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Highway Routine Maintenance Cost Estimation for Nevada

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HIGHWAY ROUTINE MAINTENANCE COST ESTIMATION FOR NEVADA

By

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ABSTRACT

Highway Routine Maintenance Cost

Estimation for Nevada

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State highway agencies are obligated to maintain existing roads for the highway systems to work efficiently and with greater longevity. Every year NDOT is responsible for approximately 13,150 lane miles of existing infrastructure. With that in mind, resources need to be provided to maintain the highway system.

The purpose of this research was to estimate annual routine maintenance cost for several typical treatment methods of highways. Five prioritization categories of highways used by NDOT were considered. Linear regression models were developed that present the relationship between costs including total maintenance cost and five maintenance cost components: labor, equipment, materials, manpower and stockpile, and the influencing factors: traffic load, road geometry, pavement structure, and climate. It was expected that the cost model depends on various roadway factors including elevation, number of lanes, age of the pavement, last year of pavement construction work, average daily traffic

(ADT), number of trucks, single axial load (ESAL), district work done, and weather conditions.

This research undertook the following steps: data review, data correlation check, and ordinary least square regression analysis. Data used for the analysis was extracted from NDOT pavement management system. Five NDOT prioritization categories were used for data processing and the analysis. The regression models incorporated the same parameters used in the NDOT pavement management system; therefore they can be simply combined with the existing database.

The analysis conducted in this study indicates that road age is a noteworthy factor for a number of life cycle segments and several maintenance cost activities. The life cycle segments varied with each prioritization category including routine maintenance activities and their schedule. For segments where the roadway age does not appear to be significant, the routine maintenance cost estimate stays constant. Routine maintenance activities may be scheduled at the times that are close to the time when a preventive maintenance or reconstruction is scheduled. This practice is reflected in the cost model that the annual maintenance cost may decline with time and suddenly increase at the end of their life cycle stages.

Lastly, recommendations have been made to provide fundamentals for future study needs. Several research needs in the cost estimation model are apparent from this assessment. These include additional information regarding cost model development using various statistical tools, periodical data update, use of a larger sample size, and different approaches for constructing prioritization categories life cycle. Also, historical data should be updated constantly due to changes in the material and construction technology. Further, the construction technology might require more or less steps with certain treatments like chip seal or flush seal. Thus, it is recommended to update the data as major construction or material technology is implemented in the routine maintenance work.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

There is an overwhelming amount of highway routine maintenance work to be done; however, the budget available to obtain a higher standard of infrastructure facilities is limited. In this situation, agencies in many states have had to take dramatic cost cutting actions effectively to be more resourceful maintaining roadway works. For instance, Nevada Department of Transportation (NDOT) has introduced reduction plans to their employees and limited the use of private contractors. Likewise, the Florida department of Transportation (FDOT) offered new plans for maintenance cost reduction (Panthi, 2009). The use of private contractors by FDOT was decreased to seventy four percent in 2003. The managers have reevaluated the cost for certain work between private firms and their in-house workforce. They noticed that the use of private firms is sometimes less expensive than the use of their own workers (Panthi, 2009). Thus, prediction of maintenance cost is very crucial to maintain budgets effectively. The intention of this study was to focus on highway routine maintenance cost estimation which should help agencies like NDOT to forecast their financial plan.

According to Parkman (2003), pavement modeling such as deterioration models is a good basis for reliably managing pavement performance. However, many of the models do not consider uncertainty associated with the selection of independent factors in their analysis. Furthermore, some of the variables are being omitted when used in the analysis or limitation occurs (Volovski, 2011).

Most infrastructure organizations have a need for yearly investigation of maintenance budget requirements. In highway routine maintenance, to achieve driver's level of comfort is directly related to maintenance cost. Therefore, it is essential to develop a model that can take into account routine maintenance activities over the life cycle of pavements. Modeling for highway routine maintenance cost requires a great understanding of pavement conditions and its lifetime, as well as prioritization of the routine maintenance work to be done. Furthermore, the knowledge of expenditure and maintenance activities is crucial for model development. For these reasons, further in-depth analysis of routing maintenance data should be conducted by using methodologies that have not been considered previously. This research study is designed to calibrate models to estimate the costs of highway routine maintenance. The ordinary least square analysis was performed to identify the significant factors (weather, elevation, district, age of pavement, etc.) influencing the routine maintenance cost. The results from the analysis are expected to be implemented by NDOT.

1.2 Background

The first bituminous roads were built in 1906 and followed by the Portland Cement Concrete roads in 1909 located in Wayne County, Michigan. From the beginning to the middle of nineteenth century, many researches worked on pavement improvement and design for various agencies such as the Highway Research Board and AASHTO.

The year 1966 was the breakthrough in technology and the pavement as a field was initiated. In 1968, the system approach was proposed for pavement management (Hudson 1968, Hutchinson 1968, Wilkins 1968). In late 1960 and beginning of 1970, definitions for pavement management systems were developed and the full range of pavement activities began to be associated with pavement management (Haas 1970). After that, many state and local agencies found interest in pavement management and started to implement this concept in infrastructure projects. Over the years, extensive studies were conducted and they were included in the two North American Management Conferences in 1985 and 1987 (NA Conf. 1985, 1987) and later in the ASTM Symposium (Hudson 1992).

According to Hudson, Haas and Zaniewski (1994), the function of the pavement varies with the specific user in modern highway facilities. It was stated that the purpose of the pavement is to serve traffic safely, comfortably, and efficiently, at a minimum or reasonable cost. Having large investments, especially with new technology implemented, even small improvements might be cost effective. It is crucial to protect road infrastructure by properly maintaining roads and not allowing for high deterioration of the roadway, thus allowing for safety of the drivers.

Maintenance cost model development is one of the most challenging tasks that many agencies deal with. The prediction of costs was studied and developed extensively in the past which resulted in various techniques and approaches adopted by states and organizations. The topic of maintenance cost estimation became popular in 90's, where more roadways were developed, thus creating more maintenance needs. Further, a higher cost of maintenance had to be spent by the agencies, creating a need for a more economic approach. In 1990, Gibby et al. introduced a new statistical analysis approach implementing regression analysis to develop models allowing for better spending expectation in highway maintenance. In their study, highway geometric and environmental factors were considered for maintenance cost forecasting. In the late 90's, a study (Sebaaly et al., 2000; Hand, 1995) was conducted for the state agency NDOT pertaining to cost estimation of maintenance by introducing four techniques. These four techniques introduced do not include various roadway characteristics such as traffic load and road functional classification. However, it is reasonable to use roadway characteristics since it can provide an objective basis for identifying current needs and estimating future needs. In 1994, Hudson, Haas, Zaniewski proposed their modern pavement management; however, their research did not include regression analysis. In recent years, Annani (2008) focused also on cost model development by presenting five approaches: PMS direct approach, 'simple roughness' approach, econometric approach, cost allocation approach, and 'perpetual overlay' indirect approach. In Annani (2008), environmental and geometric factors of the roadway were incorporated. Some of the approaches use regression analysis to model maintenance cost.

There were not many studies conducted on routine maintenance cost estimation. Most of the studies are on the preventive or rehabilitation maintenance cost model. Thus, there is a need for a study on developing models on estimating routine maintenance costs. These models will aid agencies in forecasting and better management of the routine maintenance budget.

1.3 Research Objectives and Expectation

The objective of this study was to develop highway routine maintenance models that can aid highway agencies to estimate the cost of pavement maintenance.

The scope of this study covers development of routine maintenance cost estimation models. Nevada Department of Transportation provided the pavement condition data used for model development. The raw data was extracted and used for analysis. The samples of roads were selected and time-space diagrams were generated to find the road sections being homogenous. From those sections, road characteristics data was collected and used in analysis.

This research consists of six chapters. The first chapter is an introduction to the maintenance cost development that reflects research goals and discusses the need for model development. The second chapter reviews existing literature on cost model development. It examines how the literature is related to the cost model development and leads to generating the methodology that addresses issues associated with cost estimation. The third chapter describes the methodology for developing linear regression models. Chapter four is focused on data development and processes including life cycle pavement development and discussion of prioritization categories. It presents performance data recorded and kept by the state highway agency. Chapter five includes detailed descriptions of data analysis using obtained models. This chapter is divided into five sections associated with prioritization categories. Chapter six concludes all the findings presented in this study based on the performed analysis. In addition, this chapter covers future study needs and recommendations that were drawn from this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Maintenance Management Process

Maintenance management process ensures the success of maintenance in an organization, and determines the effectiveness of the subsequent implementation of the maintenance plans, schedules, controls and improvements. Maintenance plans include philosophy, maintenance workload forecast, capacity and scheduling while maintenance organization involves work design, standards, work measurements, and project administration. Maintenance control includes works, materials, inventories, costs, and quality oriented management (McKiernan, 2012).

The process of maintenance management has its beginnings in early 1960's and was established based on the DeLeuw and Roy Jorgensen model. "It is an activity-based work planning and budgeting approach that plans, schedules, assigns, performs and evaluates work. It builds work cost and performance standards and identifies resources needed to do the work (McKiernan, 2012)."

The maintenance management is an organized method that controls what work needs to be done, determines the timeframe of the work, labor, equipment, and material resources, and projects the cost of the work to be done. According to McKieran (2012), maintenance management helps agencies meet directives and accountability requirements, explains resource and economic needs. Proper maintenance management can reduce costs up to 20% per year. In general, maintenance management consists of four stages: planning, organizing, directing, and controlling. All those stages are presented in detail in Figure 2.1.

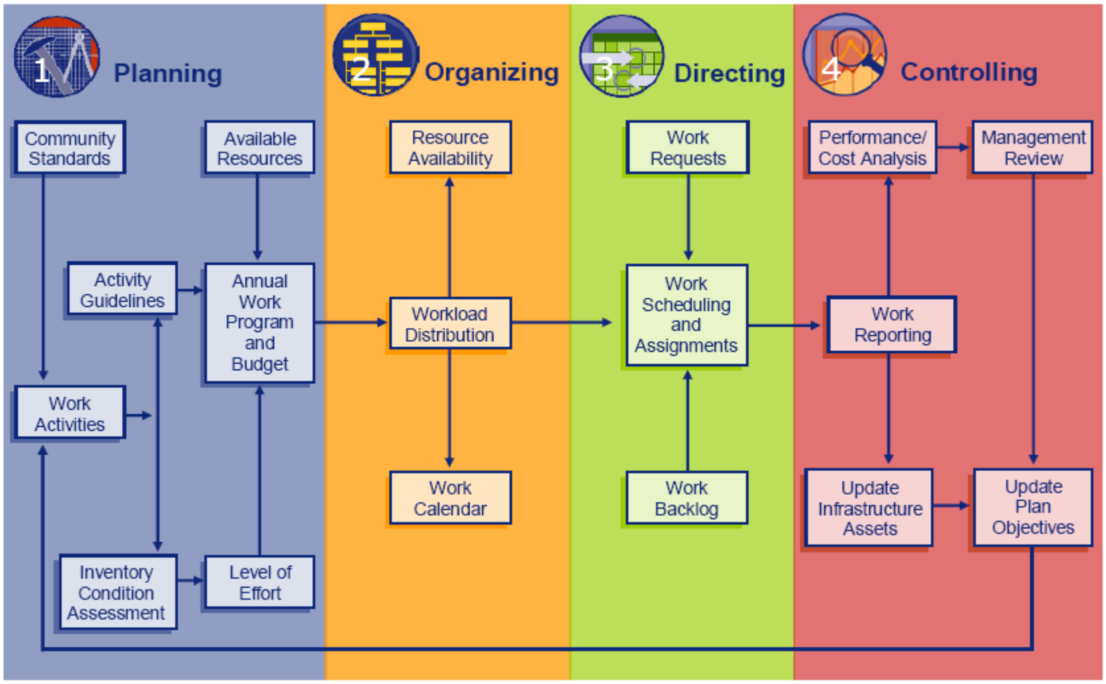


Figure 2.1 Maintenance Management Model

According to Transportation Research Circular (2012), pavement maintenance decisions need to consider the following factors: selection of alternative treatments, present serviceability of the pavement, likely performance of alternative treatments, required life of pavement, costs, traffic flow, effects on road user, and availability of resources. All those variables are crucial for effective development of pavement maintenance strategies.

According to the Ontario Ministry of Transportation, maintenance is divided into maintenance rehabilitation, routine maintenance, and major maintenance.

Table 2.1 Rehabilitation and Maintenance Division used in Ontario

	Flexible	Rigid
Rehabilitation	Hot-Mix Resurfacing Partial Depth Removal & Resurfacing Inplace Recycling Full Depth Removal & Resurfacing Cold-Mix with Sealing Course Surface Treatments Pulverization, Rombcing & Resurfacing	Unbonded Concrete Overlays Bonded Concrete Overlays Subsealing Slab Jacking Surface Texturization Cracking and Sealing (with Resurfacing) Widening and Shoulder Retrofits
Routine Maintenance	Potholes Roadside Maintenance Drainage Maintenance Localized Spray Patching Localized Distortion Repair Minor Crack Sealing	Potholes Spail Repairs Blow Ups Localized Distortion Repair Minor Ckrack and Joint Sealing
Major Maintenance	Rout and Seal Cracks Hot-Mix Patching Surface Sealing Asphalt Strip Repairs Distortion Corrections Drainage Improvements Frost Treatments Roadside Slopes and Erosion Control	Full Depth Joint Repairs Full Depth Stress Relief Joints Resealing Joints and Resealing Cracks Full Depth Slab Repair Milling of Stepped Joints and Distortion

Table 2.1 illustrates the distribution of maintenance work and activities for flexible and rigid pavements.

The Nevada Department of Transportation (NDOT, 2011) has defined highway maintenance as “the preservation of roadway facilities in a safe and useable condition.” It divided maintenance into the following categories:

1. Routine maintenance – maintenance done daily to the highway infrastructure and any activities to keep vehicles moving in a safe and efficient manner.
2. Capital improvements – any work that will postpone deteriorations or extend the life of the highway system.
3. Emergency activities – work done due to accidents and natural disasters to stabilize and restore traffic.

The Federal Highway Administration defines routine maintenance as any maintenance activity that includes any planned and routine work to keep the condition of the highway infrastructure in a good condition and to keep the level of service suitable. The purpose of routine maintenance is not to increase capacity, increase strength, or reduce aging, but to reestablish serviceability. Typical routine maintenance activities are presented in Table 2.2.

Table 2.2 FHWA Routine Maintenance Categories

Type of Activity	Increase Capacity	Increase Strength	Reduce Aging	Restore Serviceability
New Construction	X	X	X	X
Reconstruction	X	X	X	X
Major (Heavy) Rehabilitation		X	X	X
Structural Overlay		X	X	X
Minor (Light) Rehabilitation			X	X
Preventive Maintenance			X	X
Routine Maintenance				X
Corrective Maintenance				X
Catastrophic Maintenance				X

2.2 Pavement Management System (PMS)

Pavement management system (PMS) is used in pavement management. It is a tool for collecting, analyzing, maintaining, and reporting pavement data to help agencies develop the best possible strategy to maintain pavements with longevity and cost efficiency. This tool provides possible outcomes of alternative decisions (the Transportation Research Circular, 2012). PMS mainly contains models used to predict pavement performance in the selection of the optimum maintenance and rehabilitation strategy. It includes models to produce expected pavement deterioration which is usually developed based on the historical data for pavement condition. PMS is also defined by the U.S. Department of Transportation (2005) as “a system that provides information for use in implementing cost-effective reconstruction, rehabilitation, and preventive maintenance programs and results in pavement design to accommodate current and forecasted traffic in a safe, durable, and a cost-effective manner”.

2.3 Maintenance Prioritization Categories

According to Venukanthan, et al (2001), NDOT has developed network optimization software (NOS) which was to prioritize various rehabilitation and maintenance techniques. Based on the prioritization recommendations, maintenance cost model was developed. Since new software was created, the old models introduced in 1991 had to be replaced with new models. In the past, those models were developed based on the function of the roadway performance criteria only. Factors such as materials, maintenance total hours or equipment were not included in modeling.

In NDOT, PMS was created in 1980, to improve various aspects of data collection and characteristics of procedures. It is expected that this system should advance with experience as technology develops. Management of NDOT maintenance prefers the use of mill and thin HMA overlays in various road categories over major rehabilitation or reconstruction. The agency has developed five maintenance prioritization categories, each with different maintenance strategies over different life cycles. Table 2.3 lists the characteristics of these categories.

Table 2.3 NDOT Highway Roadway Prioritization Categories

Road Prioritization Category	Two Directional ADT and ESAL	Total Lanes Miles	Percent of Road Network	Life-Cycle in Years	Annual Rate of Deterioration in Lane Miles
1	Controlled Access	2,469	19	8	258
2	ESAL>540 or ADT>10,000	2,519	19	10	252
3	540>=ESAL>405 or 1600<ADT<=10,000 +NHS	2,800	21	12	233
4	405>=ESAL>270 or 400<ADT<=1,600	1,921	15	15	128
5	ADT<=400	3,387	26	20	170
TOTAL		13,096	100		1,041

It can be seen from Table 2.3 that Category 1 has the shortest pavement life cycle and has to be reconstructed after 8 years. Category 4 accounts for 15 percent of total roadway infrastructure. Category 2 and 3 life cycle is 10 and 12 respectively. Category 3 covers more road network than Category 2. Category 5 covers the most of road network resulting in 3,387 lane miles and at the same time has the longest pavement life cycle of 20 years. Because each category holds different longevity of roadway surface, it is crucial for NDOT to develop prioritization categories for pavement management.

2.4 Maintenance Cost Model

Maintenance cost model development is a difficult task. The prediction of cost varies by states and organizations. Numerous tools were used in maintenance cost development and different results were proposed. The Ministry of Ontario developed cost models based on the pavement service life and deterioration models (MTO, 1990). The cost of the actual work is calculated based on unit costs plus volume, mass or area involved. Many agencies like Ontario ministry of Transportation (MTO) or the Asphalt Institute have developed manuals with necessary calculations and detailed examples (Haas et al., 1994). The cost of actual work is calculated using present cost:

Present Cost = Future Cost × PWF

where:

PWF = present worth factor (2.1)

n = number of years to the rehabilitation implementation

i = discount rate (usually 8%)

The vehicle operating cost is calculated using data from Table 2.4. The data is based on the average daily traffic, years of deferral, and differences in PSI.

