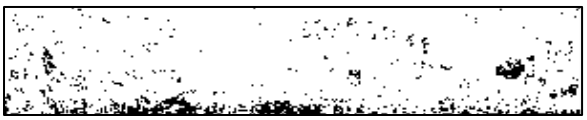
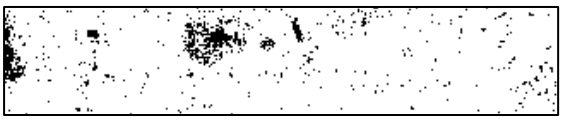
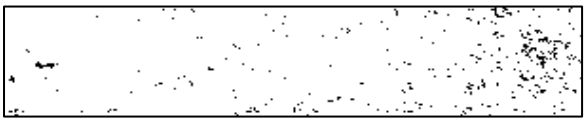
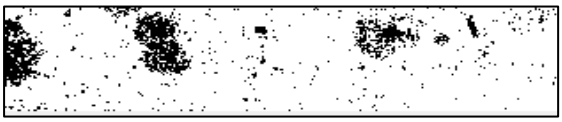
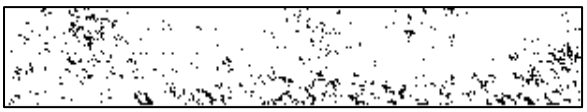
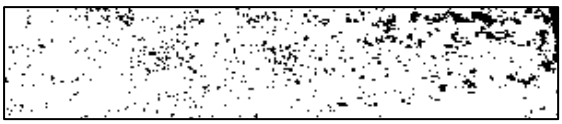
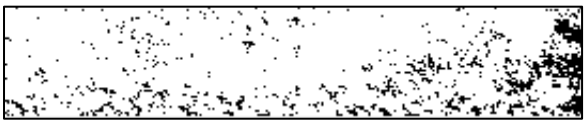
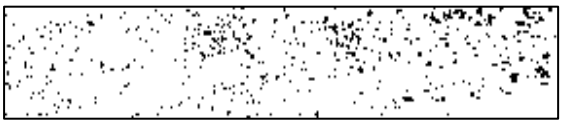
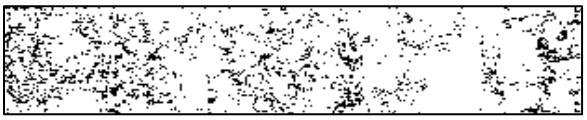
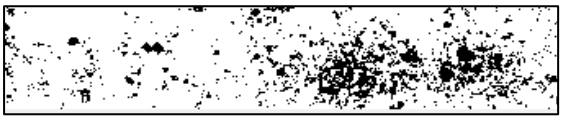
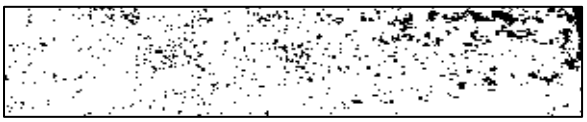
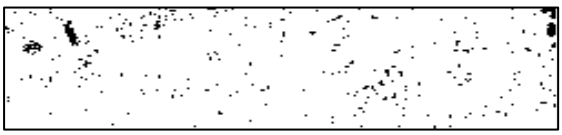
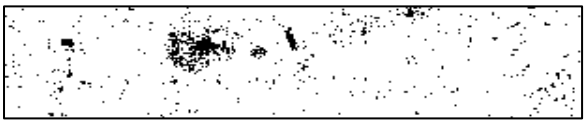
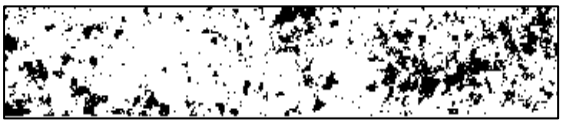
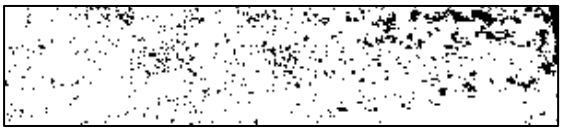
For Arterial streets: From Mexico Sq to Di Afrique (no 41 PAS Jun. (L') – Traffic Paint

No. of Samples	After 420 days	After 435 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**40.40%**	**37.78%**

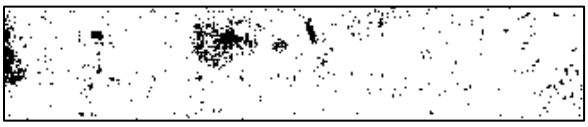
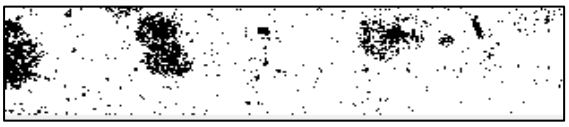
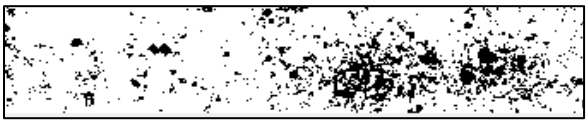
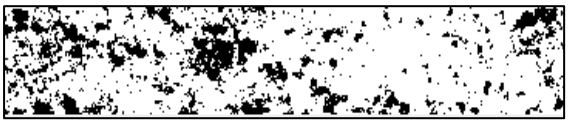
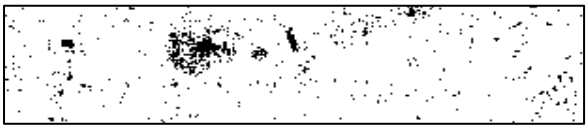
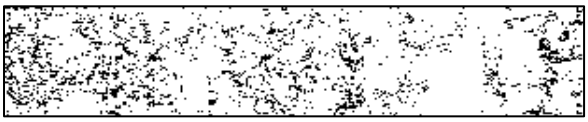
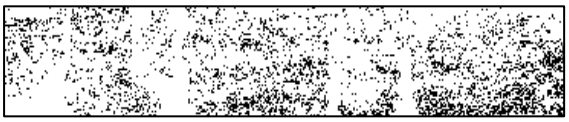
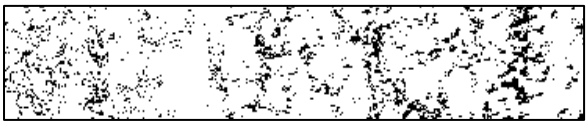
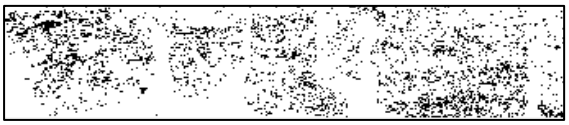
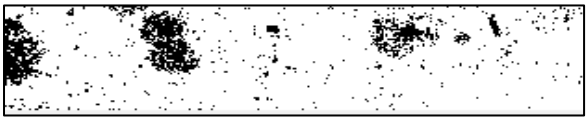
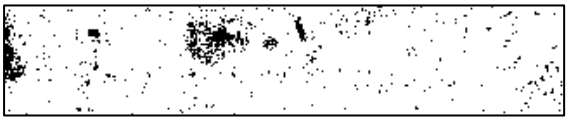
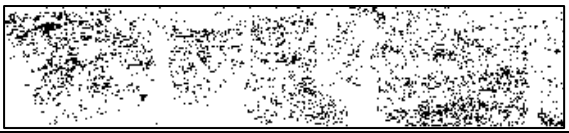
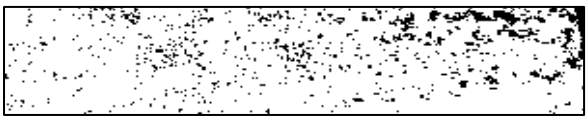
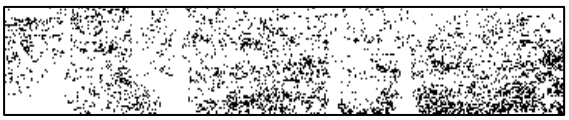
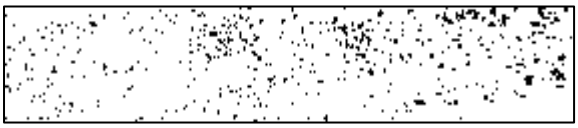
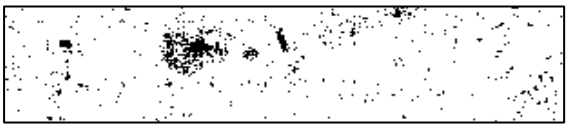
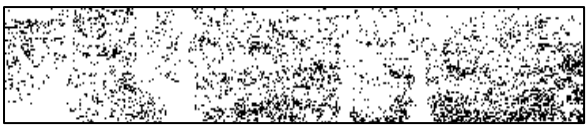
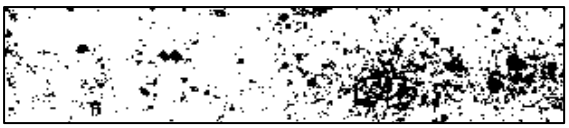
For Arterial streets: From Abo mekanisa to DagimMilinieum Hotel. (M) – Traffic Paint