Table 2.4 Vehicle Operation Cost per Mile

Years of Deferral	Difference in PSI	AADT	Annual Extra Vehicle Operating Cost $1,000	Accum. Extra Veh. Operating Cost (P.W. Basis $1,000)
1	-1.5	5,000	27	26
2	-1.8	5,000	47	66
3	-2.1	5,000	66	118
4	-2.4	5,000	89	184
1	-1.5	10,000	55	51
2	-1.8	10,000	95	132
3	-2.1	10,000	131	236
4	-2.4	10,000	179	368

The user delay cost model was developed based on queuing theory, traffic handling methods, and variables such as: type of facility, traffic volume, length, and time of the day. In many agencies, this cost was incorporated directly into pavement management system as an option since it was not a part of the agency's budget. The Table 2.5 is a representation of user delay cost for maintenance.

Table 2.5 Vehicle Operation Cost per Mile

AADT	USER DELAY COST $/DAY
<10000	Insignificant
10,000-15,000	125
16,000-20,000	350
21,000-23,000	600
24,000-25,000	1,100
26,000	1,950
27,000	3,300
28,000	5,950
29,000	10,650
30,000	19,500
31,000	34,800
32,000	57,000
33,000	88,150
34,000	130,850
35,000	180,150
36,000	238,125
37,000	307,650
38,000	388,000
39,000	483,500
40,000	609,500
>40,000	700,000

The calculation of maintenance cost included in cost estimation is described by Haas et al. (1994) as cost-effectiveness (CE). The CE is based on the net area under performance or deterioration curve and it is presented in the following equation:

Effectiveness =

$$\left[\sum_{REHAB_{YEAR}}^{PQI_R \geq PQI_M}(PQI_R - PQI_M) - \left(\sum_{PQI_N \geq PQI_M}^{REHAB_{YEARS}}(PQI_M - PQI_N)\right)\right] \cdot [ADT] \cdot [LENGTH_{SECTION}]$$

(2.2)

where

PQI_R = Pavement Quality Index (PQI) after rehabilitation and for each year until PQI_M is reached,

PQI_M = minimum acceptable level of PQI, and

PQI_N = yearly PQI from the needs year to the implementation year.

Chong (1989) has introduced another approach in development of maintenance cost which includes two calculations:

Unit Cost = Cost of (Total hours + Equipment + Materials)/Accomplishment or Production per Day (2.3)

and

Average Annual Cost = Unit Cost/ Expected Life (Years) of the Treatment Alternative. (2.4)

The treatment alternative with the lowest average annual cost would represent the desired result (Chong, 89).

According to Anani (2008), the maintenance cost is established for any maintenance activities by restoring original pavement condition from its critical state. For instance, highway roads are heavily occupied by light or heavy vehicles, which lead to pavement deterioration. Extreme weather or other environmental conditions add to the roadway corrosion as well. Thus, the highway infrastructure should be rebuilt continuously using roadway maintenance techniques. In general, the maintenance cost is mainly based on the costs resulting from an additional unit of traffic loading. Anani (2008) classifies the maintenance costs models into five approaches: PMS direct approach, ‘simple roughness’ approach, econometric approach, cost allocation approach, and ‘perpetual overlay’ indirect approach. Only two of them were considered for this study; PMS and econometric approaches. The other two approaches were considered to be theoretical and have not been tested yet. The PMS approach includes historical data for the roadway system, pavement performance model, and traffic usage. The second approach involves developing functions that connect total routine maintenance cost with variables reflecting traffic load, road geometry, pavement structure or climate.

In Gibby et al. (1990), regression analysis was introduced in highway maintenance cost development. With this approach, impact of heavy trucks on maintenance cost was studied. More than 1,100 mile sections of highway were randomly sampled which illustrate a wide range of the sample size. The collected data was first collected and pulled together. The variables included in the study are: annual average daily traffic (AADT) of heavy trucks and passenger cars, labor and material costs, age of pavement, presence or absence of a shoulder, temperature, location maintenance, existence of bridges, functional classification, and the districts where a pavement section was located. The model developed in Gibby et al. (1990) is:

$$TotalCost = \beta_1 (HT\_AADT)^{\beta_2} (P\&L\_AADT)^{\beta_3} (AGE)^{\beta_4} (AATEMP)^{\beta_6} (SHOULDER)^{\beta_5} \ldots$$
$$(e^{NOSHOULDER'})^{\beta_7} (e^{MOUNTAIN'})^{\beta_8} (e^{BRIDGE'})^{\beta_9} (e^{MNCOLLCTR'})^{\beta_{10}} (e^{DISTRICT2'})^{\beta_{11}} (e^{DISTRICT11'})^{\beta_{12}} \quad (2.5)$$

Table 2.6 Variables in a Regression Model to Estimate Total Annual Maintenance Cost

Variable	Description
TOTAL_COST	The department variable. Total pavement maintenance cost for one-mile section during the three fiscal years 1984-1987, in dollars
HT_AADT	AADT for “heavy” trucks, defined as trucks with at least 5 axles
P&L_AADT	AADT for passenger cars and “light” trucks
AGE	Pavement age, defined as the time since last major pavement work, in years
AA_TEMP	Average annual temperature, in Fahrenheit
SHOULDER	Shoulder width, in feet
NO_SHOULDER’	Dummy variable (1=no shoulder; 0=shoulder)
MOUNTAIN’	Dummy variable (1=Mountain climate; 0=not Mountain climate)
BRIDGE’	Dummy variable (1= entirely bridge section; 0=at least part of the section not a bridge)
MN_COLLCTR’	Dummy variable (1= minor collector; 0= not minor collector)
DISTRICT2’	Dummy variable (1=Caltrans District 2; 0= not District 2)
DISTRICT11’	Dummy variable (1= Caltrans District 11; 0= not District 11)

Table 2.6 represents the variables used in regression analysis that led to final model development. The study revealed that the maintenance cost for carrying trucks was significantly higher than the cost of carrying passenger vehicles. This discovery had implications in transportation procedures and tax system.

In the late 1990s, Sebaaly et al., (2000) and Hand, (1995) conducted studies for NDOT on estimating maintenance cost. Four techniques were considered in their studies:

1. Connecting annual maintenance costs to Present Service Index (PSI) levels.
2. Linking annual maintenance costs to the probability of their occurrence.
3. Creating an overall annual maintenance cost for each treatment.
4. Instituting a fixed period cumulative annual maintenance cost for each treatment.

In the first method, the Present Service Index (PSI) levels characterize pavement performance. This method was introduced due to variation of maintenance nature and its activities caused by pavement conditions. For instance, not every treatment in maintenance activities is used each year, thus making the maintenance cost oscillate considerably. The second method considers the probability of the occurrence of maintenance activities. The third method is based on the life cycle of the pavement. It calculates the yearly cost of pavement restoration after the treatment being applied. Overall, the calculations represent average annual maintenance cost. This cost includes the annual total maintenance cost occurring before the next maintenance treatment. The fourth method considers the time since the last treatment. These four methods were not based on the regression analysis. Also, these methods do not include roadway characteristics such as traffic load and road functional classification. Those characteristics are critical in determining the pavement conditions and maintenance costs.

The reason for including roadway characteristics in the modeling is to provide an objective basis for identifying current needs, estimating future needs, to provide consistency between sections and classes of pavement, and to effectively interpret current and future work (Haas et al., 1994).

Volovski (2011) has developed two models to aid agencies in prediction of annual routine maintenance costs. These models are as follow: annual maintenance expenditure (AMEX) and average annual maintenance expenditure (AveAMEX). To develop those models econometric techniques were used. The Indiana pavement segments were used accounting for 90% of the 11,300 centerline miles. The data used for the analysis include location, size, surface type, rehabilitation history, traffic volumes, functional classification, climate, and pavement condition. The response variable included in their model is continuous and censored at zero without upper bound. Four modeling approaches were taken in this study: Ordinary Least Squares, Tobit, 2-Stage Discrete/Continuous and Panel data modeling. The variables included in their research are: age of pavement, AADT, number of vehicles, average annual precipitation, urban arterial, reconstructed road, new road, length of pavement segment, and number of lanes. Data from year 2005 and 2006 were used and they were presented as 0 or 1 in their analysis. The equation used in the ordinary least square (OLS) analysis was:

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon_i \;\; i = 1,2,\cdots n \qquad (2.6)$$

Where, x is the independent variable and y_i is the dependent variable. β is a vector of parameters and y_i is continuous from - ∞ to ∞, and ε_i is the random error that is typically assumed to be normally distributed. The equation incorporated in AMEX Tobit modeling was as follow:

$$y_i = \beta x_i + \varepsilon_i \tag{2.7}$$

Where,

$i = 1,2,\cdots n$

$y_i = 0$ if $y_I = 0$

$y_i = Y_I$ if $y_I > 0$

In both statistical analyses, the dependent variable was a square root of the annual maintenance expenditure. For AveAMEX analysis, slightly different variables were used such as: length of pavement segment, AADT for the pavement segment, age, and percent of commercial vehicles, rural, number of wet days, pavement replacement, new road, and rigid pavement. It is unknown if those variables in each model were statistically significant and to what level. Also, it is unknown if the data was normally distributed in the analysis. In the conclusions of their study, it was stated that OLS provided too many outcomes resulting in zero, the Tobit model produced intuitive results and good overall fit, 2-Stage discrete/continuous model unreliable, and Panel Models is not practical for application. AveAMEX resulted in fewer outcomes with zero which leads to better OLS model representation. In addition, AveAMEX modeling exhibited high impact of data in district boundaries.

2.5 Literature Review Summary

Based on the review of the literature, it can be seen that a variety of scholarly work on pavement cost estimate modeling has been performed. Most studies focused on the preventive or rehabilitation maintenance cost model. Some studies illustrate different divisions of maintenance activities. In addition, various variables in works were incorporated in modeling or some of the models had region specific variables, which couldn't be fully applied in another demographic area. For instance, Volovski's work incorporated location, size, surface type, rehabilitation history, traffic volumes, functional classification, climate, and pavement condition variables. Gibby included in his work the following variables: annual average daily traffic (AADT) of heavy trucks and passenger cars, labor and material costs, age of pavement, presence or absence of a shoulder, temperature, location maintenance, existence of bridges, functional classification, and the districts.

CHAPTER 3

METHODOLOGY

The purpose of this study is to develop cost estimation models for routing highway maintenance. To achieve this objective, the following procedure is followed: literature review, data collection, model calibration, analysis, and conclusions.

3.1 Literature Review

The purpose of reviewing existing literature was to find any scholar work regarding the subject matter this study was focused on. There were not many studies conducted on the routine maintenance cost model development. Most studies focused on the preventive or rehabilitation maintenance cost model. Some studies illustrated different divisions of maintenance activities. For instance, NDOT grouped maintenance in three categories: routine maintenance, capital improvements, and emergency activities. In some studies, maintenance was classified into strategies such as: rehabilitation, routine maintenance, and major maintenance, example of which is Ontario. Only one study was found that the routine maintenance cost estimation was investigated using ordinary least square (OLS) analysis. However, the variables used in that study were limited.

The literature review showed PMS has been used in pavement management, and PMS mainly contains models used to predict pavement performance in selecting the optimum maintenance strategy. The database in PMS has been used for cost model development.

The review of the literature illustrated the wide range of statistical analysis used for the cost model development. Some works used more variables in analysis than others. Some studies used demographic area, which make it difficult to apply their models to other places.

3.2 Data Collection

In this study, the data collected for a previous research project conducted for NDOT (Teng, 2011) was used. In this preceding study, the raw data from NDOT PMS database was extracted to develop highway maintenance cost models. Several models were developed, one model for each routing maintenance prioritization category of roadways. The data from 2007 to 2012 were used in modeling. Each prioritization category of roadway has different assumed pavement life cycles with different maintenance treatment (see Figure 3.1). For the roadways in Category 1 and 2, 1"-1.5" Cold Mill, 2"-2.5" Hot Mix Asphalt (HMA) overlay, and Open-graded Friction Course (OGFC) are assumed to apply after eight and ten years, respectively. The maximum thickness of the overlay is considered in the analysis. In addition, shoulder seal treatment will be performed for Category 1 after 4 years and for Category 2 after 5 years. In general, the stated treatment will be performed for both categories of roadways midway through their life cycle. Unlike Categories 1 and 2, the roadways in Category 3 are provided with more treatments in the assumed lifecycle of the pavement such as: flush seal one time, chip seal twice, finishing with 2" HMA overlay and OGFC. The roadway in this category is assumed to have a life of 12 years. The roadways in Category 4 are assumed to be similar to Category 3 with respect to the treatment having chip seal repeated after four years and a longer life cycle of 15 years. Moreover, in Category 4, the final treatment has the option of OGFC or chip seal to be executed. Exceptionally, the roadways in Category 5 have the longest service life of 20 years and having all surface treatment applied as necessary. They are finished with 2" HMA overlay and chip seal.

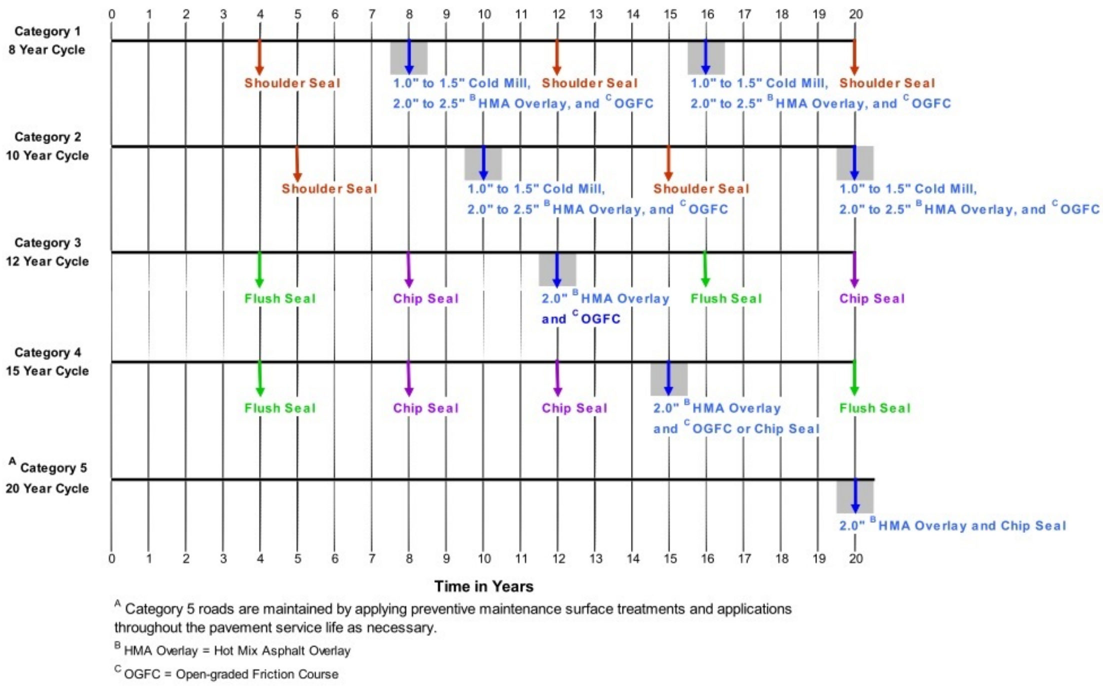


Figure 3.1 Prioritization Category Life Cycles.

It can be seen that the life cycle for the roadway in Category 3 has been divided into three stages: After reconstruction, After Flush Seal, and After Chip Seal. Likewise, four life cycle stages were included for the roadways in Category 4: After Reconstruction, After

Flush Seal, After First Chip Seal, and After the Second Chip Seal. The roadways in Category 5 have the same stage as Category 3 but for simplicity they were renamed as 5.1, 5.2, and 5.3. In addition, a 16 year service life has been chosen for Category 5 due to having its treatment applied whenever required. These life cycle and stages have been used in data collection.

In extracting data for modeling, the first step was to select a sample road from the road inventory and then generate a timeline diagram with history of maintenance activities. The second step was to find the road sections having homogeneous characteristics by employing the time-space diagrams. The road sections should have the same time series of maintenance treatments. It was assumed that each of these sections used the same maintenance treatment, having unchanged road characteristics and uniform traffic load over the entire road sections. In the third step, homogenous sections were selected. From those sections, road characteristics data was collected and used in analysis.

3.3 Data Analysis

Econometric models were used to estimate routine maintenance cost. According to Edward E. Leamer (2008), econometrics uses observational data to study economic hypothesis rather than experiment data. Econometric methodology allows estimating models and investigating their observed results without directly manipulating the system. The fundamental tool presented in econometric analysis is Ordinary Least Square (OLS) that is described in detail later in this chapter.

It is hypothesized that the routine maintenance cost is dependent on various roadway factors such as: elevation, number of lanes, age of the pavement, last year pavement construction work, average daily traffic (ADT), number of trucks, single axial load (ESAL).

Linear regression models were developed for each life cycle stage of five different maintenance prioritization categories classified by NDOT. The ordinary least squares (OLS) models can be written as:

$$Y_i = \beta \ + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_k x_{ki} + \varepsilon_i, \quad (i = 1,2,...,n) \qquad (3.1)$$

$$E(\varepsilon_i)=0, \ Var\ (\varepsilon_i)=\varepsilon^2, \ \forall\ i$$

$$E(\varepsilon_i, \varepsilon_j)=0, \ \forall\ i \neq j$$

$$cov(X_i, \varepsilon_j)=0 \text{ for all i and j}$$

$$\varepsilon_i \text{ is normally distributed, } \forall\ i$$

where β's are unknown parameters to be estimated and ε_i is the unobserved error term with certain properties (Hayashi, 2000). The *X*'s are deterministic. The variables for X's are as follow: elevation, number of lanes, age of the pavement, last year pavement construction work, average daily traffic (ADT), number of trucks, single axial load (ESAL), while the variables for y's are stockpile, labor cost, total hour cost, equipment cost, material cost and total cost.

The statistical software package STATA was used in performing the analysis of this study. All multivariate regression analyses were performed using the STATA programming language. The software used for the regression analysis was STATA 12.1 (64-bit version) which was developed to perform statistical analyses of data and complex data management. The purpose of using this program was to avoid the error-prone computations. Further, the software contains complex statistical tools that enormously aided this research.

CHAPTER 4

DATA COLLECTION

4.1 Data Sample and Development

Each year state agencies collect data pertaining to roadway conditions and update their pavement management system (PMS). The major function of PMS is to develop pavement management alternatives based on the condition of the pavement. The purpose of data collection was to extract maintenance cost, pavement and traffic data to develop routine maintenance cost models.

Data used for analysis in this study was collected in a research project sponsored by NDOT. Five steps were followed in data collection presented in Figure 4.1.1 (Teng, 2011).

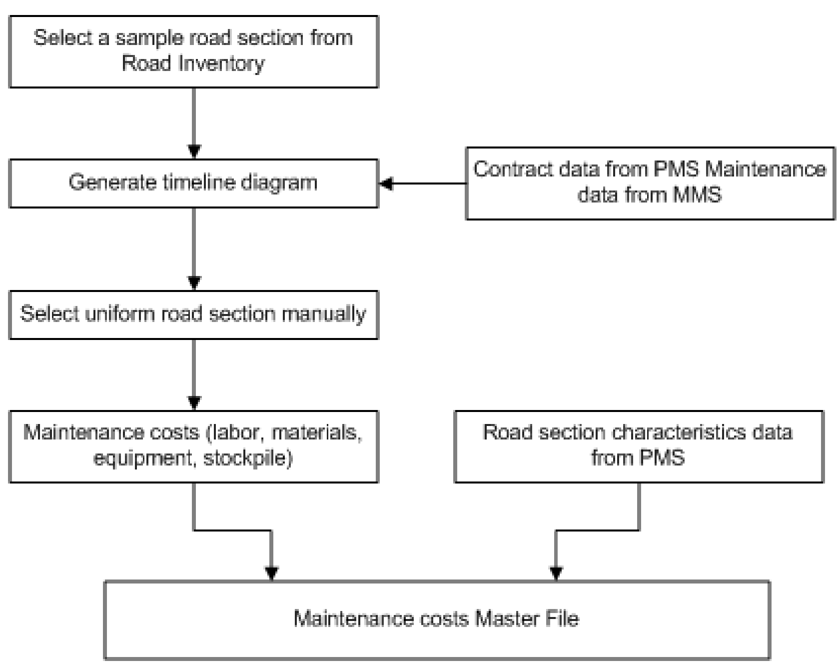
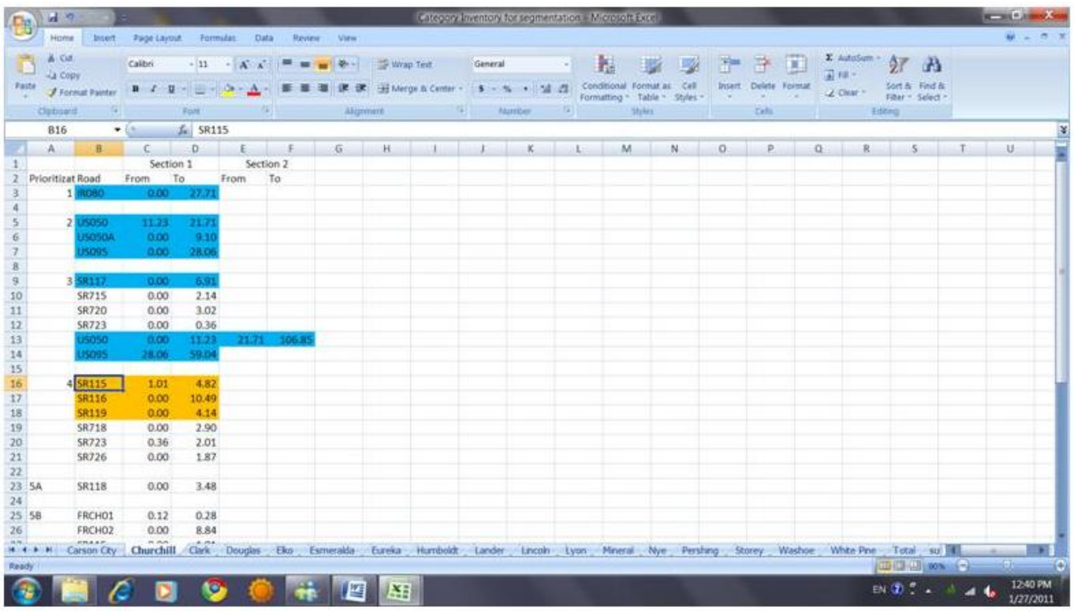


Figure 4.1.1 Procedure for Data Collection.

The collected data includes maintenance cost for labor, materials, total hours, equipment, stockpile, total cost per mile, road segment characteristics, and traffic flow data. According to Teng (2011), the first step was to select a sample road. Figure 4.1.2 demonstrates the record of roads maintained by NDOT in 2007, broken down into the five prioritization categories.



		Section 1		Section 2	
Prioritizat	Road	From	To	From	To
1	IR080	0.00	27.71		
2	US050	11.23	21.71		
	US050A	0.00	9.10		
	US095	0.00	28.06		
3	SR117	0.00	6.91		
	SR715	0.00	2.14		
	SR720	0.00	3.02		
	SR723	0.00	0.36		
	US050	0.00	11.23	21.71	106.85
	US095	28.06	59.04		
4	SR115	1.01	4.82		
	SR116	0.00	10.49		
	SR119	0.00	4.14		
	SR718	0.00	2.90		
	SR723	0.36	2.01		
	SR726	0.00	1.87		
5A	SR118	0.00	3.48		
5B	FRCH01	0.12	0.28		
	FRCH02	0.00	8.84		

Figure 4.1.2 Road Inventory for Churchill County from PMS 2007 Data.

One road could be divided into multiple sections, each with different maintenance prioritization. For instance, SR115 had two segments, one in Category 4 and the other in

Category 5. From road sample segments, the timeline diagram was generated where history of maintenance activities were present.

The second step was to employ the time-space diagrams to find the road sections that have the same set of maintenance treatments over the years and to extract the data correspondingly. Figure 4.1.3 represents the time space diagram for US50 in Churchill County.

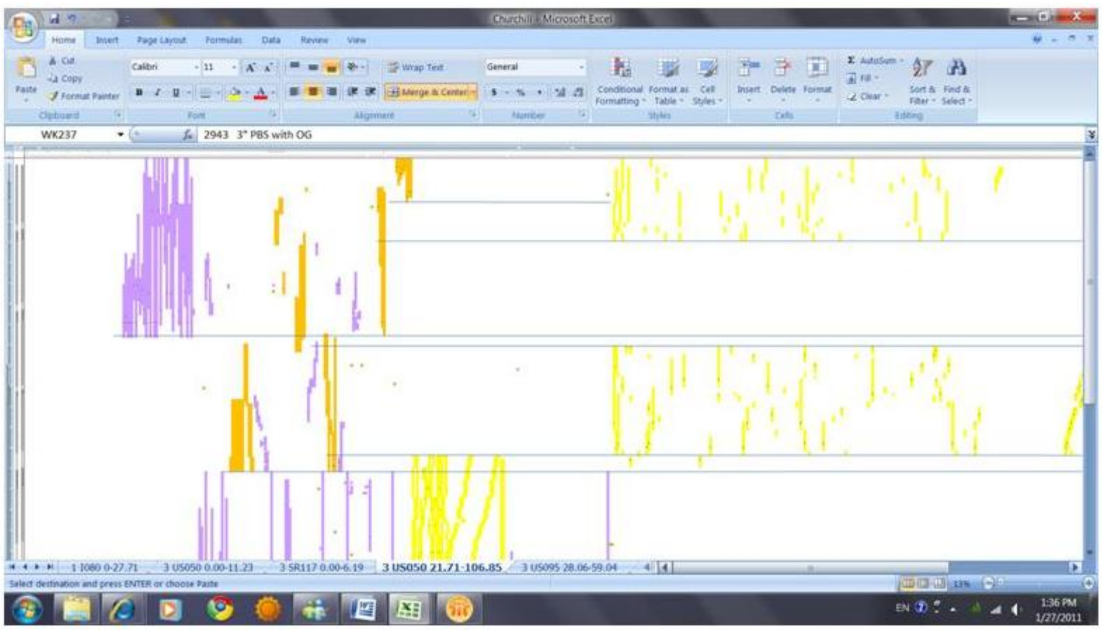


Figure 4.1.3 Time Space Diagram for US 50 in Churchill County.

This data includes base and surface repair, hand patching, machine patching, maintenance overlay, roadway capital improvements, sand, fog/flush, chip, scrub/slurry, crack filling, and cold milling. The time space diagrams for Prioritization Categories 3, 4 and 5 have minor differences from those for Categories 1 and 2. The diagram has color coding developed as follow: yellow, purple, and orange. The yellow columns designate rehabilitation and reconstruction projects that were documented in the PMS database. Purple columns indicate maintenance works performed under a flexible pavement program. Orange strips were marked on the time space diagrams to distinguish the preventive maintenance tasks, for instance fog/flush, chip, sand seal, and etc. The time space diagrams were constructed using macros in the Microsoft Excel program. Figure 4.1.4 embodies the time space diagram for I-80 in Churchill County. The horizontal lines denote homogenous segments.

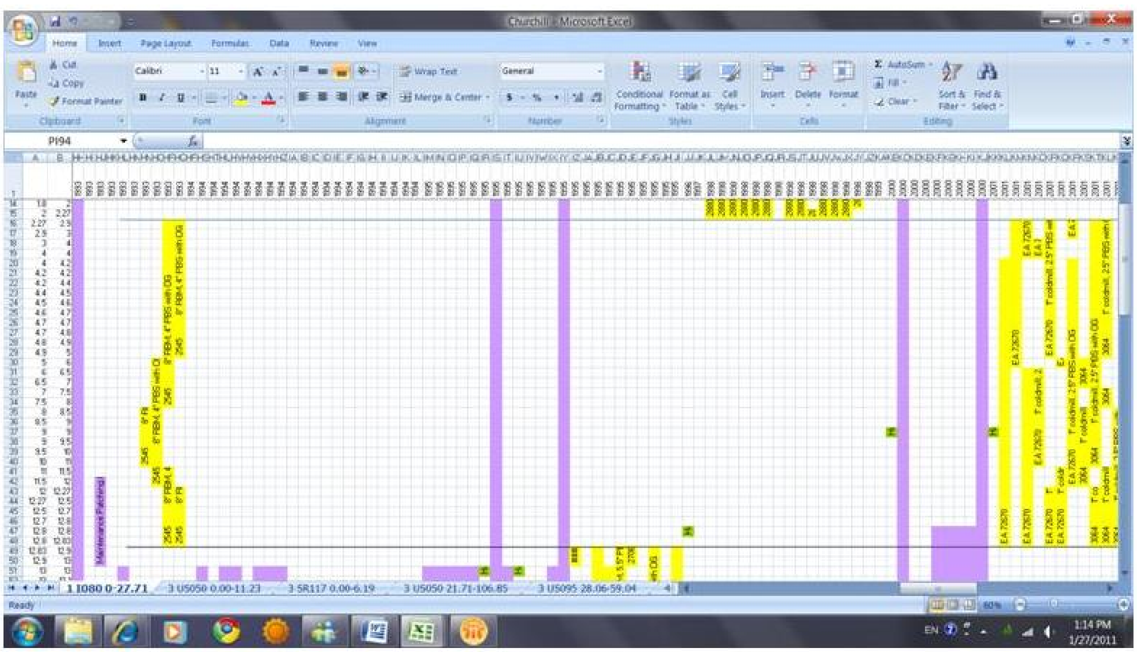


Figure 4.1.4 Time Space Diagram for I-80 of Category 1 from 0.00 to 27.71 (zoomed in).

The third step was to implement the time-space diagrams to recognize anticipated segments of the road. Figure 4.1.5 includes years in which the specific treatments were applied, shown on the right side. The left column indicate the prioritization category the treatment was performed. It was assumed that each of these sections used the same maintenance activities having the same roadway influencing factors. Moreover, it was predicted that the traffic weight would be constant throughout each roadway section. The time-space diagrams illustrate segments of the road that have homogenous maintenance treatments in the past.

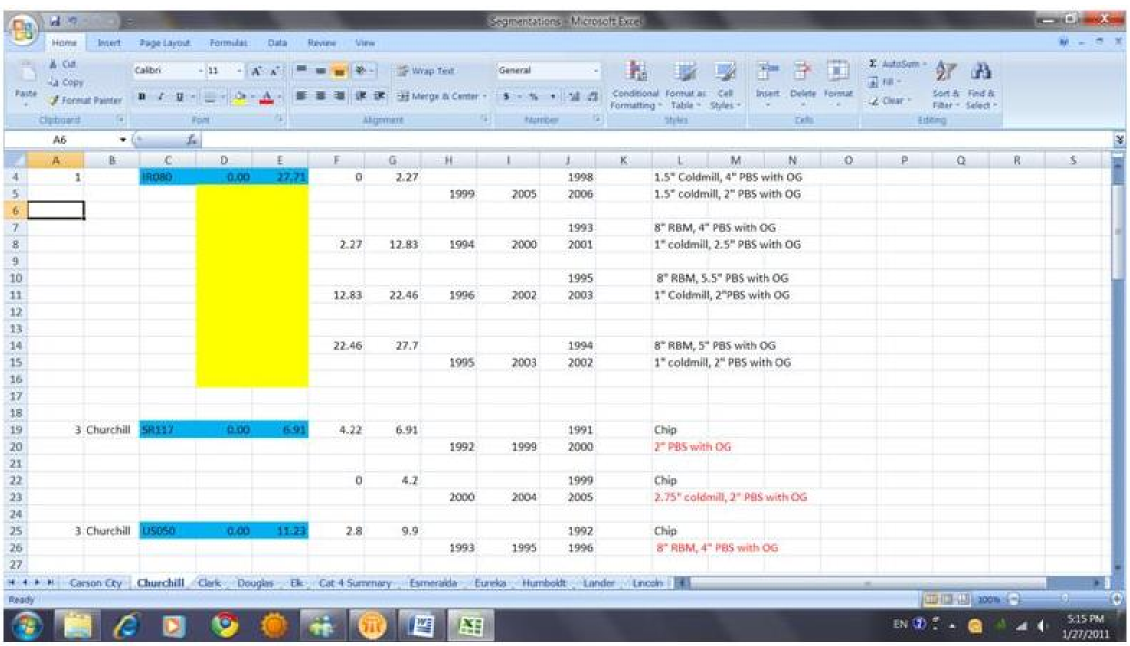
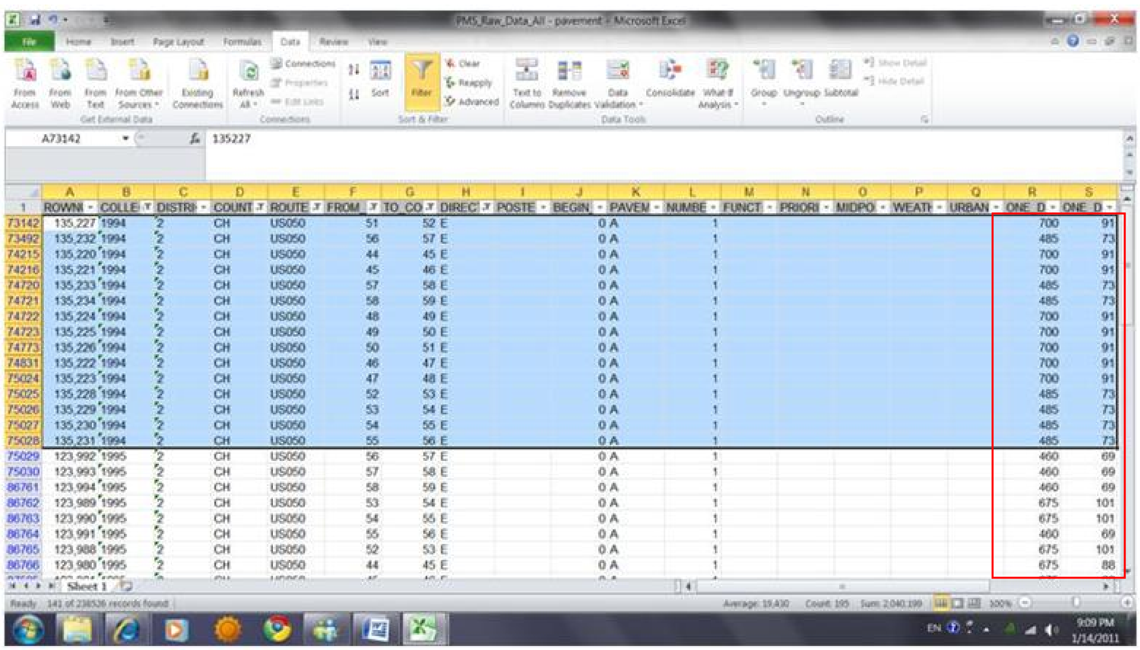


Figure 4.1.5 Identified Road Segments for Roads in Churchill County.

It is identified that homogenous segments in Categories 1 and 2 have no rehabilitation applied on any segment of the road. However, homogenous segments in other categories do not include preventive or rehabilitation completed between rehabilitation and any preventive maintenance time period. Figure 4.1.5 represents four segments of I-80 in Churchill County stretched between 0.00 and 27.71. The following segments were recognized throughout the mentioned stretched of the road: 0.00-2.27, 2.27-12.83, 12.83-22.46, and 22.46-27.27. Each of the sections has time period beginning and ending with rehabilitation.

In the fourth step, the averaging mile-by-mile of the traffic flow data is extracted. First, the average of the ADT for one year is calculated for a road characteristic data. The same technique is applied to calculate the other years. Once the data is obtained, it is transferred to the cost data sheet. Figure 4.1.6 illustrates the filtered data for the road segment East US 50 from 43.71 to 59.96 in Churchill.



1	ROWNI	COLLE	DISTRI	COUNT	ROUTE	FROM	TO_CO	DIREC	POSTE	BEGIN	PAVEM	NUMBE	FUNCT	PRIORI	MIDPO	WEATH	URBAN	ONE_D	ONE_D
73142	135,227	1994	2	CH	US050	51	52	E		0	A	1						700	91
73492	135,232	1994	2	CH	US050	56	57	E		0	A	1						485	73
74215	135,220	1994	2	CH	US050	44	45	E		0	A	1						700	91
74216	135,221	1994	2	CH	US050	45	46	E		0	A	1						700	91
74720	135,233	1994	2	CH	US050	57	58	E		0	A	1						485	73
74721	135,234	1994	2	CH	US050	58	59	E		0	A	1						485	73
74722	135,224	1994	2	CH	US050	48	49	E		0	A	1						700	91
74723	135,225	1994	2	CH	US050	49	50	E		0	A	1						700	91
74773	135,226	1994	2	CH	US050	50	51	E		0	A	1						700	91
74831	135,222	1994	2	CH	US050	46	47	E		0	A	1						700	91
75024	135,223	1994	2	CH	US050	47	48	E		0	A	1						700	91
75025	135,228	1994	2	CH	US050	52	53	E		0	A	1						485	73
75026	135,229	1994	2	CH	US050	53	54	E		0	A	1						485	73
75027	135,230	1994	2	CH	US050	54	55	E		0	A	1						485	73
75028	135,231	1994	2	CH	US050	55	56	E		0	A	1						485	73
75029	123,992	1995	2	CH	US050	56	57	E		0	A	1						460	69
75030	123,993	1995	2	CH	US050	57	58	E		0	A	1						460	69
86761	123,994	1995	2	CH	US050	58	59	E		0	A	1						460	69
86762	123,989	1995	2	CH	US050	53	54	E		0	A	1						675	101
86763	123,990	1995	2	CH	US050	54	55	E		0	A	1						675	101
86764	123,991	1995	2	CH	US050	55	56	E		0	A	1						460	69
86765	123,988	1995	2	CH	US050	52	53	E		0	A	1						675	101
86766	123,980	1995	2	CH	US050	44	45	E		0	A	1						675	88

Figure 4.1.6 Road Characteristics Data from NDOT PMS Data.