No. of Samples	After 450 days	After 465 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**38.28%**	**35.64%**

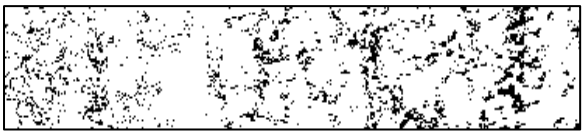
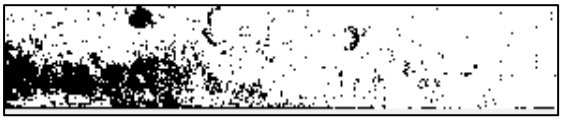
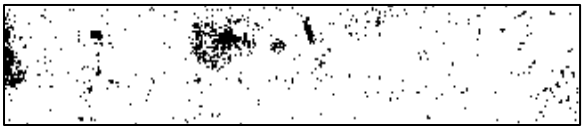
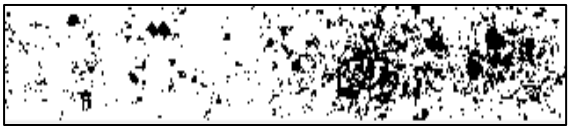
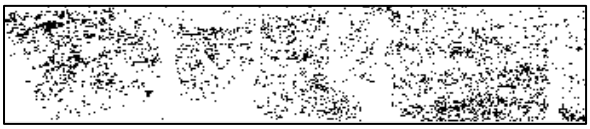
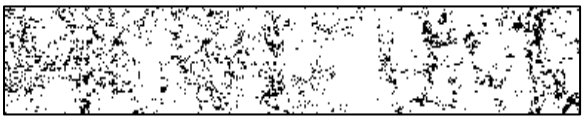
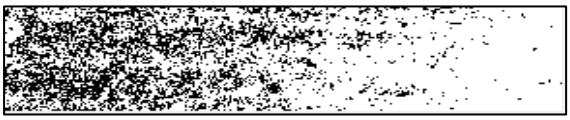
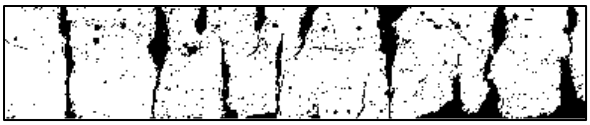
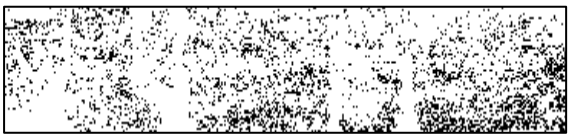
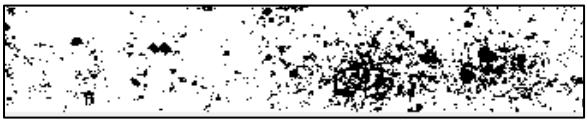
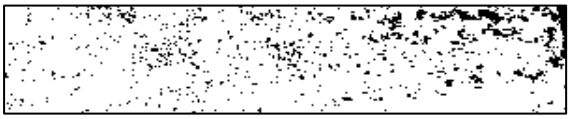
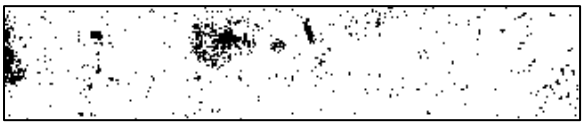
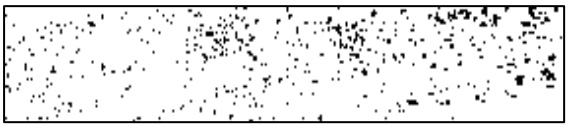
For Arterial streets: From Legahare toTeodros Sq. (A) – Thermoplastic

No. of Samples	After 180 days	After 195 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**95.23%**	**94.25%**

For Arterial streets: From Popurale to cherkos church to meskerem mazoria. (B) - Thermoplastic

No. of Samples	After 210 days	After 225 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**87.59%**	**85.61%**

For Arterial streets: From Banko di Roma Jun to Eribekentu Jun. (C) – Thermoplastic

No. of Samples	After 240 days	After 255 days
1		
2		
3		
4		
5		
6		
7		
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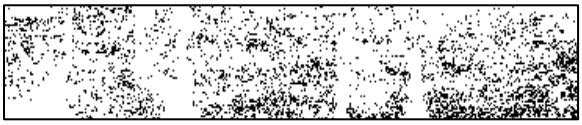
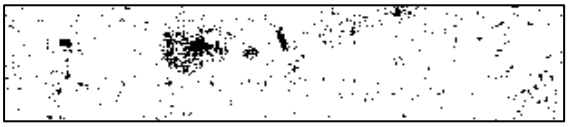
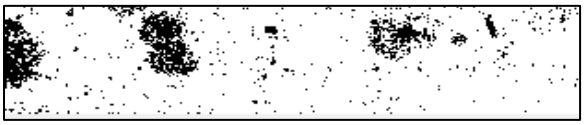
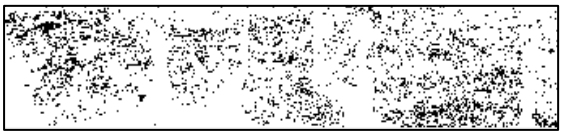
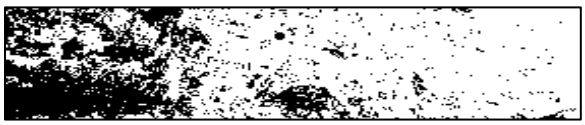
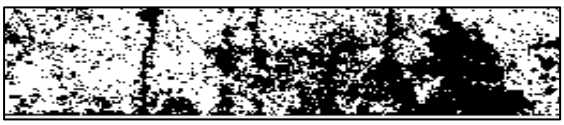
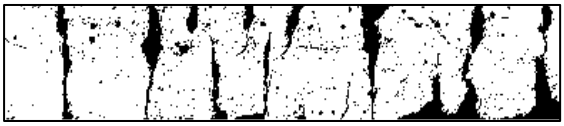
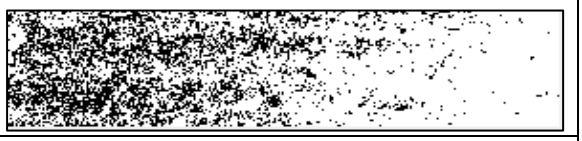
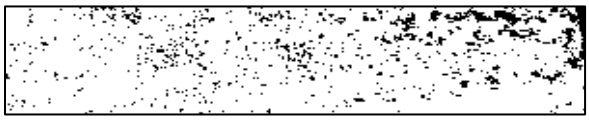
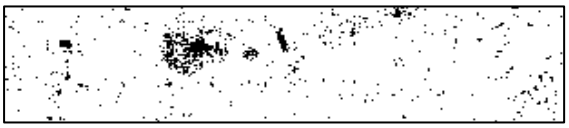
9		
10		
Average Value	**87.59%**	**86.02%**

For Arterial streets: From Bisrate gabriel (191 road) to Lafto Moll. (D) – Thermoplastic