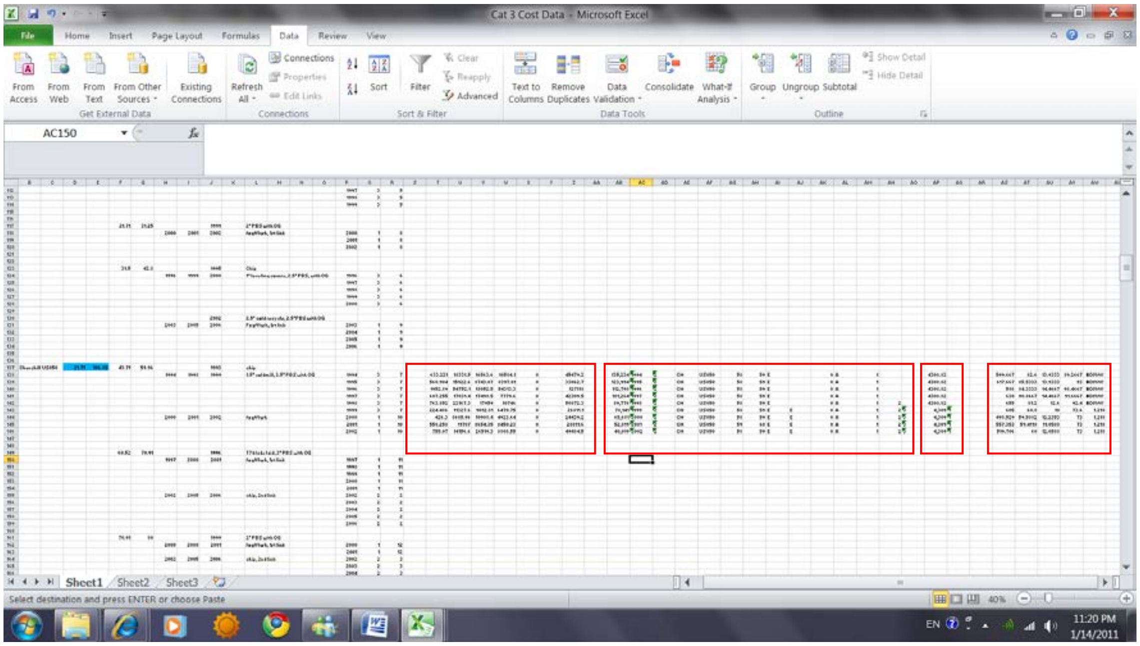
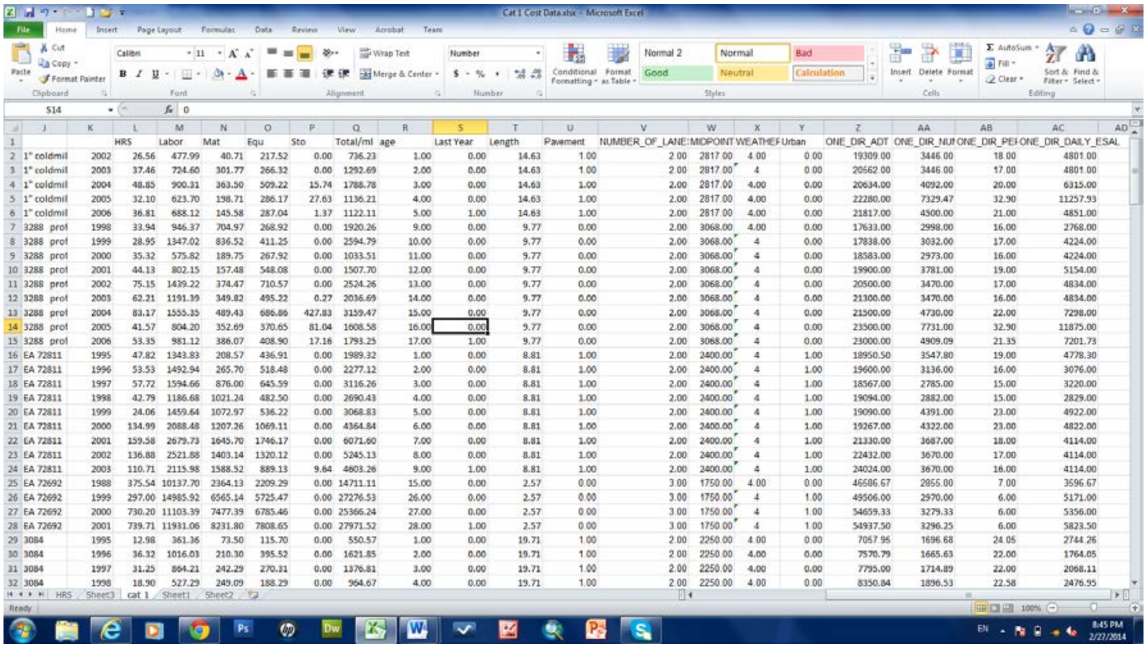


Figure 4.1.7 Maintenance Costs and Road Characteristics in the Cost Data Master File

In the fifth step, homogenous sections were selected and road features were extracted respectively (Teng, 2011). Figure 4.1.7 shows the data obtained from all these steps, which are used in the analysis.

In this study, inventory data has been extracted from PMS. This data includes treatment methods, years of maintenance, total cost per mile, total hours, equipment, materials, stockpile, labor, pavement age, district, number of lanes, midpoint elevation, weather, urban, AADT, number of trucks, and ESAL. Figure 4.1.8 indicates the outcome of the extraction of the data from the NDOT inventory.



	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
1			HRS	Labor	Mat	Equ	Sto	Total/ml	age	Last Year	Length	Pavement	NUMBER_OF_LANE	MIDPOINT	WEATHEF	Urban	ONE_DIR_ADT	ONE_DIR_NUI	ONE_DIR_PEI	ONE_DIR_DAILY_ESAL
2	1" coldmil	2002	26.56	477.99	40.71	217.52	0.00	736.23	1.00	0.00	14.63	1.00	2.00	2817.00	4.00	0.00	19309.00	3446.00	18.00	4801.00
3	1" coldmil	2003	37.46	724.60	301.77	266.32	0.00	1292.69	2.00	0.00	14.63	1.00	2.00	2817.00	4	0.00	20562.00	3446.00	17.00	4801.00
4	1" coldmil	2004	48.85	900.31	363.50	509.22	15.74	1788.78	3.00	0.00	14.63	1.00	2.00	2817.00	4.00	0.00	20634.00	4092.00	20.00	6315.00
5	1" coldmil	2005	32.10	623.70	198.71	286.17	27.63	1136.21	4.00	0.00	14.63	1.00	2.00	2817.00	4.00	0.00	22280.00	7329.47	32.90	11257.93
6	1" coldmil	2006	36.81	688.12	145.58	287.04	1.37	1122.11	5.00	1.00	14.63	1.00	2.00	2817.00	4.00	0.00	21817.00	4500.00	21.00	4851.00
7	3288 prof	1998	33.94	946.37	704.97	268.92	0.00	1920.26	9.00	0.00	9.77	0.00	2.00	3068.00	4.00	0.00	17633.00	2998.00	16.00	2768.00
8	3288 prof	1999	28.95	1347.02	836.52	411.25	0.00	2594.79	10.00	0.00	9.77	0.00	2.00	3068.00	4	0.00	17838.00	3032.00	17.00	4224.00
9	3288 prof	2000	35.32	575.82	189.75	267.92	0.00	1033.51	11.00	0.00	9.77	0.00	2.00	3068.00	4	0.00	18583.00	2973.00	16.00	4224.00
10	3288 prof	2001	44.13	802.15	157.48	548.08	0.00	1507.70	12.00	0.00	9.77	0.00	2.00	3068.00	4	0.00	19900.00	3781.00	19.00	5154.00
11	3288 prof	2002	75.15	1439.22	374.47	710.57	0.00	2524.26	13.00	0.00	9.77	0.00	2.00	3068.00	4	0.00	20500.00	3470.00	17.00	4834.00
12	3288 prof	2003	62.21	1191.39	349.82	495.22	0.27	2036.69	14.00	0.00	9.77	0.00	2.00	3068.00	4	0.00	21300.00	3470.00	16.00	4834.00
13	3288 prof	2004	83.17	1555.35	489.43	686.86	427.83	3159.47	15.00	0.00	9.77	0.00	2.00	3068.00	4	0.00	21500.00	4730.00	22.00	7298.00
14	3288 prof	2005	41.57	804.20	352.69	370.65	81.04	1608.58	16.00	0.00	9.77	0.00	2.00	3068.00	4	0.00	23500.00	7731.00	32.90	11875.00
15	3288 prof	2006	53.35	981.12	386.07	408.90	17.16	1793.25	17.00	1.00	9.77	0.00	2.00	3068.00	4	0.00	23000.00	4909.09	21.35	7201.73
16	EA 72811	1995	47.82	1343.83	208.57	436.91	0.00	1989.32	1.00	0.00	8.81	1.00	2.00	2400.00	4	1.00	18950.50	3547.80	19.00	4778.30
17	EA 72811	1996	53.53	1492.94	265.70	518.48	0.00	2277.12	2.00	0.00	8.81	1.00	2.00	2400.00	4	1.00	19600.00	3136.00	16.00	3076.00
18	EA 72811	1997	57.72	1594.66	876.00	645.59	0.00	3116.26	3.00	0.00	8.81	1.00	2.00	2400.00	4	1.00	18567.00	2785.00	15.00	3220.00
19	EA 72811	1998	42.79	1186.68	1021.24	482.50	0.00	2690.43	4.00	0.00	8.81	1.00	2.00	2400.00	4	1.00	19094.00	2882.00	15.00	2829.00
20	EA 72811	1999	24.06	1459.64	1072.97	536.22	0.00	3068.83	5.00	0.00	8.81	1.00	2.00	2400.00	4	1.00	19090.00	4391.00	23.00	4922.00
21	EA 72811	2000	134.99	2088.48	1207.26	1069.11	0.00	4364.84	6.00	0.00	8.81	1.00	2.00	2400.00	4	1.00	19267.00	4322.00	23.00	4822.00
22	EA 72811	2001	159.58	2679.73	1645.70	1746.17	0.00	6071.60	7.00	0.00	8.81	1.00	2.00	2400.00	4	1.00	21330.00	3687.00	18.00	4114.00
23	EA 72811	2002	136.88	2521.88	1403.14	1320.12	0.00	5245.13	8.00	0.00	8.81	1.00	2.00	2400.00	4	1.00	22432.00	3670.00	17.00	4114.00
24	EA 72811	2003	110.71	2115.98	1588.52	889.13	9.64	4603.26	9.00	1.00	8.81	1.00	2.00	2400.00	4	1.00	24024.00	3670.00	16.00	4114.00
25	EA 72692	1988	375.54	10137.70	2364.13	2209.29	0.00	14711.11	15.00	0.00	2.57	0.00	3.00	1750.00	4.00	0.00	46586.67	2855.00	7.00	3596.67
26	EA 72692	1999	297.00	14985.92	6565.14	5725.47	0.00	27276.53	26.00	0.00	2.57	0.00	3.00	1750.00	4	1.00	49506.00	2970.00	6.00	5171.00
27	EA 72692	2000	730.20	11103.39	7477.39	6785.46	0.00	25366.24	27.00	0.00	2.57	0.00	3.00	1750.00	4	1.00	54659.33	3279.33	6.00	5356.00
28	EA 72692	2001	739.71	11931.06	8231.80	7808.65	0.00	27971.52	28.00	1.00	2.57	0.00	3.00	1750.00	4	1.00	54937.50	3296.25	6.00	5823.50
29	3084	1995	12.98	361.36	73.50	115.70	0.00	550.57	1.00	0.00	19.71	1.00	2.00	2250.00	4.00	0.00	7057.95	1696.68	24.05	2744.26
30	3084	1996	36.32	1016.03	210.30	395.52	0.00	1621.85	2.00	0.00	19.71	1.00	2.00	2250.00	4.00	0.00	7570.79	1665.63	22.00	1764.05
31	3084	1997	31.25	864.21	242.29	270.31	0.00	1376.81	3.00	0.00	19.71	1.00	2.00	2250.00	4.00	0.00	7795.00	1714.89	22.00	2068.11
32	3084	1998	18.90	527.29	249.09	188.29	0.00	964.67	4.00	0.00	19.71	1.00	2.00	2250.00	4.00	0.00	8350.84	1896.53	22.58	2476.95

Figure 4.1.8 Cost Data Master File

4.2 Prioritization

In NDOT, roadways are classified into five prioritization categories for maintenance work. Maintenance policy has been established for different categories of the roadways: life cycle length, maintenance treatments and their application time during their life cycle. Figure 4.2.1 represents five prioritization categories.

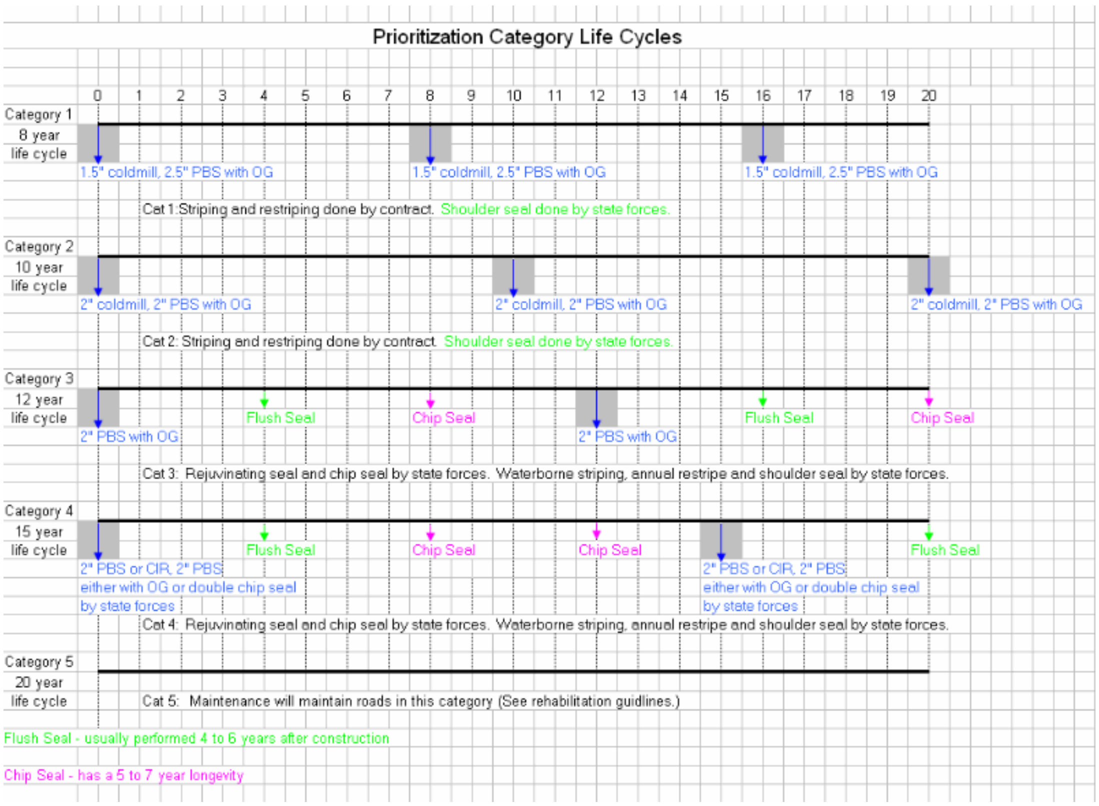


Figure 4.2.1 Cost Data Master File.

For the roadway in Categories 1 and 2, the same maintenance treatments are applied which are 1"-1.5" Cold Mill, 2"-2.5" Hot Mix Asphalt (HMA) overlay, and Open-graded Friction Course (OGFC). According to Teng (2011), the life cycle is divided into the following stages:

<u>Life cycle stage in Category 1</u>: Cat 1 After Reconstruction.

<u>Life cycle stage in Category 2</u>: Cat 2 After Reconstruction.

<u>Life cycle stage in Category 3:</u>

Cat 3 After Reconstruction,

Cat 3 After Flush Seal,

Cat 3 After Chip Seal.

Life cycle stages in Category 4:

Cat 4 After Construction,

Cat 4 After Flush Seal,

Cat 4 After 1st Chip Seal,

Cat 4 After 2nd Chip Seal.

Life cycle stages in Category 5:

Cat 5 After Reconstruction,

Cat 5 Middle After Flush, Cat Middle After Chip, and

Cat 5 Last After Chip, Cat 5 Last After Flush.

These stages were created based on the roadway life cycle of pavement infrastructure as shown in Figure 4. From Figure 4.7 it can be seen that Categories 1 and 2 have only one life cycle. In Category 1, the lifecycle starts from reconstruction and ends at the next reconstruction stage. In Category 2, the lifecycle starts and ends with coldmill and PBS with Open Graded. There are three life cycle stages for Categories 3 and 5, and four life cycle stages in Category 4. Unlike Categories 1 and 2, the roadways in Category 3 are provided with more treatments in the assumed life cycle of the pavement such as: flush seal one time, chip seal twice, finishing with 2" HMA overlay and OGFC. The roadways in Category 4 are assumed to be similar to category 3 with respect to the treatment having chip seal repeated after four years. Moreover, in Category 4, the final treatment has options of OGFC or chip seal to be executed. Remarkably, the roadways in Category 5 have the longest service life and having all surface treatment applied as necessary. The Category 5 prioritization is completed with 2" HMA overlay and chip seal.