No. of Samples	After 270 days	After 285 days
1		
2		
3		
4		
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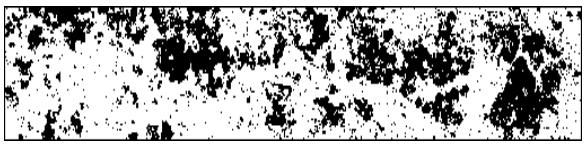
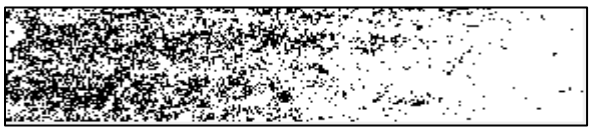
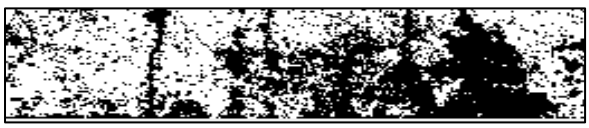
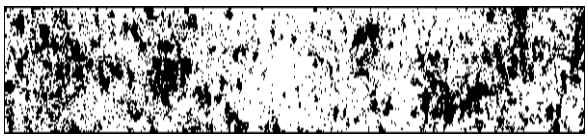
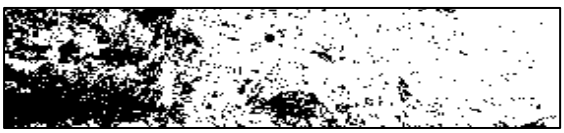
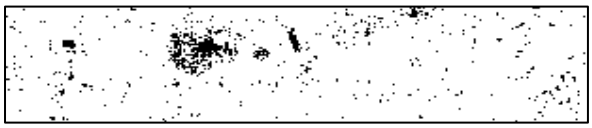
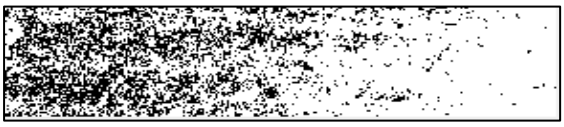
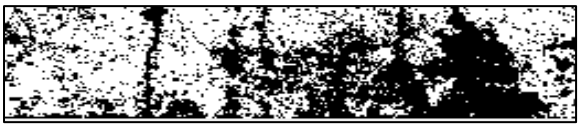
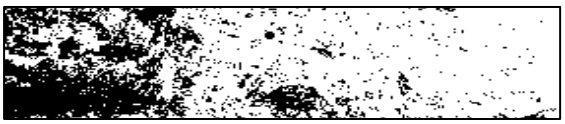
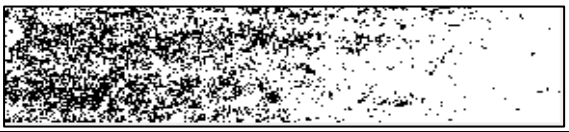
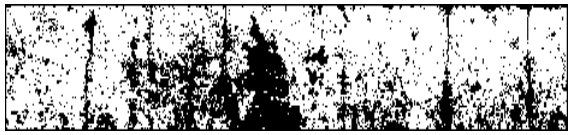
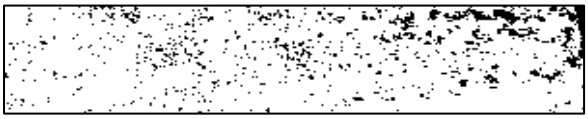
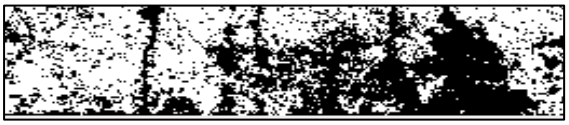
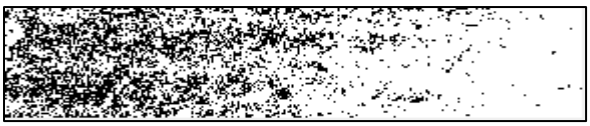
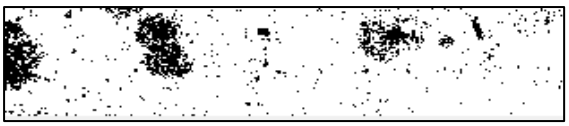
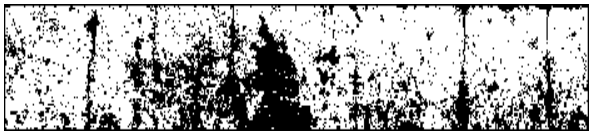
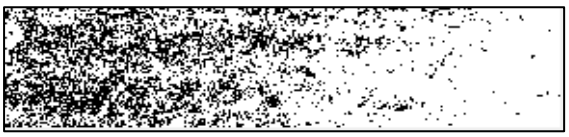
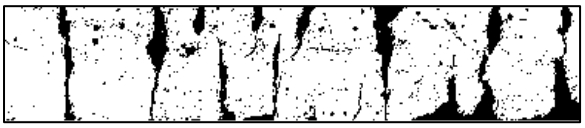
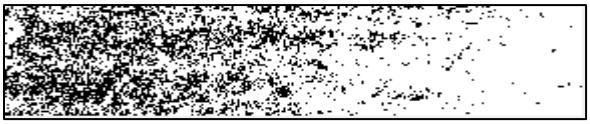
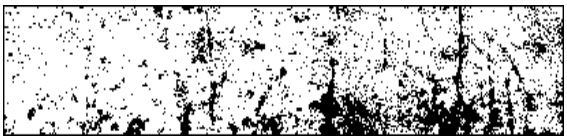
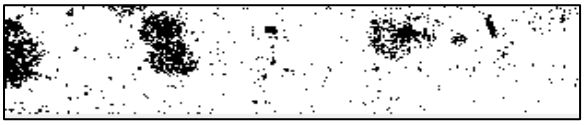
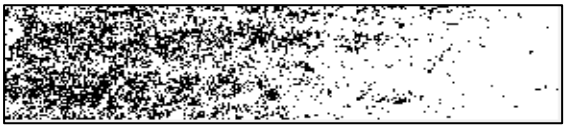
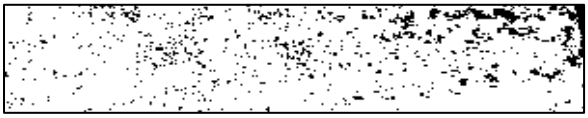
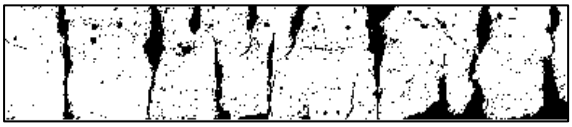
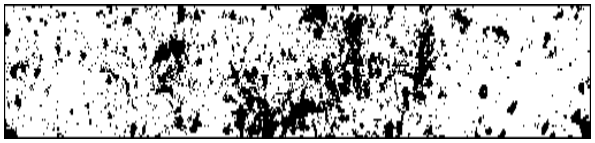
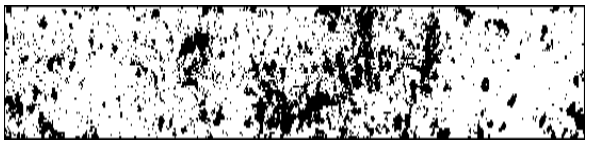
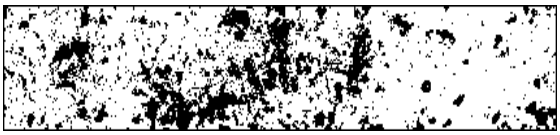
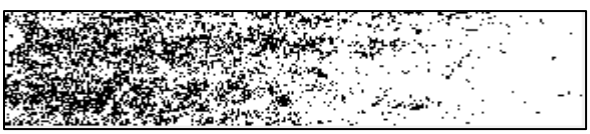
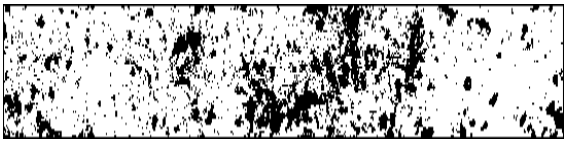
6		
7		
8		
9		
10		
Average Value	**67.28%**	**65.93%**

For Arterial streets: From Winget to Asko Bridge. (E) – Thermoplastic

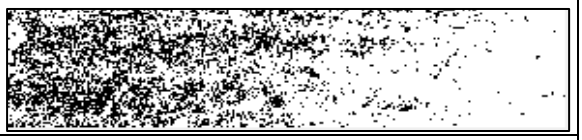
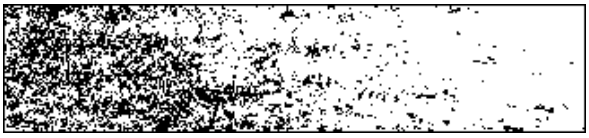
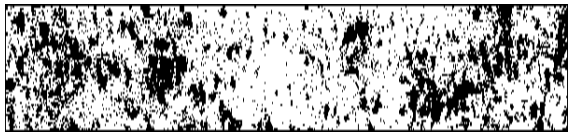
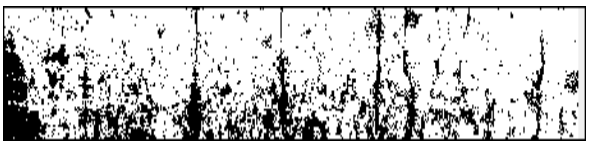
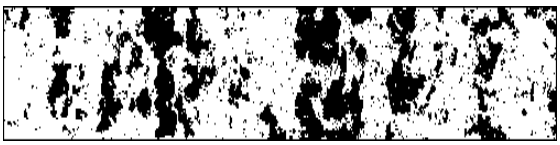
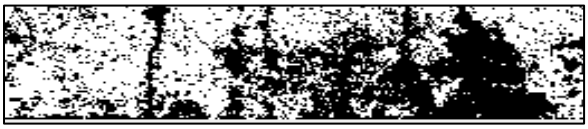
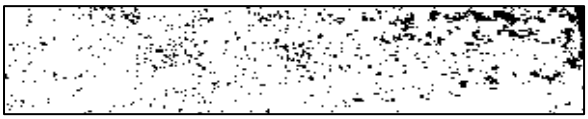
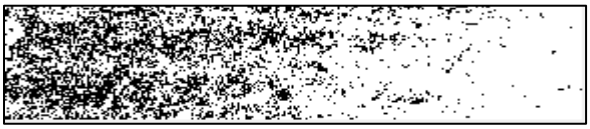
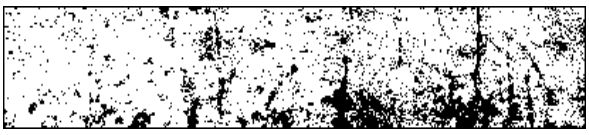
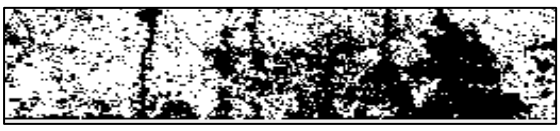
No. of Samples	After 300 days	After 315 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**68.84%**	**68.84%**

For Arterial streets: From Dan Techno office through no 108 to Bole Printing Junction.

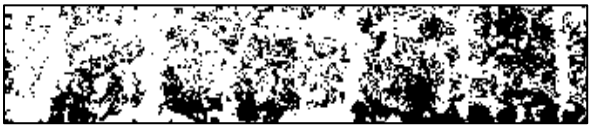
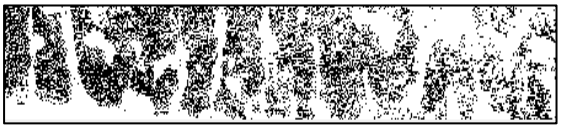
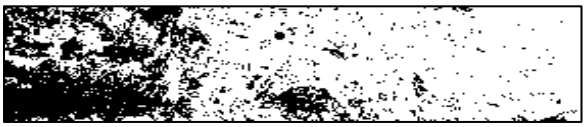
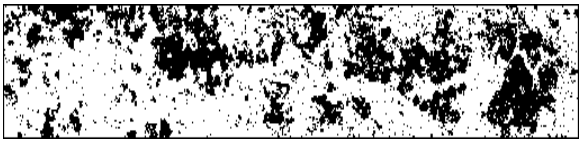
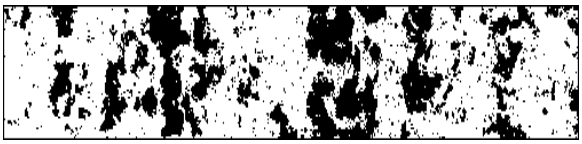
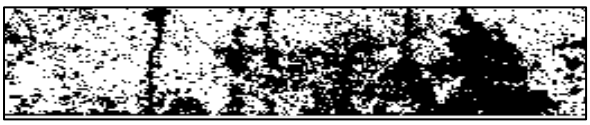
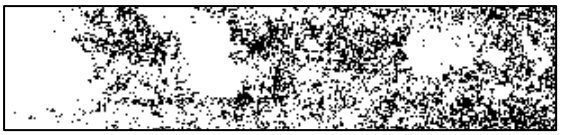
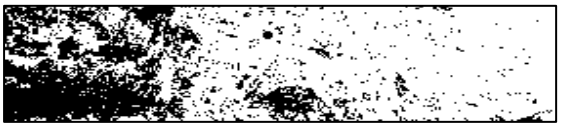
(F) – Thermoplastic

No. of Samples	After 330 days	After 345 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**79.65%**	**77.03%**

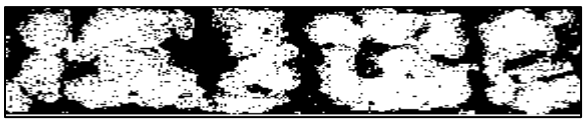
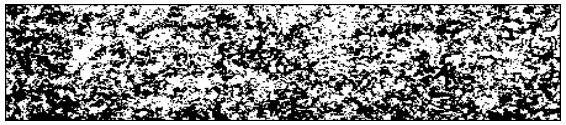
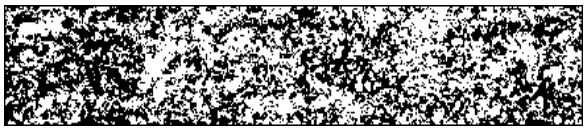
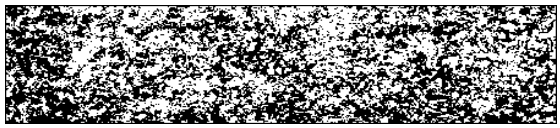
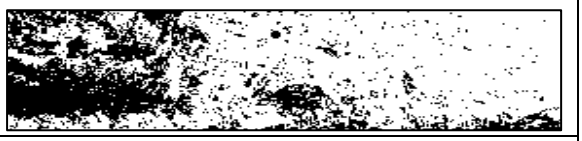
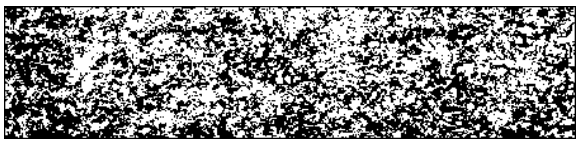
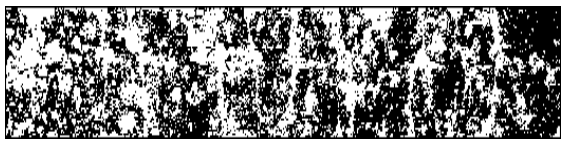
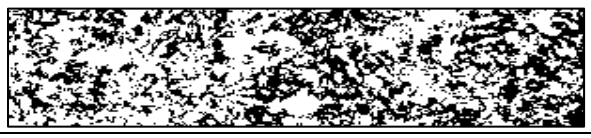
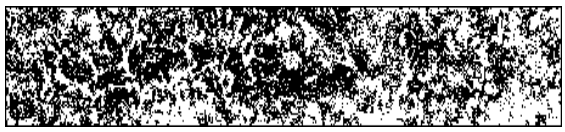
For Arterial streets: From Entoto street junction to Raguel. (G) – Thermoplastic

No. of Samples	After 360 days	After 375 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**77.05%**	**68.68%**

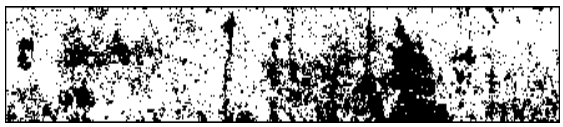
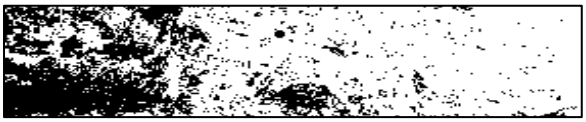
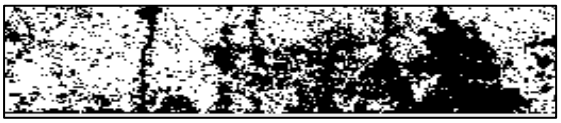
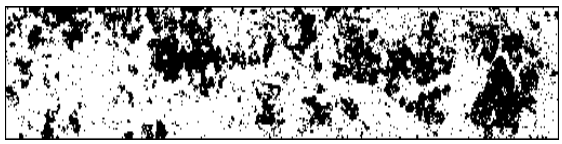
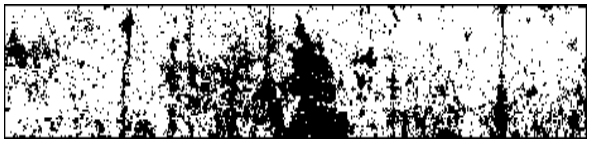
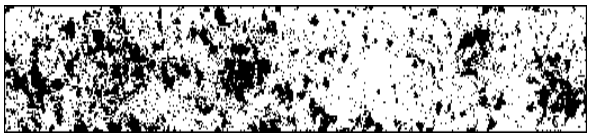
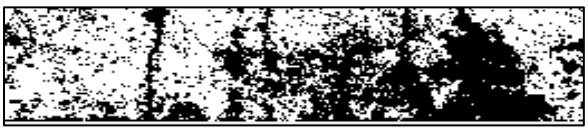
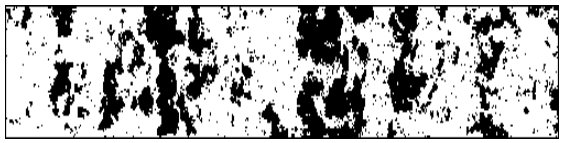
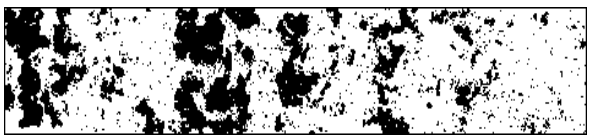
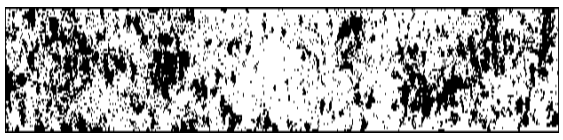
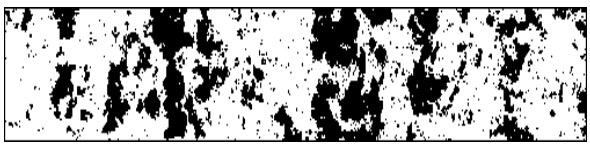
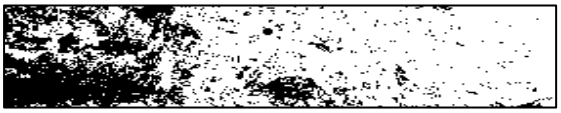
For Arterial streets: From Bole Shewa dabo (Bole Garad) through Aster Buna to USA Aid office. (H) – Thermoplastic

No. of Samples	After 390 days	After 405 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**67.98%**	**65.93%**