Time-space diagrams represent maintenance activities applied to the pavement during maintenance work. The maintenance activities consist of the following tasks:

1. Base & Surface Repair
2. Hand Patching
3. Machine Patching
4. Maintenance Overlay, Inlay (Scheduled Betterment)
5. Roadway Capital Improvements (Scheduled Betterment)
6. Sand
7. Fog/Flush
8. Chip
9. Scrub/Slurry
10. Crack Filling
11. Cold Milling
12. Snow Removal

The roadway sections having the same maintenance activities were selected for analysis. The time-space diagrams vary slightly among the prioritization categories. Categories 3, 4, and 5 differ from categories 1 and 2. The time-space diagrams were created based on a macro programming routine using Microsoft Excel as a tool. According to Teng (2011), the procedure in Figure 4.2.2 was used to create time-space diagram. The variables for maintenance cost analysis were identified using filtering function in Excel. Thus, all the maintenance activities associated with the road section were included and only roads with the same maintenance treatment were selected for further study.

Data file AllData:

1. Loop through each segment
   a) Find the year
   b) Find mileage points
   c) If the current “Contract Repair Strat” is different from previous one in this year column, or the corresponding cells are colored already, insert a year column
   d) Put “Contract” and “Contract Repair Strat” in the cells and color
2. Merge any contiguous cells with the same color and same text, turn text up.

Figure 4.2.2 Procedures for Time-Space Diagrams Using Macro

Traffic flow varied over the year, thus the annual average was used in analysis. Similarly, for long stretches of roads, the midpoint elevations were averaged. Other roadway factors such as constant traffic flow or midpoint elevations did not change with the length of the road segment; therefore a different procedure was implemented. This procedure did not involve taking an average of the numerical data over the segment of road. Since the data for the same segment of road varied over the years, the range of time period was adjusted as well. Based on the procedure and Microsoft Spreadsheet program created by Teng (2011), the maintenance cost data was put together. This cost data was developed for total cost, total hours, equipment, materials, stockpile, and labor.

CHAPTER 5

ROUTINE MAINTENANCE COST MODEL DEVELOPMENT

5.1 Routine Maintenance Cost for Roads in Priority Category 1

Routine maintenance costs for the roads in Prioritization Category 1 were analyzed based on the eight year pavement life cycle using linear regression models. The results of the models are listed in Table 5.1 and 5.1A (Appendix). Figure 5.1.1 illustrates life cycle for the road in Category 1.

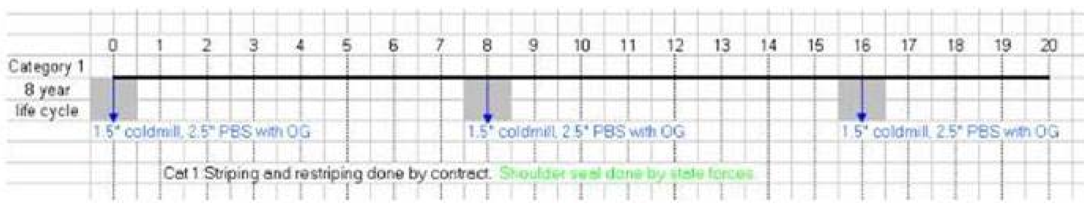


Figure 5.1.1 Life Cycle for Priority Category 1 Roads.

The results from the regression model for the total cost indicate that the variables that are significant are: age, pavement type, number of trucks, elevation, and weather conditions. The coefficient of the age is positive indicating that the total cost of the maintenance increases every year which is illustrated in Table 5.1. Similarly, the coefficient of concrete asphalt (in Table 5.1 called "Pavement") is positive, suggesting that the roads with concrete surfaces require higher maintenance costs than rigid concrete pavement. Comparable with age and pavement type, elevation of the road segment also plays an important role in the determination of maintenance costs. The coefficient for the factor ‘Elevation’ is negative implying that the roads at low elevation are more maintained, however, roads at higher elevations require less maintenance. It is because the data samples were taken from the Las Vegas area, where the highways I-15 and US 95 outside of the metropolitan area are at low elevation demanding more maintenance. Maintenance activities differ with the conditions of infrastructure that depends on the amount of daily traffic passing through. The positive coefficient for number of trucks indicate that greater number of trucks traveling each day on the roads results in greater deterioration, which triggers more maintenance activities, thus higher maintenance cost. Weather is another very important factor that the maintenance cost depends on. The variable for weather is positive demonstrating that weather conditions are influential to the total maintenance cost. It indicates that the Category 1 roads require additional maintenance activities due to the work during extreme weather, such as snow removal. The coefficient of length is negative, suggesting that some part of the roads require less or no maintenance. Some parts of the road might have not been affected by other factors, for instance weathering or traffic volume, which would leave the road in good condition.These observations also can be found in other maintenance cost components, including labor cost, equipment cost, stockpile, and materials cost that are illustrated in Table 5.1. Age and elevation is the most significant variables used for cost estimates since they are included in all other cost components. Weather, number of trucks and pavement factors are contained within labor, equipment, total hours, and materials which indicate that is one of the factors affecting maintenance cost. ESAL is the only variable incorporated in stockpile cost. Also, only labor costs have rural or urban variables included.

Table 5.1 Regression Models for Roads in Priority Category 1.

<table>
<tr><th>Total Cost</th><th>Coefficient</th><th>Standard Error</th><th>Significance P>|t|</th><th>Total Hours</th><th>Coefficient</th><th>Standard Error</th><th>Significance P>|t|</th></tr>
<tr><td>Age</td><td>0.0269</td><td>0.0105</td><td>0.012</td><td>Age</td><td>0.03</td><td>0.0102</td><td>0.004</td></tr>
<tr><td>Pavement</td><td>0.896</td><td>0.1654</td><td>0</td><td>Length</td><td>-0.0239</td><td>0.0108</td><td>0.029</td></tr>
<tr><td>No_Trucks</td><td>0.0004</td><td>0.0001</td><td>0</td><td>Pavement</td><td>0.6802</td><td>0.1617</td><td>0</td></tr>
<tr><td>Elevation</td><td>-0.0006</td><td>0.0002</td><td>0</td><td>Elevation</td><td>-0.0006</td><td>0.0002</td><td>0</td></tr>
<tr><td>Weather</td><td>1.4975</td><td>0.2691</td><td>0</td><td>Weather</td><td>1.3056</td><td>0.2591</td><td>0</td></tr>
<tr><td rowspan="2">Constant</td><td rowspan="2">3</td><td rowspan="2">1.324</td><td rowspan="2">0.025</td><td>No_Trucks</td><td>0.0004</td><td>0</td><td>0</td></tr>
<tr><td>Constant</td><td>0.0085</td><td>1.2753</td><td>0.995</td></tr>
<tr><td>Labor Cost</td><td></td><td></td><td></td><td>Materials</td><td></td><td></td><td></td></tr>
<tr><td>Age</td><td>0.025</td><td>0.0097</td><td>0.01</td><td>Age</td><td>0.0385</td><td>0.016</td><td>0.017</td></tr>
<tr><td>Pavement</td><td>0.7995</td><td>0.1535</td><td>0</td><td>Pavement</td><td>0.9578</td><td>0.2497</td><td>0</td></tr>
<tr><td>Elevation</td><td>-0.0006</td><td>0.0001</td><td>0</td><td>Elevation</td><td>-0.0005</td><td>0.0002</td><td>0.038</td></tr>
<tr><td>Weather</td><td>1.48</td><td>0.2454</td><td>0</td><td>Weather</td><td>1.6069</td><td>0.416</td><td>0</td></tr>
<tr><td>Urban</td><td>-0.2611</td><td>0.1218</td><td>0.033</td><td>No_Trucks</td><td>0.0004</td><td>0.0001</td><td>0</td></tr>
<tr><td>No_Trucks</td><td>0.0003</td><td>0</td><td>0</td><td rowspan="2">Constant</td><td rowspan="2">0.5338</td><td rowspan="2">2.0328</td><td rowspan="2">0.793</td></tr>
<tr><td>Constant</td><td>2.588</td><td>1.2097</td><td>0.034</td></tr>
<tr><td>Equipment</td><td></td><td></td><td></td><td>Stockpile</td><td></td><td></td><td></td></tr>
<tr><td>Age</td><td>0.034</td><td>0.0118</td><td>0.004</td><td>Age</td><td>0.0346</td><td>0.06</td><td>0.038</td></tr>
<tr><td>Pavement</td><td>0.9804</td><td>0.184</td><td>0</td><td>Elevation</td><td>-0.0032</td><td>0.001</td><td>0.002</td></tr>
<tr><td>Elevation</td><td>-0.0007</td><td>0.0002</td><td>0</td><td>ESAL</td><td>0.0011</td><td>0.0005</td><td>0.029</td></tr>
<tr><td>Weather</td><td>1.5099</td><td>0.2994</td><td>0</td><td rowspan="3">Constant</td><td rowspan="3">8.286</td><td rowspan="3">1.9444</td><td rowspan="3">0</td></tr>
<tr><td>No_Trucks</td><td>0.0004</td><td>0.0001</td><td>0</td></tr>
<tr><td>Constant</td><td>1.52</td><td>1.4733</td><td>0.303</td></tr>
</table>

The variable is negative indicating the labor is cheaper in urban areas than in rural. It might be caused by shorter laborer travel time or distance to the work area. Length is another variable shown in total hour's component. Since the length is negative it designates less roadway needs maintenance.

Figure 5.1.2 illustrates routine maintenance cost with an average elevation of 2,405 feet and an average AADT of 26,708 has been grown with time. This indicates the maintenance cost gets more expensive every year. The cost for the first year is $4507 and for the last year is $4573, resulting in total difference of $66.

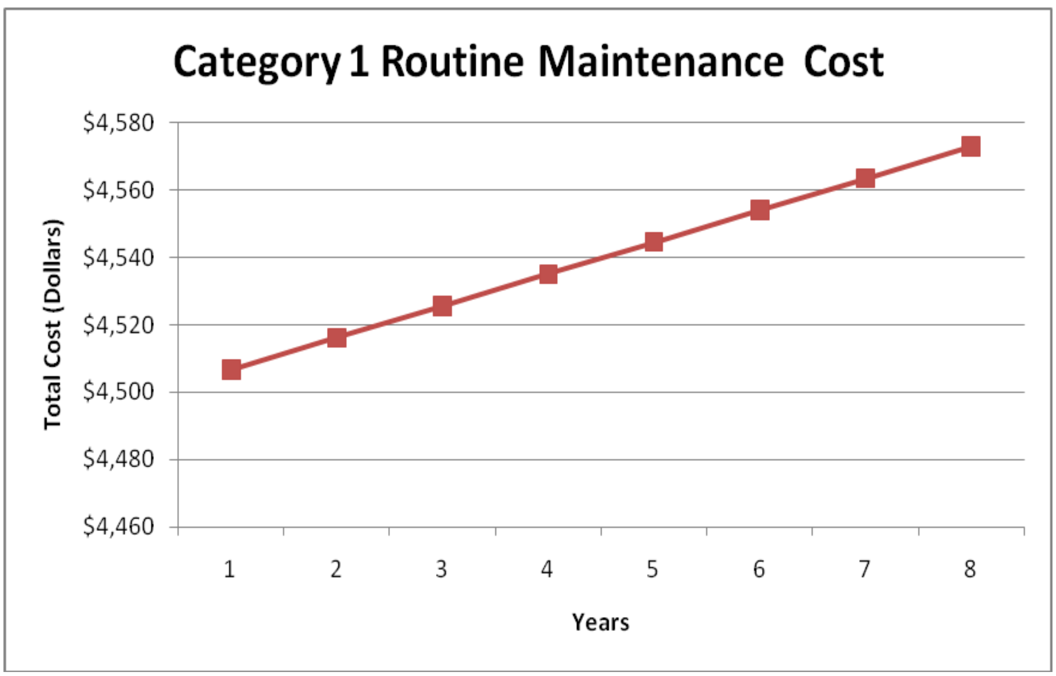


Figure 5.1.2 Total Routine Maintenance Costs for Category 1 Roads.

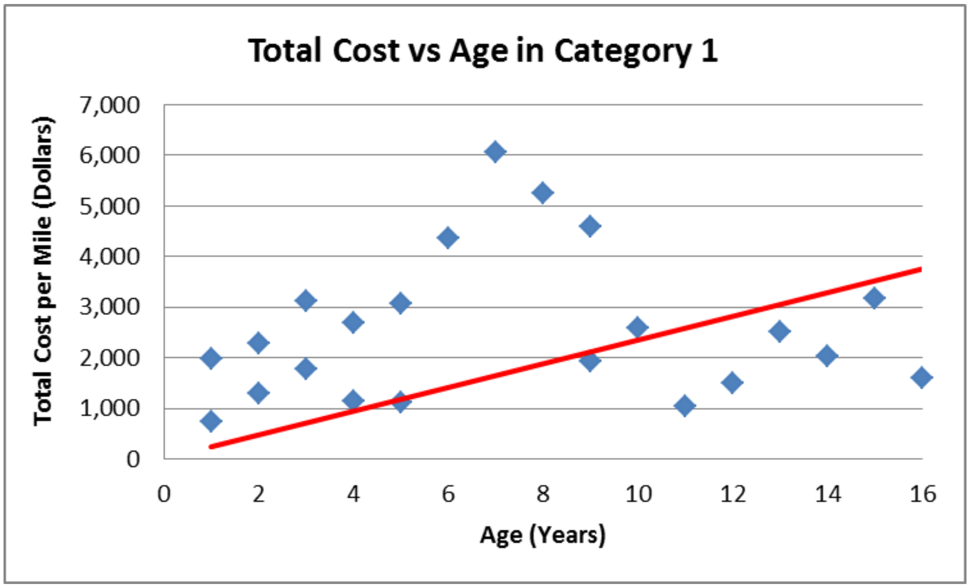


Figure 5.1.3 Total Routine Maintenance Costs vs Age - Category 1.

5.2 Routine Maintenance Cost for Roads in Priority Category 2

Prioritization Category 2 routine maintenance costs were analyzed based on the 10 year pavement life-cycle using linear regression models. The results of the models are listed in Table 5.2 and 5.2A (Appendix) and are shown at the end of this section. Figure 5.2.1 illustrates life cycle for priority Category 2 roads that was developed based on the data collected from NDOT's management system.

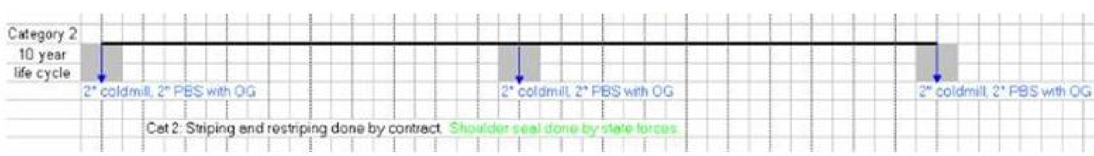


Figure 5.2.1 Life Cycle for Priority Category 2 Roads.

From Table 5.2 it can be seen that the total maintenance cost changed with time each year. The coefficient of the age is negative indicating that the cost of the maintenance decreases every year. Based on the results, the routine maintenance cost is the most expensive the first year the treatment is applied and each year after less treatment is needed. The coefficient of length is also negative, suggesting that some part of the roads require less or no maintenance. Some parts of the road might have not been affected by other factors, for instance weathering or traffic volume, which would leave the road in good condition. The road would not get deteriorated and would require less or no maintenance. The samples collected for Category 2 were from areas across the State of Nevada, unlike the case for Category 1, where the samples were taken from Clark County only. District was the only one positive variable concluding that the maintenance cost varied among the three districts in the state of Nevada.

The cost variation is reasonable since different districts may adopt different maintenance practices in terms of materials and equipment used in their districts. These observations also can be found in other maintenance cost components, including labor cost, stockpile cost, equipment cost, and materials cost. Length is the most significant variable shown in all cost components.

Table 5.2 Regression Models for Roads in Priority Category 2.

Total Cost	Coefficient	Standard Error	Significance P>|t|
Length	-0.0585	0.0180	0.002
District 1	0.7573	0.1856	0.000
Age	0.0448	0.0190	0.021
Constant	6.9242	0.3447	0.000
Labor Cost			
Length	-0.1063	0.0278	0.000
District 1	-2.2368	0.6558	0.001
Elevation	0.0012	0.0003	0.000
Lanes	-0.4190	0.1893	0.029
Constant	7.4234	0.7876	0.000
Equipment			
Last Year	-0.7672	0.2057	0.000
Length	-0.0956	0.0179	0.000
Elevation	0.0003	0.0001	0.000
Urban	-0.6520	0.1543	0.000
Constant	5.5586	0.3350	0.000
Total Hours	Coefficient	Standard Error	Significance P>|t|
Length	-0.0719	0.0142	0.000
District 1	-1.9400	0.6555	0.004
Elevation	0.0013	0.0003	0.000
Constant	2.5483	0.2756	0.000
Materials			
Last Year	-0.7672	0.2057	0.000
Length	-0.0956	0.0179	0.000
Elevation	0.0003	0.0001	0.000
Urban	-0.6520	0.1543	0.000
Constant	5.5586	0.3350	0.000
Stockpile			
Age	0.6033	0.1050	0.000
Length	0.2293	0.0351	0.000
Elevation	0.0062	0.0010	0.000
ESAL	0.0023	0.0007	0.006
Constant	-31.0700	5.3204	0.000

The coefficient of length is negative; however, in stockpile the length is positive. It is caused by the longer distance to deliver the materials to the maintenance work site. Elevation factor is contained within labor, equipment, total hours, materials, and stockpile components affecting maintenance cost. The variable is positive meaning in higher elevations maintenance cost get more expensive. Similar to Category 1, ESAL is the only variable incorporated in stockpile cost.

Materials and equipment costs have rural or urban variables included. The variable is negative indicating the urban areas are cheaper than rural. Variable age is significant only to total cost and stockpile. The coefficient of the age is positive in stockpile indicating that the cost of the maintenance increases every year.

Figure 5.2.2 below illustrates that the routine maintenance cost with an average elevation of 3,987 feet and an average AADT of 11,787, has grown with time, thus indicating that the maintenance cost gets more expensive every year. The cost for the first year is $1,020 and for the last year is $1,082, resulting in total difference of $62; therefore, the difference in price between first and last year is also minuscule. Those results are based on the average elevation and average AADT. Comparing with the numbers in Figure 5.1.2, the difference between Category 1 and Category 2 in total maintenance cost is quite visible resulting in total amount of $ 3,553 for the first year and $3,425 for the last year.

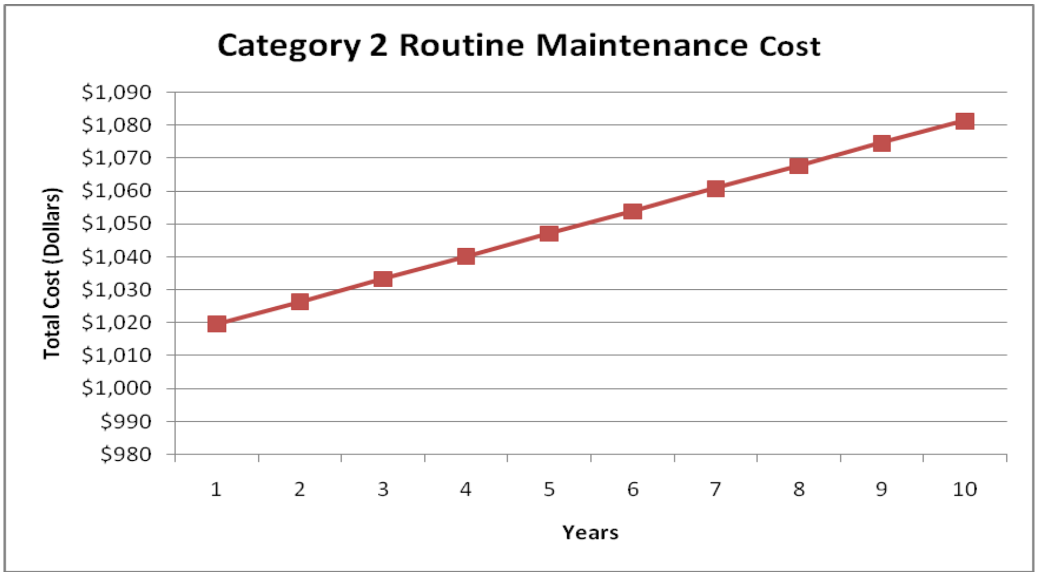


Figure 5.2.2 Total Routine Maintenance Costs for Category 2 Roads.

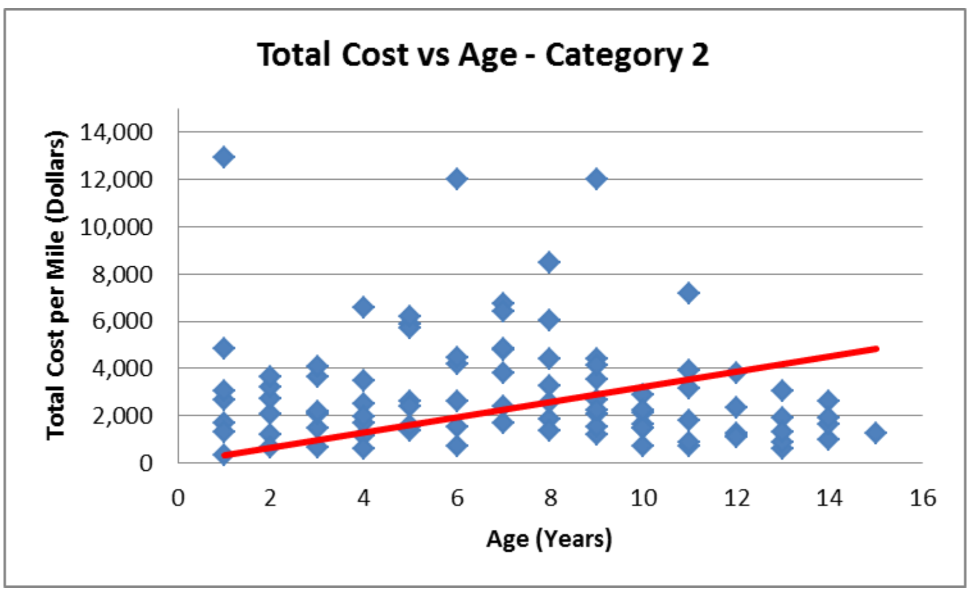


Figure 5.2.3 Total Routine Maintenance Costs vs Age - Category 2.

5.3 Routine Maintenance Cost for Roads in Priority Category 3

Prioritization Category 3 routine maintenance costs were analyzed based on the 12 year pavement life-cycle using linear regression models. The results of the models are listed in Tables 5.3.1, 5.3.2, 5.3.3 and in Tables 5.3.1A, 5.3.2A, 5.3.3A (Appendix). The comparison of the models is shown at the end of this section. Figure 5.3.1 illustrates life cycle for priority Category 3 roads that was developed based on the data collected from NDOT's management system.

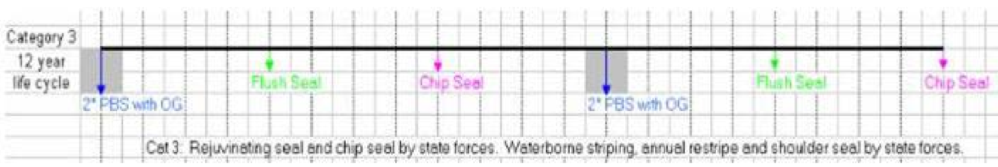


Figure 5.3.1 Life Cycle for Roads in Priority Category 3.

After Construction

The variables that become significant in the “After Construction” segment are last year, elevation, and number of trucks. All the factors have the same coefficients signs except the last year variable. It implies the last year maintenance was cheaper because some routine maintenance activities were saved considering that flush seal is applied in the last year. This result can be found in other maintenance cost components as well.

Table 5.3.1 Regression Models for Roads in Priority Category 3: After Construction.

After Construction			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Last_Year	-0.5555	0.1793	0.003
Elevation	0.0003	0.0001	0.001
No_Trucks	0.0076	0.0019	0.000
Constant	6.2757	0.4458	0.000
LABOR COST			
Last Year	-0.5652	0.1735	0.002
Temperature	0.3704	0.1386	0.009
No_Trucks	0.0065	0.0017	0.000
Constant	6.5539	0.2332	0.000
EQUIPMENT			
Last_Year	-0.6686	0.2045	0.002
Elevation	0.0004	0.0001	0.000
No_Trucks	0.0060	0.0022	0.007
Constant	4.5657	0.5083	0.000
MANPOWER	Coefficient	Standard Error	Significance P>|t|
Last_Year	-0.3679	0.1817	0.046
No_Trucks	0.0175	0.0033	0.000
ESAL	-0.0133	0.0025	0.000
Constant	3.0376	0.1766	0.000
MATERIALS			
Age	0.1191	0.0617	0.057
Last_Year	-0.9186	0.2709	0.001
Elevation	0.0004	0.0001	0.002
ESAL	0.0113	0.0029	0.000
Constant	4.0593	0.7043	0.000
STOCKPILE			
Last_Year	0.6194	0.2179	0.006
Elevation	0.0003	0.0001	0.014
AADT	-0.0012	0.0003	0.000
No_Trucks	0.0334	0.0071	0.000
ESAL	-0.0210	0.0046	0.000
Constant	1.3865	0.6009	0.024

The labor cost has two variables; elevation and AADT in which AADT is more significant. On the other hand, the equipment model has three variables in which elevation is the most significant and number of trucks is the least. The total hours model has two variables; elevation and AADT where AADT is more substantial than elevation likewise in the labor cost model. The materials model has four variables, where ESAL is the most noteworthy and elevation is the least. The last model, stockpile has also four variables similarly to the model for materials. The least significant variable is elevation and the most significant is ESAL.

After Flush

Table 5.3.2 presents results for the life cycle segment 'After Flush', which ends at a reconstruction. The coefficient of the age is not significant and thus not included in the model implying the maintenance cost stays constant through its life cycle. The district variable was positive indicating that the maintenance cost varied among the three districts in the State of Nevada. The cost variation can be visible since different districts may adopt different maintenance practices in terms of the materials and equipment used in their districts. The length factor is significant implying maintenance cost for a highway segment depends on the length of the roadway segment, i.e., the longer a pavement section is the higher the cost is. Similar observations can be found in other maintenance cost components, including labor cost, stockpile cost, total hours, equipment cost, and materials cost.

Table 5.3.2 Regression Models for Roads in Priority Category 3: After Flush.

After Flush Seal			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Length	-0.0486	0.0140	0.001
District	0.5031	0.1901	0.010
Constant	6.7900	0.4149	0.000
LABOR COST			
No_Trucks	0.0042	0.0021	0.044
Constant	6.9235	0.2214	0.000
EQUIPMENT			
District	0.4747	0.2037	0.023
Constant	5.6020	0.4707	0.000
MANPOWER			
No_Trucks	0.0188	0.0044	0.000
ESAL	-0.0141	0.0031	0.000
Constant	3.0110	0.1978	0.000
MATERIALS			
Elevation	0.0004	0.0001	0.008
Temperature	-0.6368	0.2045	0.003
No_Trucks	0.0065	0.0027	0.019
Constant	4.8079	0.6914	0.000
STOCKPILE			
Age	0.0420	0.0307	0.176
Elevation	-0.0001	0.0001	0.163
Constant	0.3069	0.2695	0.259

The labor cost model has only one influential factor, i.e., number of trucks. The equipment model has also only one variable district. The total hours model has two equally significant variables; number of trucks and ESAL. The materials model has variable trucks and temperature significant. The stockpile model has two variables age and elevation significant.

After Chip Seal

The regression model for ‘After Chip Seal’ (see Table 5.3.3) indicate that the coefficient for the last year maintenance activities is positive, implying that last year maintenance was more expensive than the previous years in this life cycle stage. Elevation is another factor that contributes to total routine maintenance cost significantly. Its coefficient is for elevation is positive, implying that the roads at higher elevations may have more impact of extreme weather as well as have other road features that need additional maintenance. As stated earlier, maintenance activities differ with the conditions of infrastructure that depends on the amount of the daily traffic passing through. Higher number of trucks has superior impact on roads, leading to pavement deterioration and greater need for maintenance. These observations also can be found in other maintenance cost components, including labor cost, stockpile cost, equipment cost, and materials cost.

The labor cost model has two significant variables: last year and number of trucks. The equipment model has two variables significant: number of trucks and elevation. The total hours model has three significant factors: last year, number of trucks, and ESAL. Materials and stockpile models have four factors significant: last year, elevation, ESAL, and number of truck.

Table 5.3.3 Regression Models for Roads in Priority Category 3: After Chip Seal.

After Chip Seal			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Last_Year	0.1441	0.0870	0.117
Elevation	0.0004	0.0002	0.042
No_Trucks	0.0102	0.0035	0.010
Constant	4.4756	1.1585	0.001
LABOR COST			
Elevation	0.0002	0.0002	0.211
AADT	0.0006	0.0002	0.008
Constant	4.6850	0.8629	0.000
EQUIPMENT			
Elevation	0.0004	0.0002	0.026
No_Trucks	0.0079	0.0004	0.048
Constant	3.6865	0.9926	0.002
MANPOWER			
Elevation	0.0003	0.0002	0.100
AADT	0.0006	0.0002	0.012
Constant	0.8442	0.9890	0.405
MATERIALS			
Last_Year	0.3469	0.1424	0.027
Elevation	0.0008	0.0003	0.028
ESAL	0.0216	0.0070	0.007
Constant	0.3680	1.9973	0.856
STOCKPILE			
Elevation	-0.0009	0.0004	0.040
No_Trucks	0.0417	0.0127	0.005
ESAL	-0.0535	0.0156	0.003
Constant	2.62967	1.9041	0.186

Based on Table 5.3.4, the After Construction stage has the most number of variables influencing the cost model. The variable that influences many cost components is last year. It means that maintenance cost in the last year is significantly different from other years in their life cycle. Other variables such as number of trucks, elevation, and ESAL are also significant in many cost components.

Table 5.3.4 Routine Maintenance Treatment Stages in Category 3.

After Construction			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Last_Year	-0.5555	0.1793	0.003
Elevation	0.0003	0.0001	0.001
No_Trucks	0.0076	0.0019	0.000
Constant	6.2757	0.4458	0.000
LABOR COST			
Last Year	-0.5652	0.1735	0.002
Temperature	0.3704	0.1386	0.009
No_Trucks	0.0065	0.0017	0.000
Constant	6.5539	0.2332	0.000
EQUIPMENT			
Last_Year	-0.6686	0.2045	0.002
Elevation	0.0004	0.0001	0.000
No_Trucks	0.0060	0.0022	0.007
Constant	4.5657	0.5083	0.000
MANPOWER			
Last_Year	-0.3679	0.1817	0.046
No_Trucks	0.0175	0.0033	0.000
ESAL	-0.0133	0.0025	0.000
Constant	3.0376	0.1766	0.000
MATERIALS			
Age	0.1191	0.0617	0.057
Last_Year	-0.9186	0.2709	0.001
Elevation	0.0004	0.0001	0.002
ESAL	0.0113	0.0029	0.000
Constant	4.0593	0.7043	0.000
STOCKPILE			
Last_Year	0.6194	0.2179	0.006
Elevation	-0.0003	0.0001	0.014
AADT	-0.0012	0.0003	0.000
No_Trucks	0.0334	0.0071	0.000
ESAL	-0.0210	0.0046	0.000
Constant	1.3865	0.6009	0.024

After Flush Seal			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Length	-0.0486	0.0140	0.001
District	0.5031	0.1901	0.010
Constant	6.7900	0.4149	0.000
LABOR COST			
No_Trucks	0.0042	0.0021	0.044
Constant	6.9235	0.2214	0.000
EQUIPMENT			
District	0.4747	0.2037	0.023
Constant	5.6020	0.4707	0.000
MANPOWER			
No_Trucks	0.0188	0.0044	0.000
ESAL	-0.0141	0.0031	0.000
Constant	3.0110	0.1978	0.000
MATERIALS			
Elevation	0.0004	0.0001	0.008
Temperature	-0.6368	0.2045	0.003
No_Trucks	0.0065	0.0027	0.019
Constant	4.8079	0.6914	0.000
STOCKPILE			
Age	0.0420	0.0307	0.176
Elevation	-0.0001	0.0001	0.163
Constant	0.3069	0.2695	0.259

After Chip Seal			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Last_Year	0.1441	0.0870	0.117
Elevation	0.0004	0.0002	0.042
No_Trucks	0.0102	0.0035	0.010
Constant	4.4756	1.1585	0.001
LABOR COST			
Elevation	0.0002	0.0002	0.211
AADT	0.0006	0.0002	0.008
Constant	4.6850	0.8629	0.000
EQUIPMENT			
Elevation	0.0004	0.0002	0.026
No_Trucks	0.0079	0.0004	0.048
Constant	3.6865	0.9926	0.002
MANPOWER			
Elevation	0.0003	0.0002	0.100
AADT	0.0006	0.0002	0.012
Constant	0.8442	0.9890	0.405
MATERIALS			
Last_Year	0.3469	0.1424	0.027
Elevation	0.0008	0.0003	0.028
ESAL	0.0216	0.0070	0.007
Constant	0.3680	1.9973	0.856
STOCKPILE			
Elevation	-0.0009	0.0004	0.040
No_Trucks	0.0417	0.0127	0.005
ESAL	-0.0535	0.0156	0.003
Constant	2.62967	1.9041	0.186

The temperature variable is significant only in the labor cost component in the After Construction stage. It means that weather influences the cost of maintenance work. For instance, cold causes more road deterioration and needs more routine maintenance such as snow removal and picking up tree leaves. Rainy weather needs more checks on drainage which may need minor clearance. The AADT variable is significant only in stockpile cost component. Since the variable is negative, the cost components in the After Flush stage have more significant variables, in which number of trucks is the most common factor.

This factor is positive indicating higher number of trucks has superior impact on roads leading to pavement deterioration and greater need for maintenance. Elevation is an influencing factor in most of the cost components as well. Among all the cost components, only total cost is relevant to the length, which implies that there are cost items applicable to length that cannot be taken account in the cost components, but would be significant when all the cost components are counted together. For example, supervisors need to inspect highway regularly, the cost of which may not be significant to each cost component including labor. In After Chip stage, the most common variable is elevation. Other factors influencing the costs in the After Chip stage are AADT, ESAL, and number of trucks.

Figure 5.3.2 represents three different routine maintenance segments. Each segment is displayed versus time defined in years. Each life cycle segment starts at the next year with new major routine maintenance activities.

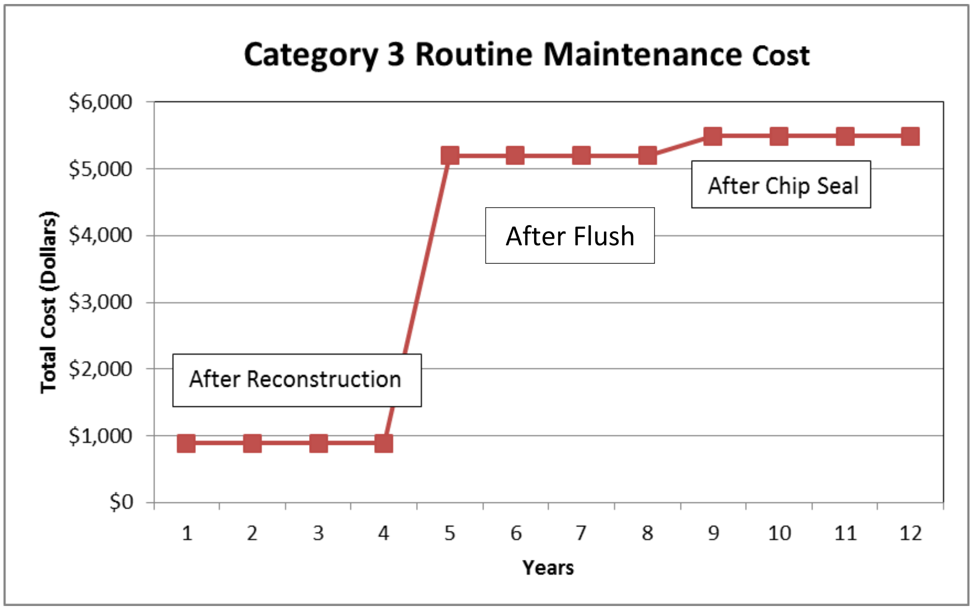


Figure 5.3.2 Total Maintenance Costs for a 12-Year Life Cycle for Category 3 Roads.