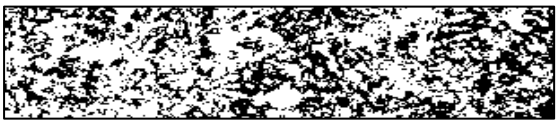
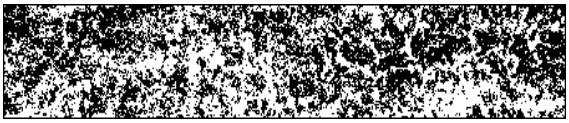
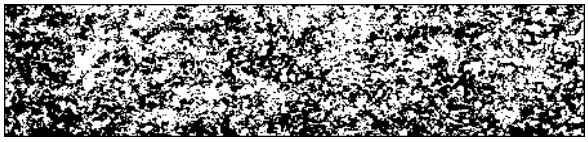
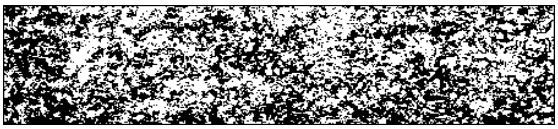
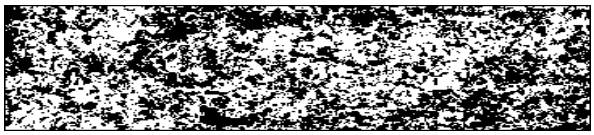
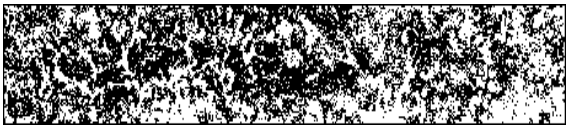
For Arterial streets: From Megenana to Minilik hospital. (I) – Thermoplastic

No. of Samples	After 420 days	After 435 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**52.49%**	**50.32%**

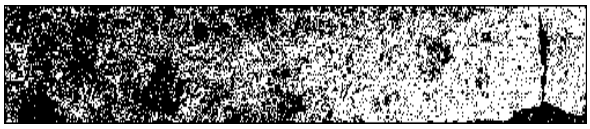
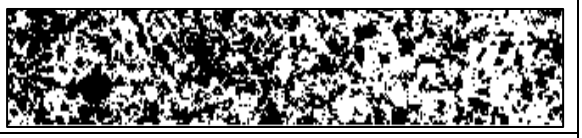
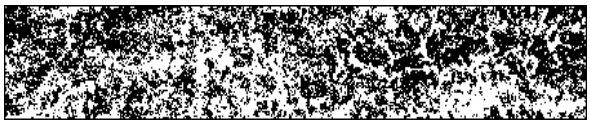
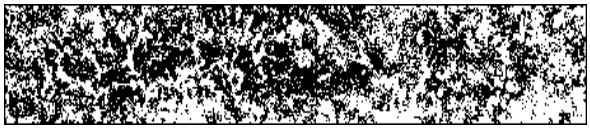
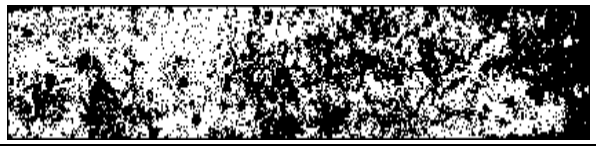
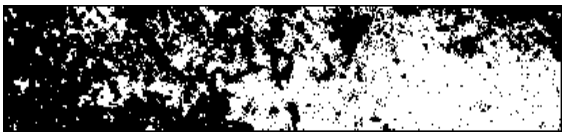
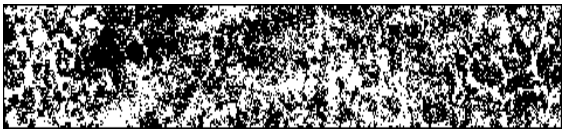
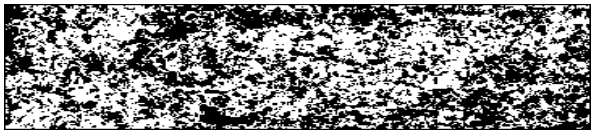
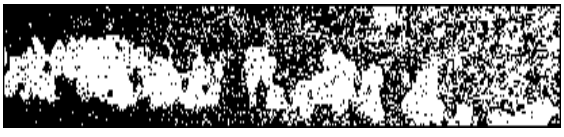
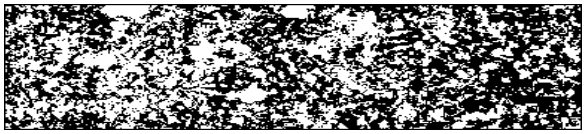
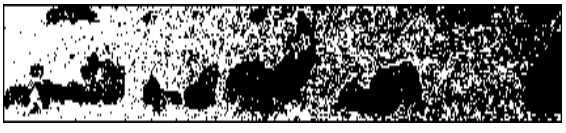
For Arterial streets: From queen's college junction (road 59) to Mesalemia junction Road 60. (J) – Thermoplastic

No. of Samples	After 450 days	After 465 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**69.45%**	**67.98%**

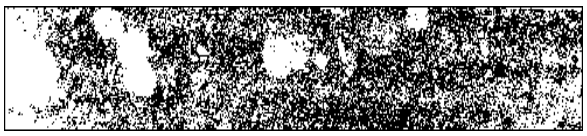
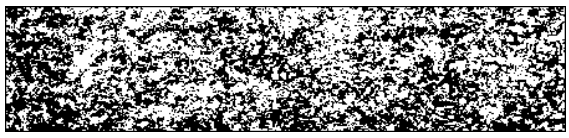
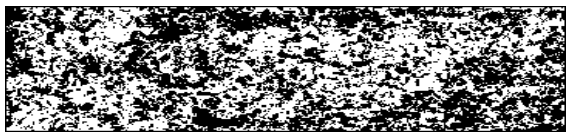
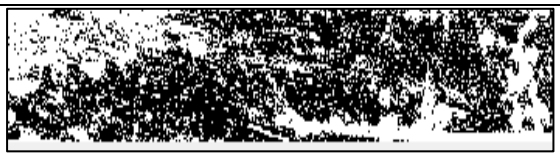
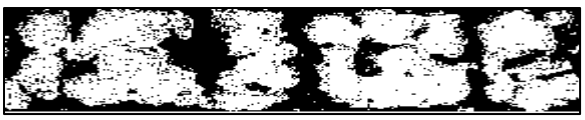
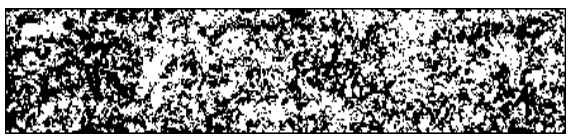
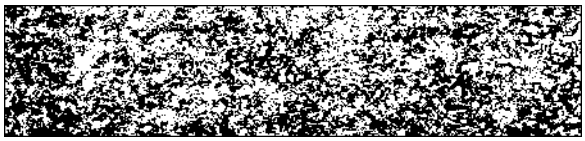
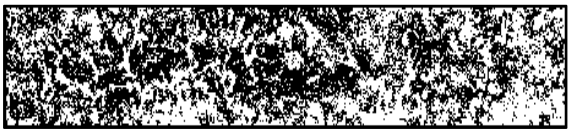
For Arterial streets: From Kebena bridge through Germen embacy to Bella. (K) – Thermoplastic

No. of Samples	After 480 days	After 495 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**51.35%**	**50.00%**

For Arterial streets: From asfawe tekle hotel to ehel berenda. (L) – Thermoplastic

No. of Samples	After 510 days	After 525 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**49.70%**	**47.33%**

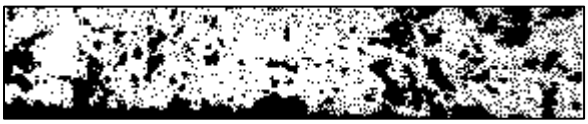
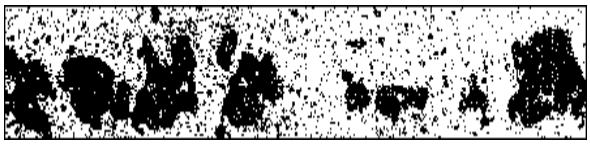
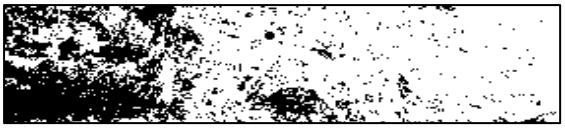
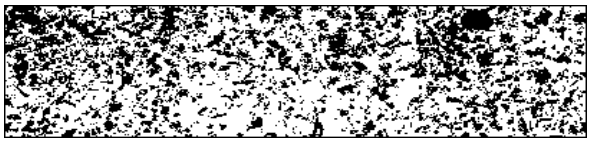
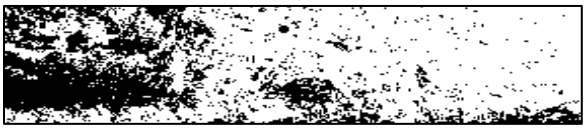
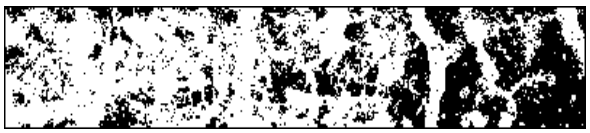
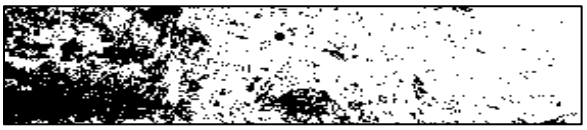
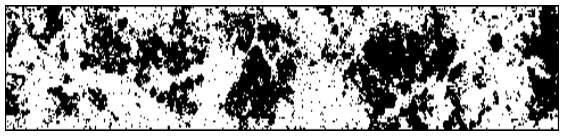
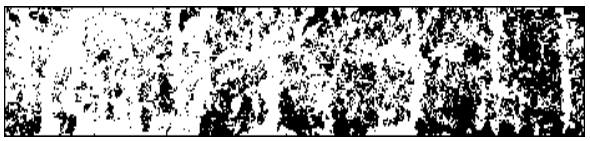
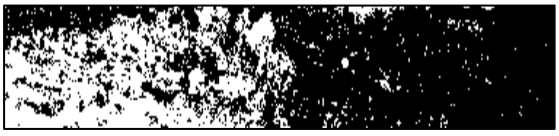
For Arterial streets: From Lipzing Sq (German School) to Megenana Adwa Sq. (M) – Thermoplastic

No. of Samples	After 540 days	After 555 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**52.49%**	**51.35%**

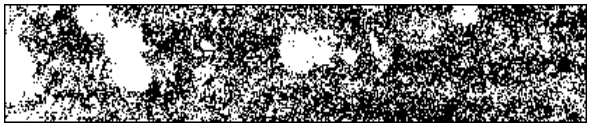
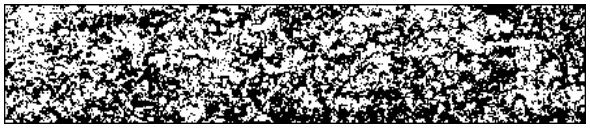
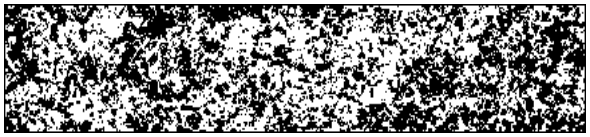
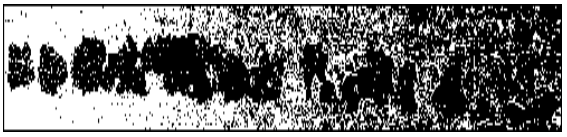
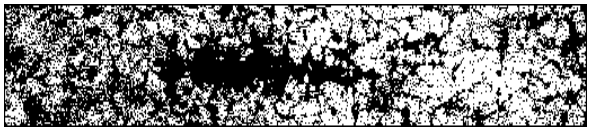
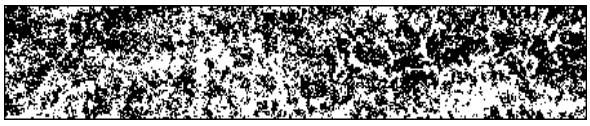
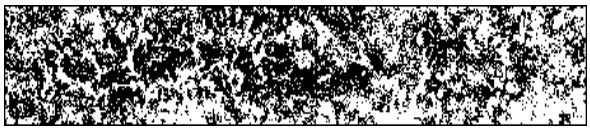
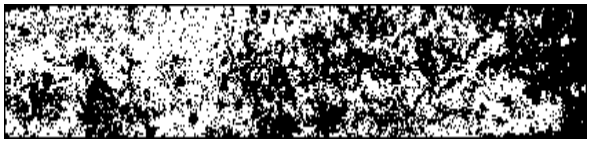
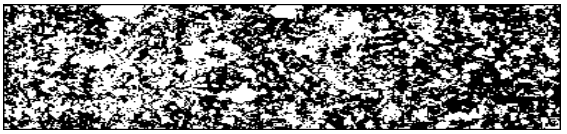
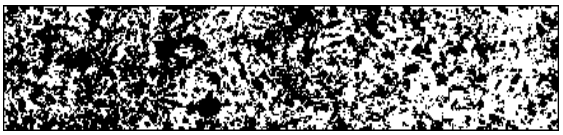
For Arterial streets: From water work construction office through Worku sefer to no 153 PAS. (N) – Thermoplastic

No. of Samples	After 570 days	After 585 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**53.66%**	**52.28%**

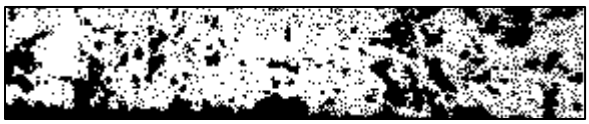
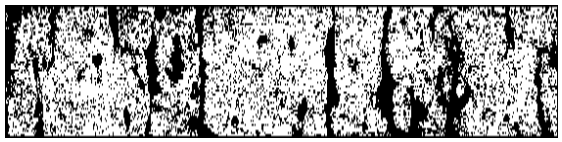
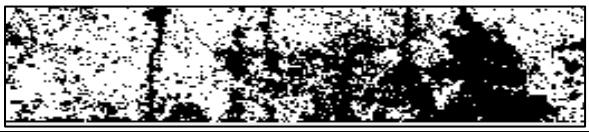
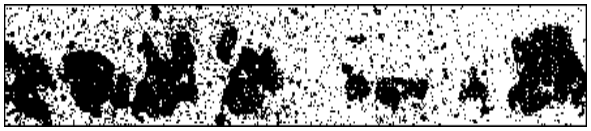
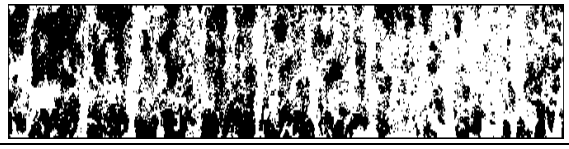
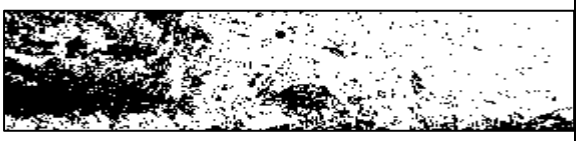
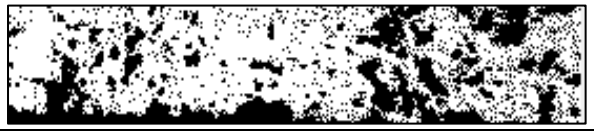
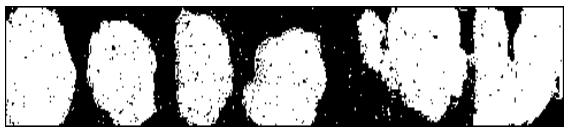
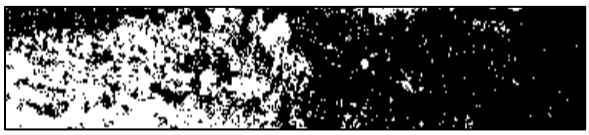
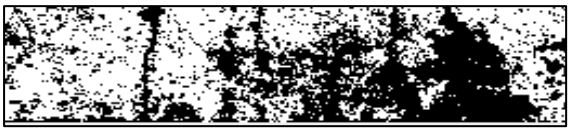
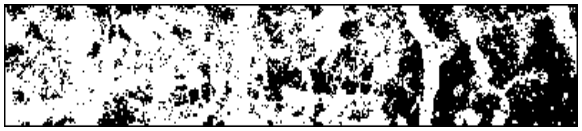
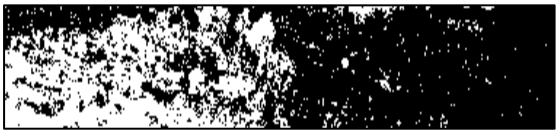
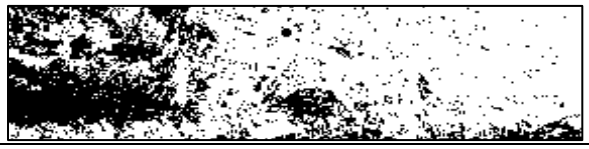
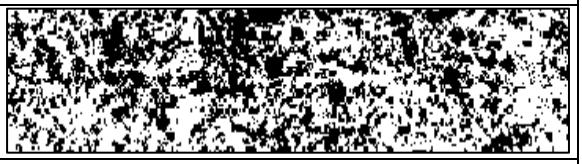
For Arterial streets: From National palace (Gabrel Jun.) to Hilton hotel. (O) – Thermoplastic

No. of Samples	After 600 days	After 615 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**62.68%**	**61.77%**