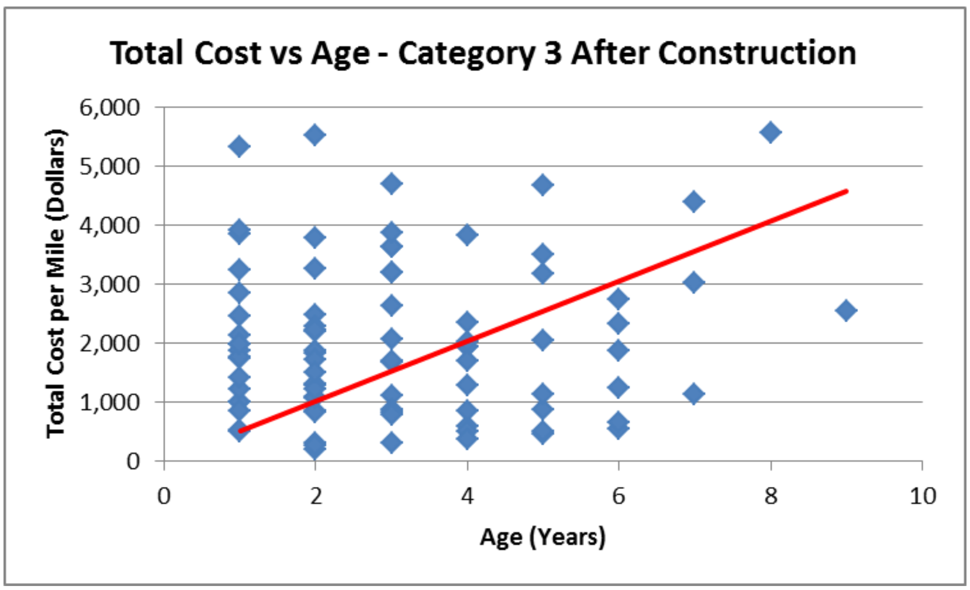


Figure 5.3.3 Total Routine Maintenance Costs vs Age - Category 3 After Construction.

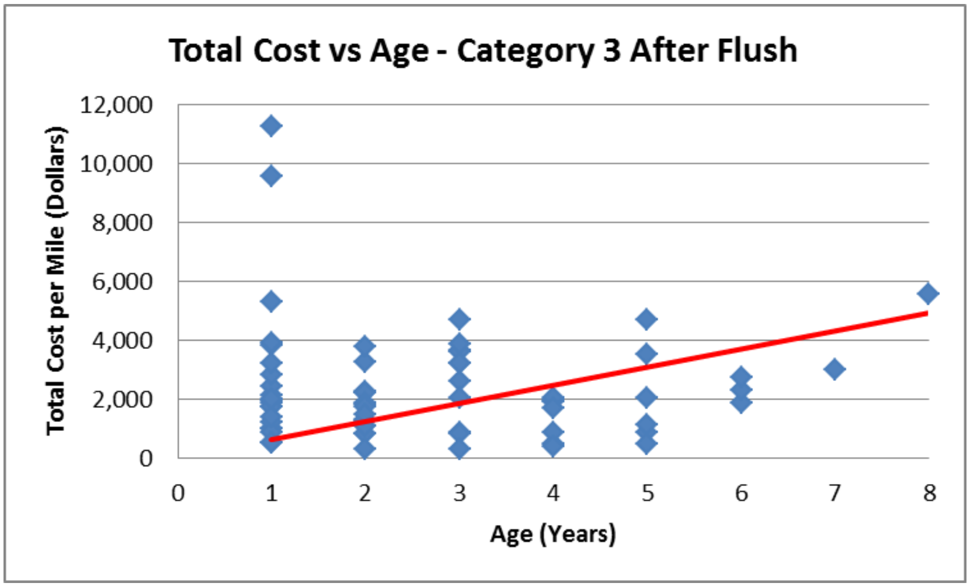


Figure 5.3.4 Total Routine Maintenance Costs vs Age - Category 3 After Flush.

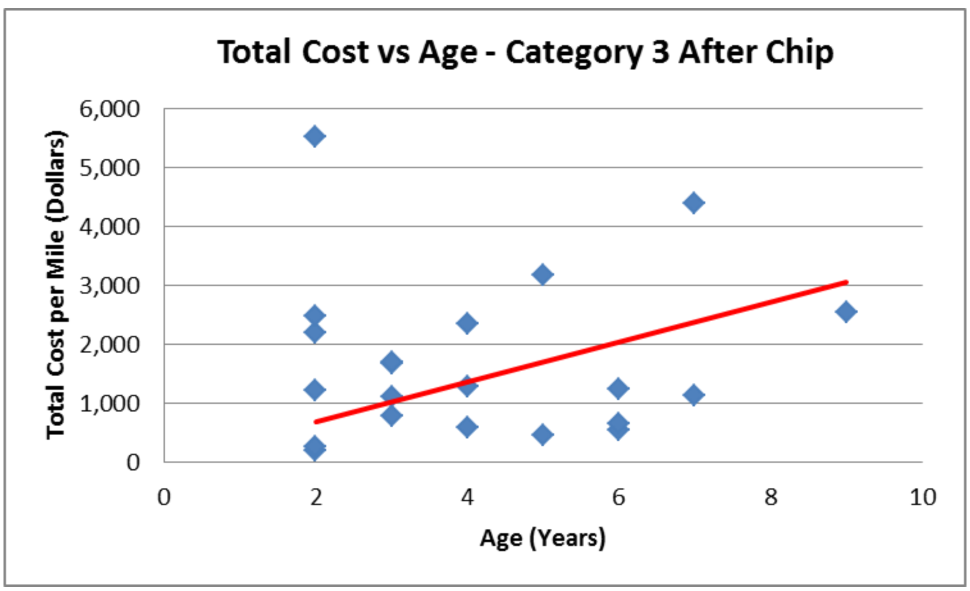


Figure 5.3.5 Total Routine Maintenance Costs vs Age - Category 3 After Chip.

5.4 Routine Maintenance Cost for Roads in Priority Category 4

Routine maintenance cost for the roads in Category 4 was analyzed based on the 15-year pavement life-cycle (see Figure 5.4.1). Four linear regression models were developed, one for each life cycle segment: after construction, after flush, after chip1, and after chip2. Each life cycle segment starts at the next year with new major routine maintenance activities and ends when these activities are completed. The results of the models are listed in Tables 5.4.1, 5.4.2, 5.4.3, 5.4.4 and in Tables 5.4.1A, 5.4.2A, 5.4.3A , 5.4.4A (Appendix). The comparison of the models is shown at the end of this section.

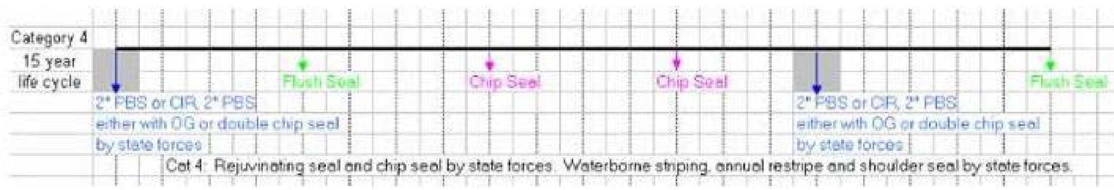


Figure 5.4.1 Life Cycles for Roads in Priority Category 4.

After Construction

The variables that are significant in the “After Construction” stage are: last year, average daily traffic and ESAL (see Table 5.4.1). The ESAL variable is negative indicating that less damage is done during this life cycle stage, leading to lower cost of highway maintenance. This result is counterintuitive and warrants further investigation. Labor cost model has five significant variables. The equipment model has the same number of noteworthy variables as the model for labor. The total hours model also has five significant variables. The materials model has three significant variables. The model for stockpile has eight important variables.

Table 5.4.1 Regression Models for Roads in Priority Category 4: After Construction

After Construction							
Total Cost	Coefficient	Standard Error	Significance P>|t|	Total Hours	Coefficient	Standard Error	Significance P>|t|
Last_Year	0.8256	0.1544	0	Last_Year	0.8321	0.1537	0
AADT	0.001	0.0003	0	Elevation	0.0003	0.0001	0.001
ESAL	-0.0097	0.0027	0.001	No_Trucks	0.0337	0.0109	0.003
				ESAL	-0.0248	0.0072	0.001
Constant	7.0117	0.1372	0	District	0.4782	0.1378	0.001
				Constant	1.146	0.4962	0.023
Labor Cost				Materials			
Last_Year	0.7104	0.1543	0	Last_Year	1.1599	0.1531	0
Elevation	0.0003	0.0001	0.001	District	0.3247	0.0967	0.001
No_Trucks	0.027	0.011	0.016	AADT	0.0009	0.0003	0.001
ESAL	-0.0212	0.0072	0.004				
District	0.4607	0.1384	0.001	Constant	4.7646	0.2352	0
Constant	4.6225	0.4983	0				
Equipment				Stockpile			
Last_Year	0.5561	0.2076	0.009	Age	1.1901	0.1312	0.003
Elevation	0.0003	0.0001	0.003	Last_Year	-1.245	0.2303	0.012
No_Trucks	0.0344	0.0148	0.022	Length	1.5816	0.1797	0.003
ESAL	-0.0248	0.0097	0.013	Elevation	0.0147	0.0016	0.003
District	0.3766	0.1861	0.046	Temperature	-4.888	0.908	0.013
				No_Trucks	0.1724	0.0502	0.041
Constant	3.78	0.6703	0	ESAL	-0.0679	0.0199	0.042
				District	26.4982	3.5326	0.005
				Constant	41.2227	4.1073	0.002

After Flush

In the After Flush stage, the variable age is significant for the total cost and it is negative, which implies that maintenance cost declined each year. The variable last year is positive implying that more expenditure was incurred in the last year, the year before flush seal. Elevation is another factor that is significant for the total routine maintenance cost. Its coefficient is positive suggesting that given that roads at higher elevations have more chance of extreme weather as well as having other road features that need more maintenance.

The District variable was negative implying that the maintenance cost District 1 has the lowest routine maintenance cost every year among the three districts in the State of Nevada.

Table 5.4.2 Regression Models for Roads in Priority Category 4: After Flush.

Total Cost	Coefficient	Standard Error	Significance P>|t|	Total Hour	Coefficient	Standard Error	Significance P>|t|
Age	-0.23647	0.06499	0.001	Last_Year	1.3774	0.1611	0
Last_Year	2.1447	0.2024	0	Length	-0.046	0.0162	0.006
District 1	-0.3911	0.1006	0	District 1	-0.3706	0.1	0
Elevation	0.0004	0.0001	0.003	Elevation	0.0005	0.0001	0
Temperatur	-0.4724	0.1348	0.001	Temperatur	-0.6164	0.1294	0
Constant	7.6815	0.7692	0	Constant	2.6661	0.5811	0
Labor Cost				Materials			
Age	-0.156	0.0633	0.016	Age	-0.3098	0.1017	0.003
Last_Year	1.542	0.1971	0	Last_Year	3.1022	0.3406	0
Length	-0.0401	0.0161	0.015	District 1	-0.4882	0.1689	0.005
District 1	-0.3619	0.0998	0.001	Temperatur	-0.3597	0.1769	0.046
Elevation	0.0005	0.0001	0				
Temperatur	-0.4786	0.1379	0.001	Constant	8.1076	0.6315	0
Constant	6.3688	0.7483	0				
Labor Cost				Materials			
Age	-0.2949	0.0762	0	Age	0.8153	0.1483	0
Last_Year	1.6951	0.252	0	District 1	1.8223	0.298	0
District 1	-0.7111	0.1372	0	Temperatur	-0.8932	0.2696	0.006
Elevation	0.0006	0.0002	0				
Temperatur	-0.7376	0.1634	0				
No_Trucks	-0.0207	0.0073	0.006	Constant	-1.4572	0.9774	0.16
ESAL	0.0138	0.0064	0.034				
Constant	6.4783	1.0069	0				

The coefficient for temperature is negative suggesting that lower temperature areas require more maintenance due to weather such as snow removal. Similar observations also can be found in maintenance cost components, including labor cost, stockpile cost, equipment cost, and manpower cost, which can be found in Table 5.4.2.

<u>After Chip1</u>

In the second segment in Category 4, the variable age is statistically significant (see Table 5.4.3) which indicates maintenance cost rises each year. Even though this variable is statistically significant, the absolute value of this coefficient is very small; resulting in total difference in cost that is minor. The ESAL variable is negative indicating that less damage is done to pavement with higher ESAL, which is counterintuitive. More investigation should be conducted based on this observation.

The Labor cost model has three significant variables. The equipment model has three significant variables as well: age, number of trucks and ESAL. The Total hours model has only two significant variables: age and elevation. The materials model has only one factor temperature. The last model stockpile, has number trucks and ESAL significant.

Table 5.4.3 Regression Models for Roads in Priority Category 4: After Chip 1.

After Chip 1			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Age	0.098469	0.04507	0.032
ESAL	-0.0211	0.0055	0.000
Constant	7.4097	0.2376	0.000
LABOR COST			
Age	0.1613	0.0444	0.000
No_Trucks	0.0486	0.0155	0.002
ESAL	-0.0660	0.0152	0.000
Constant	6.3817	0.2283	0.000
EQUIPMENT			
Age	0.1677	0.0531	0.002
No_Trucks	0.0492	0.0185	0.009
ESAL	-0.0707	0.0182	0.000
Constant	5.9642	0.2729	0.000
TOTAL HOURS			
Elevation	0.0002	0.0001	0.007
Age	0.0960	0.0468	0.043
Constant	1.6877	0.3695	0.000
MATERIALS			
Temperature	-0.3907	0.1044	0.000
Constant	6.2028	0.2514	0.000
STOCKPILE			
No_Trucks	0.0514	0.0190	0.008
ESAL	-0.0379	0.0186	0.045
Constant	-0.1219	0.2457	0.621

After Chip2

The variables significant for the total cost in ‘After Chip 2’ stage are age and ESAL (see Table 5.4.4). The labor cost model has three variables significant: age, number of trucks and ESAL. The equipment model has three significant variables. The most essential factor is elevation and the least essential is district. The total hours model has two significant variables: elevation and age. The materials model has only one significant variable which is temperature. The stockpile model has two significant variables: number of truck and ESAL. From Table 5.4.4 and Table 5.4.5 it can be seen that the costs in the After Construction and After Chip 2 stages have the more influencing factors. The most repetitive factors are district, appearing in each of the cost components. Temperature is another variable that appeared in each cost component in the After Construction stage. It means that weather significantly influences routine maintenance work. The age factor appears in each cost component. Other variables such as number of trucks, elevation, and ESAL were noticed in many cost components. The After Flush stage has many influencing variables where district is the most common factor.

Length is another factor being repetitive in total cost, materials, and stockpile cost components. Equipment and stockpile costs are relevant to number of trucks. Since the variable is positive, it designates the higher number of trucks has more impact on roads leading to pavement deterioration and greater need for maintenance. Other variables such as elevation and ESAL were observed in several cost components. The After Chip 2 stage has the least number of variables influencing maintenance cost. Only age, ESAL, number of trucks, elevation, and temperature are observed in various cost components. The Materials cost component has only one significant variable temperature. Variable age appears in total cost, labor cost, equipment, and total hours. Since the age is positive it indicates every year the maintenance cost increases. Other factors influencing After Chip2 stage are: elevation, ESAL, and number of trucks.

Table 5.4.4 Regression Models for Roads in Priority Category 4: After Chip 2.

After Chip 2			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Age	0.098469	0.04507	0.032
ESAL	-0.0211	0.0055	0.000
Constant	7.4097	0.2376	0.000
LABOR COST			
Age	0.1613	0.0444	0.000
No_Trucks	0.0486	0.0155	0.002
ESAL	-0.0660	0.0152	0.000
Constant	6.3817	0.2283	0.000
EQUIPMENT			
Age	0.1677	0.0531	0.002
No_Trucks	0.0492	0.0185	0.009
ESAL	-0.0707	0.0182	0.000
Constant	5.9642	0.2729	0.000
TOTAL HOURS			
Elevation	0.0002	0.0001	0.007
Age	0.0960	0.0468	0.043
Constant	1.6877	0.3695	0.000
MATERIALS			
Temperature	-0.3907	0.1044	0.000
Constant	6.2028	0.2514	0.000
STOCKPILE			
No_Trucks	0.0514	0.0190	0.008
ESAL	-0.0379	0.0186	0.045
Constant	-0.1219	0.2457	0.621

Table 5.4.5 Routine Maintenance Treatment Stages in Category 4.