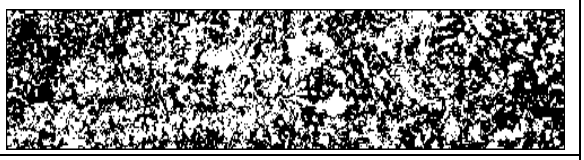
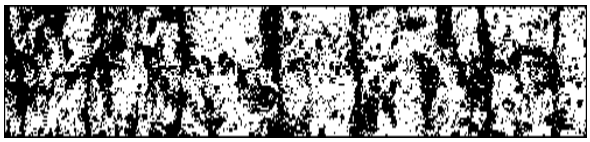
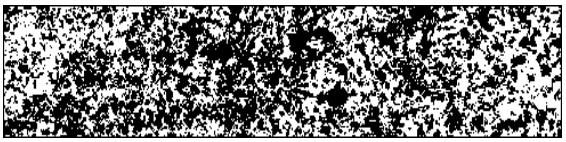
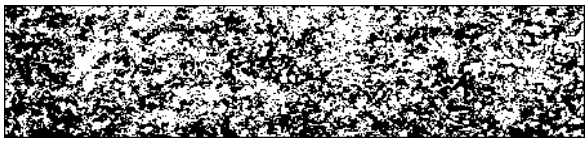
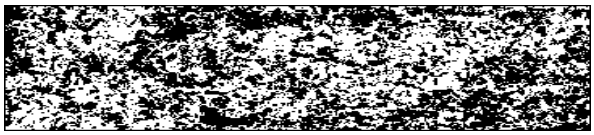
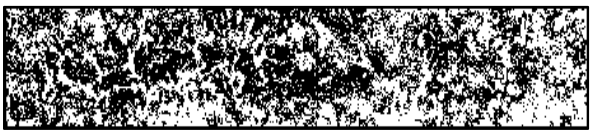
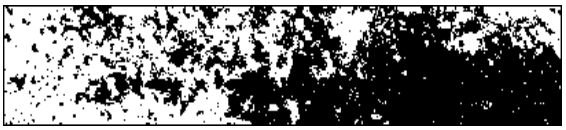
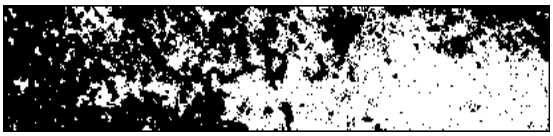
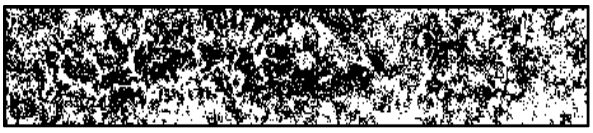
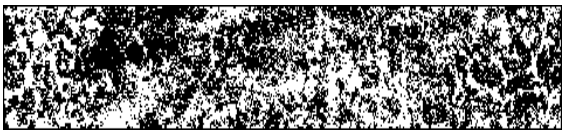
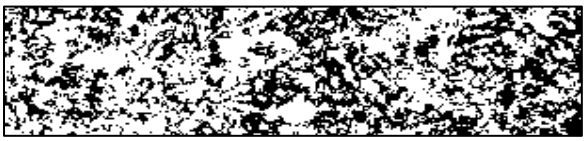
For Arterial streets From K/Meheret church (no 201 PAS) through new setelment to Alfa university. (P) – Thermoplastic

No. of Samples	After 630 days	After 645 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**50.75%**	**48.27%**

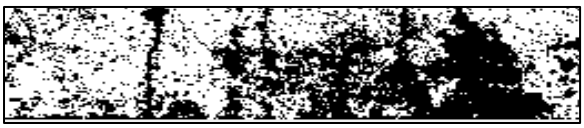
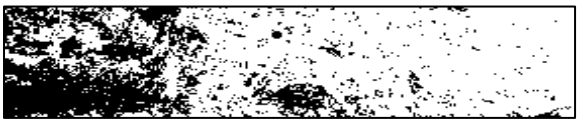
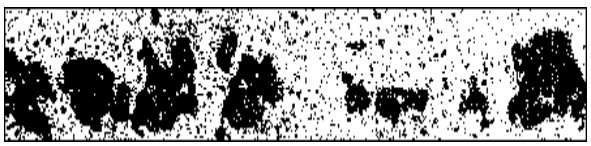
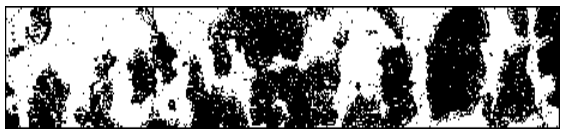
For Arterial streets: From Yordanos hotel to Kazanchiz meberat. (Q) – Thermoplastic

No. of Samples	After 660 days	After 675 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**62.59%**	**61.32%**

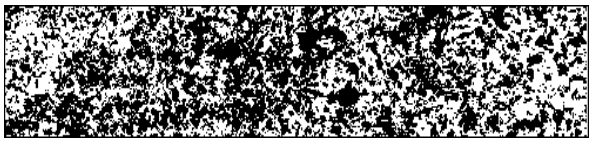
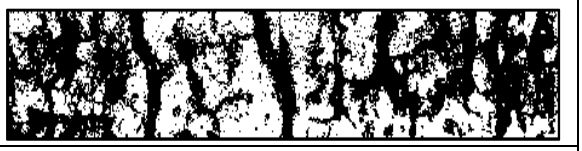
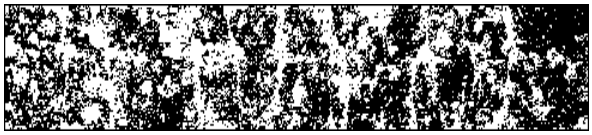
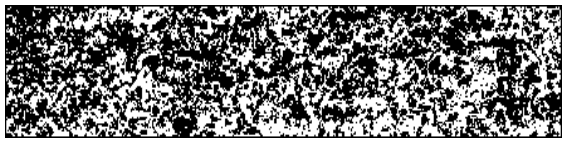
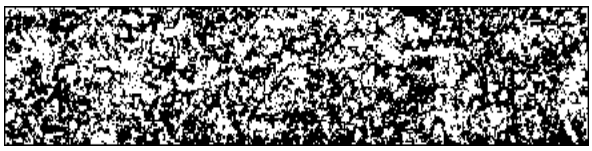
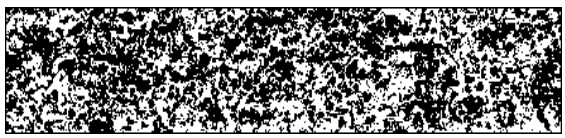
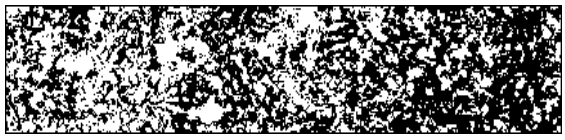
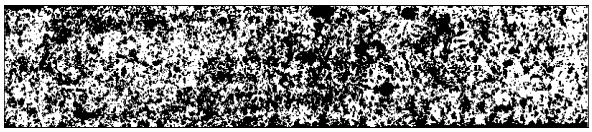
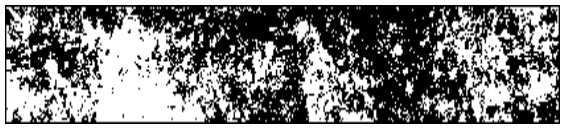
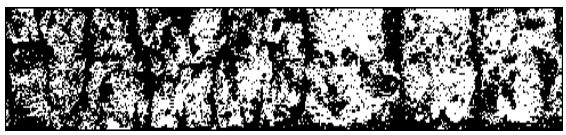
For Arterial streets: From Japan Embassy to RR. (R) – Thermoplastic

No. of Samples	After 690 days	After 705 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**51.55%**	**47.76%**

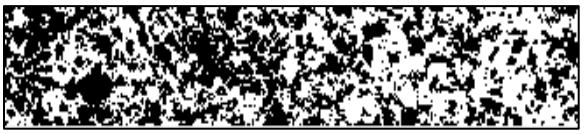
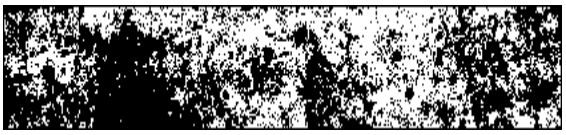
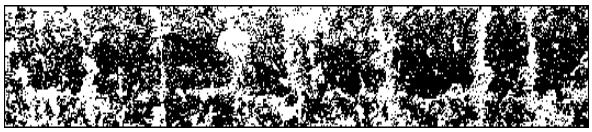
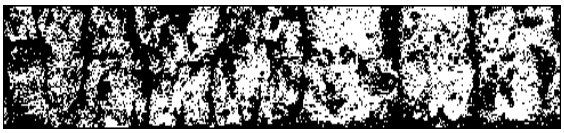
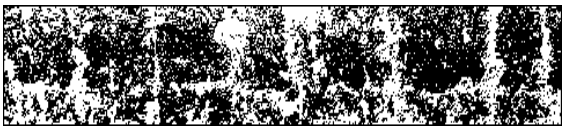
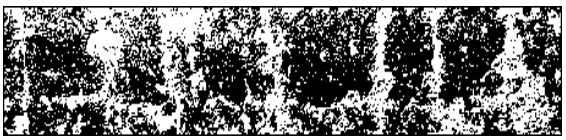
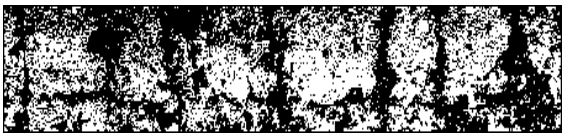
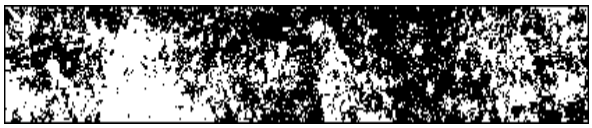
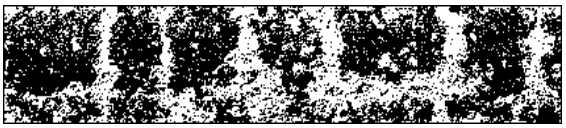
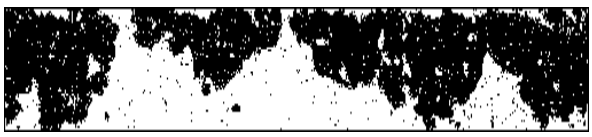
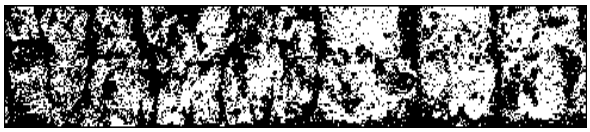
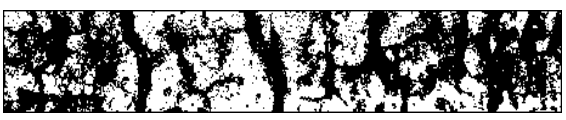
For Arterial streets: From Megenana Sq through CMC to Ayat Sq. (S) – Thermoplastic

No. of Samples	After 720 days	After 735 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**62.59%**	**54.90%**

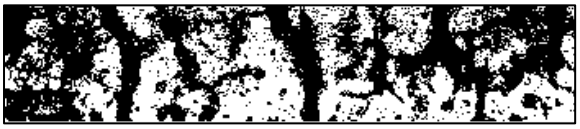
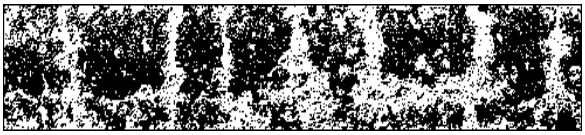
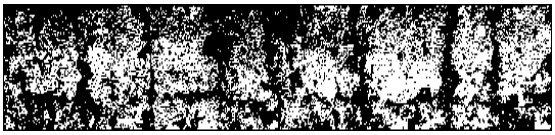
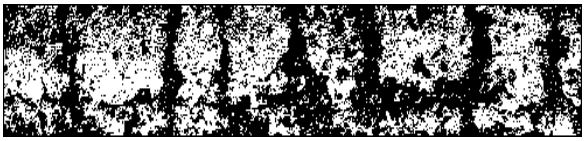
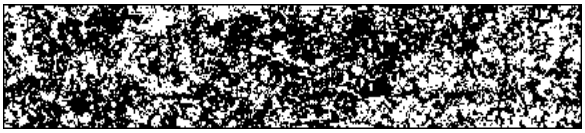
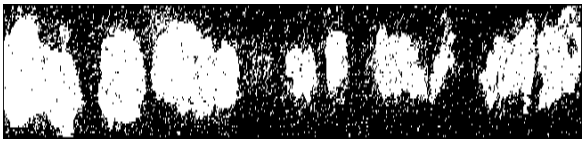
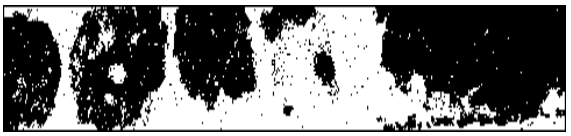
For Arterial streets: From Pushikin Sq through Kera to Gotera. (T) – Thermoplastic

No. of Samples	After 750 days	After 765 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**48.27%**	**45.36%**

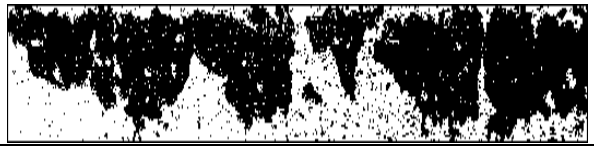
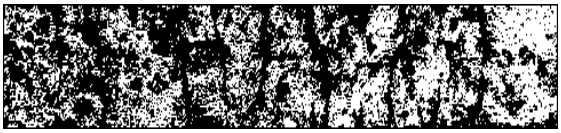
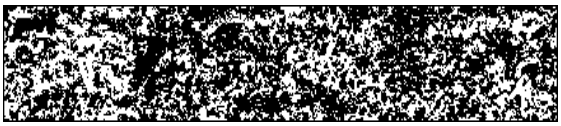
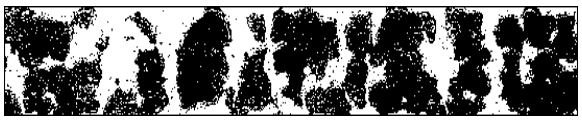
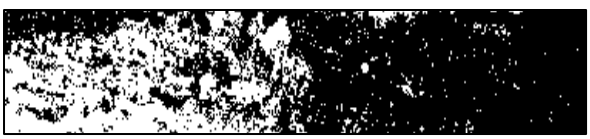
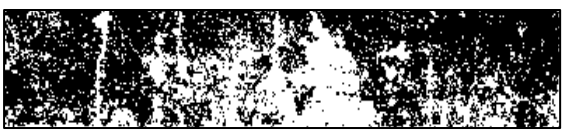
For Arterial streets: From Mexico Sq to Tinbajo Monopol Sq. (U) – Thermoplastic

No. of Samples	After 780 days	After 795 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**46.17%**	**44.58%**

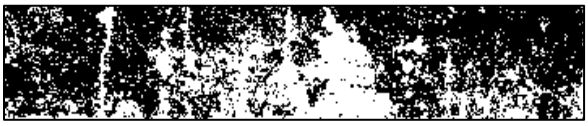
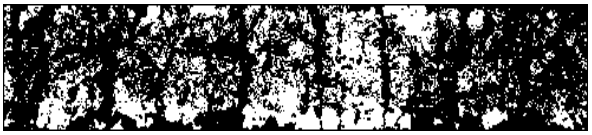
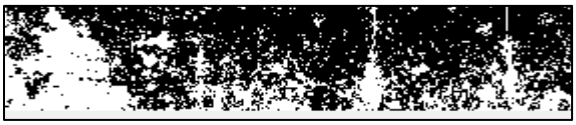
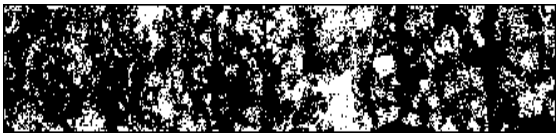
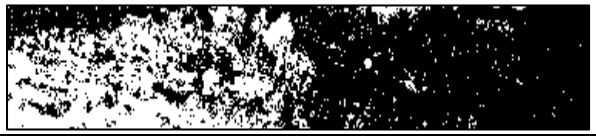
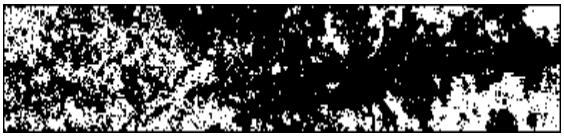
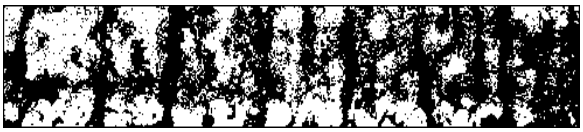
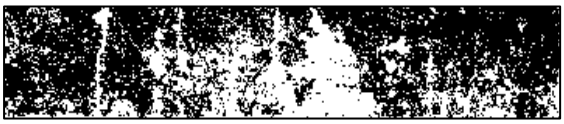
For Arterial streets: From T junction of streets (no 31) to bisrate gebriel. (V) – Thermoplastic

No. of Samples	After 810 days	After 825 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**43.66%**	**42.25%**

For Arterial streets: From CPU college to grand palace tewdros road. (W) – Thermoplastic

No. of Samples	After 840 days	After 855 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**42.54%**	**40.97%**

For Arterial streets: From Afincho-Ber - to behaind Ketchene church. (X) – Thermoplastic

No. of Samples	After 870 days	After 885 days
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average Value	**30.29%**	**29.37%**

APPENDIX H. PHOTO GALLERY

Motor Cycle Conduct with 21.8MP SONY Video Camera

21.8MP SONY Video Camera