After Construction			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Age	-0.23647	0.06499	0.001
Last_Year	2.1447	0.2024	0.000
District	-0.3911	0.1006	0.000
Elevation	0.0004	0.0001	0.003
Temperature	-0.4724	0.1348	0.001
Constant	7.6815	0.7692	0.000
LABOR COST			
Age	-0.1560	0.0633	0.016
Last_Year	1.5420	0.1971	0.000
Length	-0.0401	0.0161	0.015
District	-0.3619	0.0998	0.001
Elevation	0.0005	0.0001	0.000
Temperature	-0.4786	0.1379	0.001
Constant	6.3688	0.7483	0.000
EQUIPMENT			
Age	-0.2949	0.0762	0.000
Last_Year	1.6951	0.2520	0.000
District	-0.7111	0.1372	0.000
Elevation	0.0006	0.0002	0.000
Temperature	-0.7376	0.1634	0.000
No_Trucks	-0.0207	0.0073	0.006
ESAL	0.0138	0.0064	0.034
Constant	6.4783	1.0069	0.000
TOTAL HOURS			
Last_Year	1.3774	0.1611	0.000
Length	-0.0460	0.0162	0.006
District	-0.3706	0.1000	0.000
Elevation	0.0005	0.0001	0.000
Temperature	-0.6164	0.1294	0.000
Constant	2.6661	0.5811	0.000
MATERIALS			
Age	-0.3098	0.1017	0.003
Last_Year	3.1022	0.3406	0.000
District	-0.4882	0.1689	0.005
Temperature	-0.3597	0.1769	0.046
Constant	8.1076	0.6315	0.000
STOCKPILE			
Age	0.8153	0.1483	0.000
District	1.8223	0.2980	0.000
Temperature	-0.8932	0.2696	0.006
Constant	-1.4572	0.9774	0.160

After Flush Seal			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Last_Year	1.8338	0.1875	0.000
Length	0.0439	0.0154	0.005
Elevation	0.0002	0.0001	0.003
Temperature	0.5283	0.2034	0.011
District	1.7216	0.4678	0.000
Constant	8.0617	0.4781	0.000
LABOR COST			
Last_Year	1.2480	0.1661	0.000
AADT	0.0012	0.0005	0.001
District	0.4187	0.1459	0.005
Constant	6.8440	0.2004	0.000
EQUIPMENT			
Last_Year	0.5562	0.2076	0.009
Elevation	0.0003	0.0001	0.003
No_Trucks	0.0344	0.0148	0.022
ESAL	-0.0248	0.0097	0.013
District	0.3766	0.1861	0.046
Constant	3.7800	0.6703	0.000
TOTAL HOURS			
Last_Year	1.3409	0.1673	0.000
District	-0.2350	0.1031	0.025
AADT	0.0011	0.0005	0.022
Perc_Trucks	0.0217	0.0066	0.001
Constant	4.0213	0.2776	0.000
MATERIALS			
Last_Year	2.4668	0.2847	0.000
Length	0.0475	0.0218	0.031
District	-0.6710	0.1884	0.001
Constant	6.2256	0.3159	0.000
STOCKPILE			
Age	0.2392	0.0784	0.003
Length	0.0785	0.0303	0.011
Elevation	0.0007	0.0001	0.000
Temperature	1.9384	0.4304	0.000
No_Trucks	0.0864	0.0214	0.000
ESAL	-0.0578	0.0169	0.001
District	-4.7463	0.9425	0.000
Constant	-4.5283	1.0998	0.000

After Chip 1			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Age	0.098469	0.04507	0.032
ESAL	-0.0211	0.0055	0.000
Constant	7.4097	0.2376	0.000
LABOR COST			
Age	0.1613	0.0444	0.000
No_Trucks	0.0486	0.0155	0.002
ESAL	-0.0660	0.0152	0.000
Constant	6.3817	0.2283	0.000
EQUIPMENT			
Age	0.1677	0.0531	0.002
No_Trucks	0.0492	0.0185	0.009
ESAL	-0.0707	0.0182	0.000
Constant	5.9642	0.2729	0.000
TOTAL HOURS			
Elevation	0.0002	0.0001	0.007
Age	0.0960	0.0468	0.043
Constant	1.6677	0.3695	0.000
MATERIALS			
Temperature	-0.3907	0.1044	0.000
Constant	6.2028	0.2514	0.000
STOCKPILE			
No_Trucks	0.0514	0.0190	0.008
ESAL	-0.0379	0.0186	0.045
Constant	-0.1219	0.2457	0.621

After Chip 2			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Last_Year	0.8256	0.1544	0.000
AADT	0.0010	0.0003	0.000
ESAL	-0.0097	0.0027	0.001
Constant	7.0117	0.1372	0.000
LABOR COST			
Last_Year	0.7104	0.1543	0.000
Elevation	0.0003	0.0001	0.001
No_Trucks	0.0270	0.0110	0.016
ESAL	-0.0212	0.0072	0.004
District	0.4607	0.1384	0.001
Constant	4.6225	0.4983	0.000
EQUIPMENT			
Last_Year	0.5561	0.2076	0.009
Elevation	0.0003	0.0001	0.003
No_Trucks	0.0344	0.0148	0.022
ESAL	-0.0248	0.0097	0.013
District	0.3766	0.1861	0.046
Constant	3.7800	0.6703	0.000
TOTAL HOURS			
Last_Year	0.8321	0.1537	0.000
Elevation	0.0003	0.0001	0.001
No_Trucks	0.0337	0.0109	0.003
ESAL	-0.0248	0.0072	0.001
District	0.4782	0.1378	0.001
Constant	1.1460	0.4962	0.023
MATERIALS			
Last_Year	1.1599	0.1531	0.000
District	0.3247	0.0967	0.001
AADT	0.0009	0.0003	0.001
Constant	4.7646	0.2352	0.000
STOCKPILE			
Age	1.1901	0.1312	0.003
Last_Year	-1.2450	0.2303	0.012
Length	1.5816	0.1797	0.003
Elevation	-0.0147	0.0016	0.003
Temperature	-4.8880	0.9080	0.013
No_Trucks	0.1724	0.0502	0.041
ESAL	-0.0679	0.0199	0.042
District	26.4982	3.5326	0.005
Constant	41.2227	4.1073	0.002

The last stage in Category 4 After Chip2 has the variable last year in each of the cost components. Elevation is a common variable observed in all components besides total cost and materials. ESAL is a common variable observed in all cost components besides materials cost. AADT can be found only in total cost and materials cost components. Since the variable is positive, it means more traffic occurs on certain segments of the road leading to more deterioration of the road, thus more maintenance is needed. Stockpile components have many variables: age, last year, length, elevation, temperature, number of trucks, ESAL, and district. The summary of all stages is presented in the Table 5.4.5. The Figure 5.4.2 represents cost for four treatment stages. From the graph After Flush is the most expensive treatment stage and after construction is the least costly. After Chip 2 stage is more costly to perform than After Chip1 and After Construction stages.

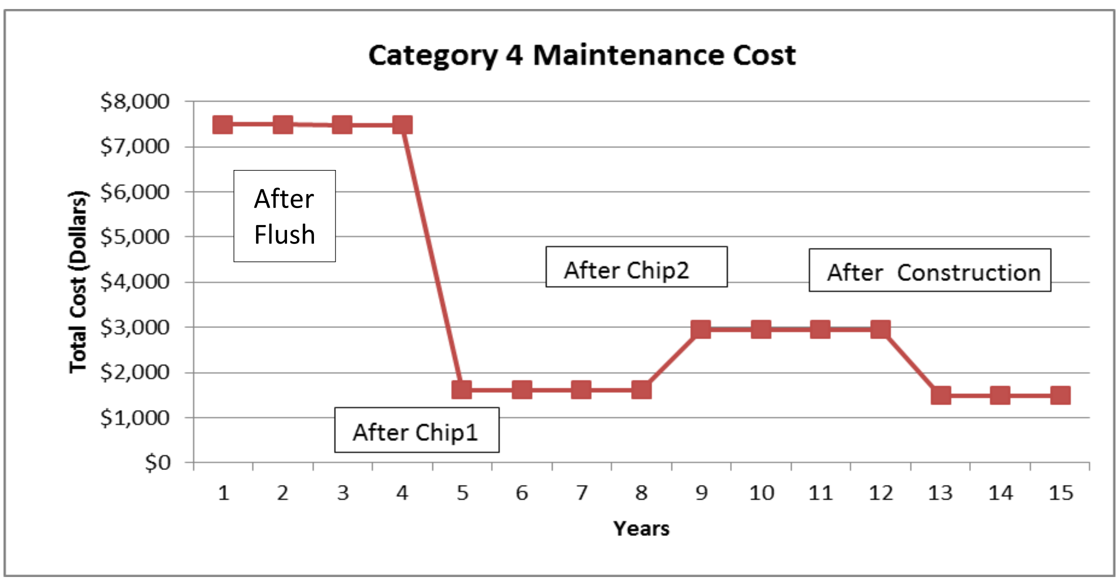


Figure 5.4.2 Total Maintenance Costs for a 15 Year Life Cycle for Category 4 Roads.

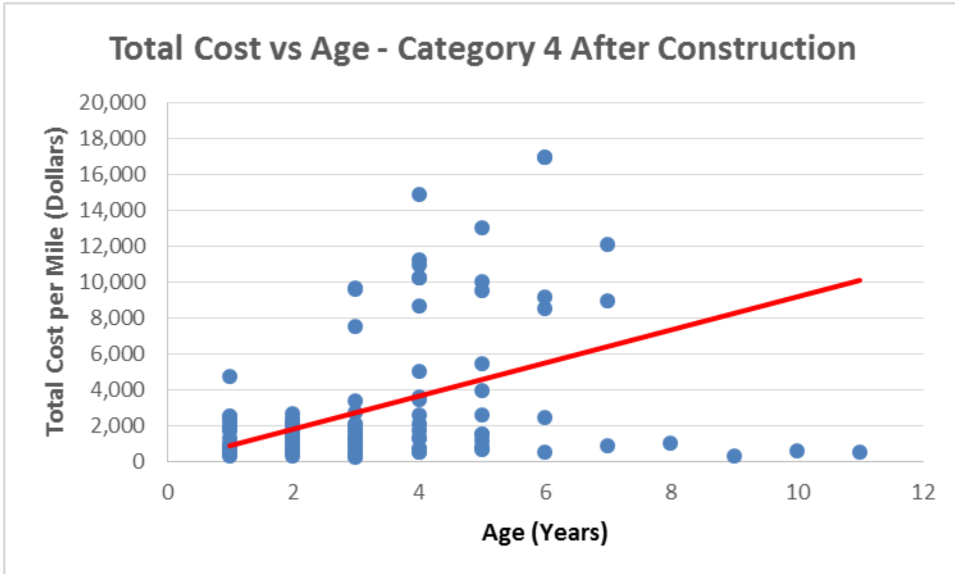


Figure 5.4.3 Total Routine Maintenance Costs vs Age - Category 4 After Construction.

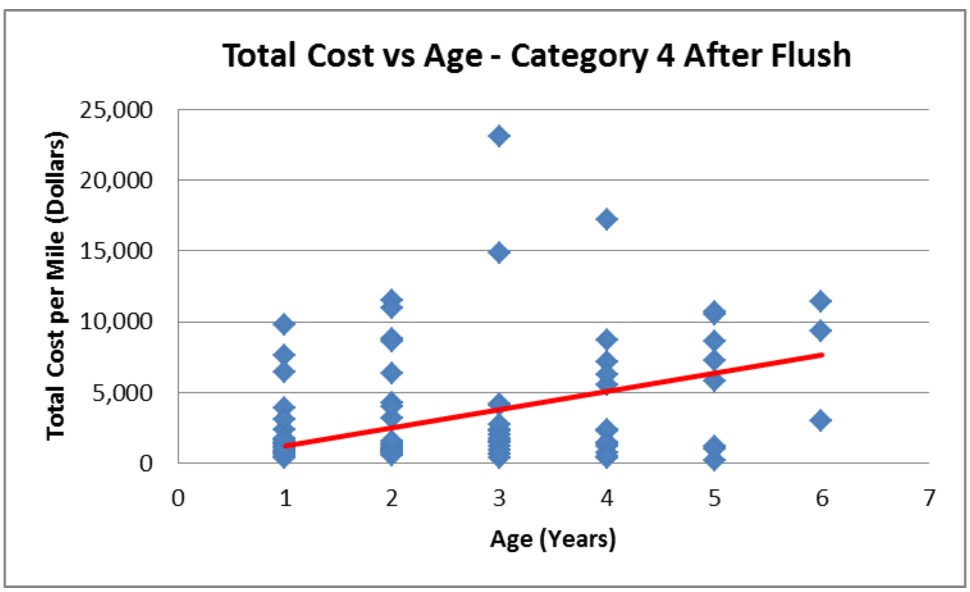


Figure 5.4.4 Total Routine Maintenance Costs vs Age - Category 4 After Flush.

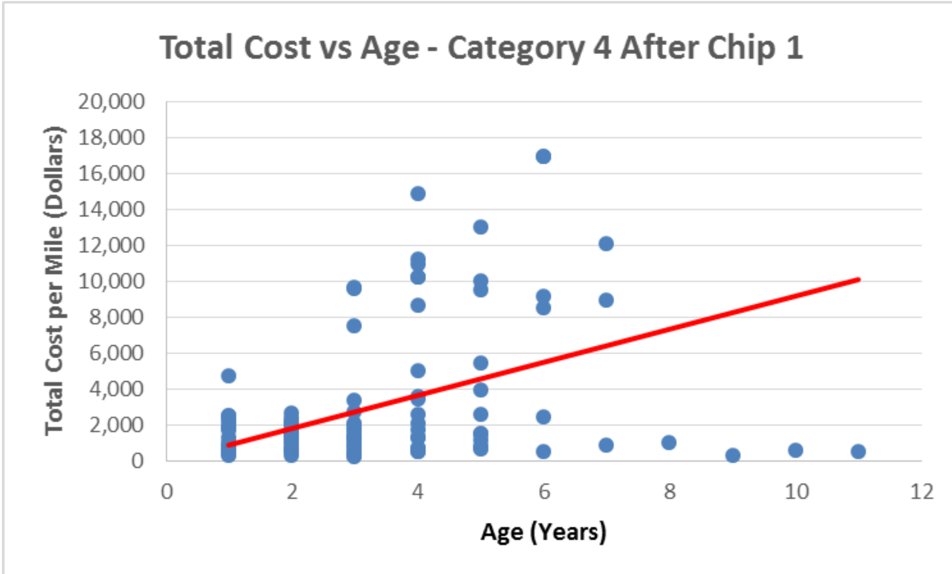


Figure 5.4.5 Total Routine Maintenance Costs vs Age - Category 4 After Chip 1.

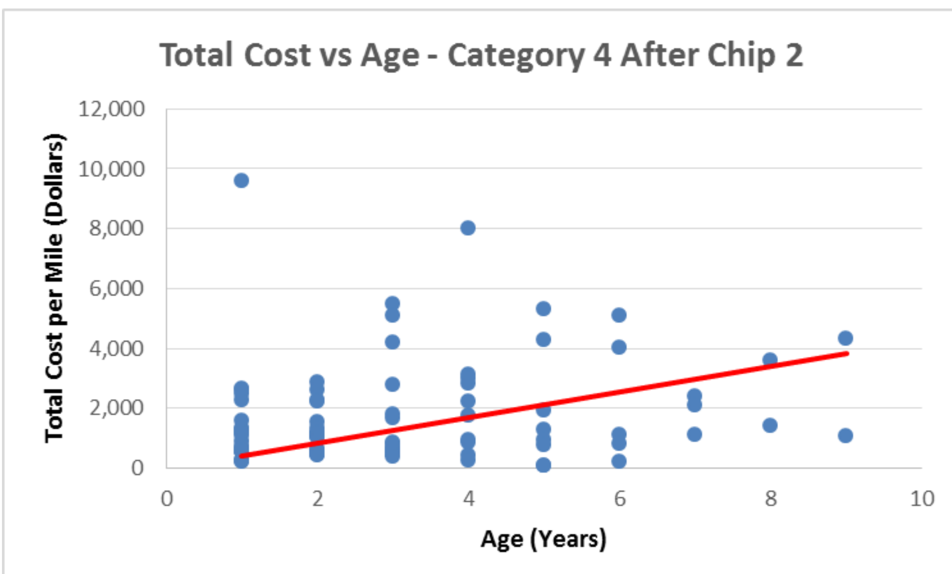


Figure 5.4.6 Total Routine Maintenance Costs vs Age - Category 4 After Chip 2.

5.5 Routine Maintenance Cost for Roads in Priority Category 5

Prioritization Category 5 routine maintenance costs were analyzed based on the 20 year pavement life-cycle using linear regression models. The results of the models are listed in Tables 5.5.1, 5.5.2, 5.5.3 and in Tables 5.5.1A, 5.5.2A, 5.5.3A (Appendix). The comparison of the models is shown at the end of this section. Figure 5.5.1 illustrates life cycle for priority Category 5 roads that was developed based on the data collected from NDOT's management system.

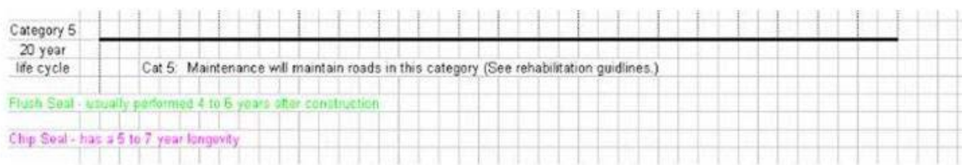


Figure 5.5.1 Life Cycles for Roads in Priority Category 5.

There is no clear definition on the life cycle stages for the roads in Priority Category 5, as illustrated in Figure 5.5.1. In this study, three life cycle segments were created and they are: maintenance after reconstruction, maintenance after flush seal, and maintenance after chip seal. For simplicity these three life cycle stages are called: first (5-1), second (5-2), and third (5-3). Each life cycle stage starts at the next year with new major routine maintenance activities. The first stage starts with a reconstruction having 2” PBS with OG. The second stage starts when a flush or chip seal is performed and ends before another flush or chip seal is performed. The third stage starts when a flush or a chip seal is performed and ends before a reconstruction. The second segment can be repetitive which is derived from the life cycle segments in Category 4.

Segment 5-1

From Table 5.5.1 it can be seen that four variables are significant in the total cost component: age, last year, elevation, and number of trucks. The age coefficient proved to be relevant implying maintenance cost between the reconstruction and flush seal increased every year. It is a natural expectation that total maintenance cost increases with year. The coefficient for the last year maintenance activities is positive, which may imply more preparation for flush seal needs to be performed next year. Elevation is significant and its coefficient is positive, which indicates that road at higher elevations has more of a chance of extreme weather as well as having other road features that need maintenance. The negative coefficient for number of trucks indicated the trucks traveling generate less maintenance cost, which is counterintuitive and worth future study.

These observations also can be found in other maintenance cost components, including labor cost, stockpile cost, equipment cost, total hours, and materials cost. The Labor cost model has five significant variables: last year, elevation, AADT, number of trucks and ESAL. The age coefficient proved to be relevant implying maintenance cost between the reconstruction and flush seal increased every year. It is a natural expectation that total maintenance cost increases with year. The coefficient for the last year maintenance activities is positive, which may imply more preparation for flush seal needs to be performed next year. Elevation is significant and its coefficient is positive, which indicates that roads at higher elevations have more chance of extreme weather as well as have other road features that need maintenance. Traffic flow AADT shows a positive impact since the variable is positive. Equipment model has three variables last year, elevation, and number of trucks.

Table 5.5.1 Regression Models for Roads in Priority Category 5: Stage 1.

Stage 1			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Age	0.1160	0.0437	0.009
Last_Year	0.8923	0.1680	0.000
Elevation	0.0043	0.0001	0.000
No_Trucks	-0.0122	0.0036	0.001
Constant	4.8363	0.4583	0.000
LABOR COST			
Last_Year	0.7657	0.1486	0.000
Elevation	0.0003	0.0001	0.000
AADT	0.0049	0.0022	0.027
No_Trucks	-0.0535	0.0184	0.004
ESAL	0.0232	0.0117	0.048
Constant	4.4674	0.4229	0.000
EQUIPMENT			
Last_Year	0.8864	0.1750	0.000
Elevation	0.0007	0.0001	0.000
No_Trucks	-0.0146	0.0041	0.000
Constant	2.5413	0.4832	0.000
TOTAL HOURS			
Last_Year	0.8835	0.1494	0.000
Length	-0.0480	0.0183	0.009
Elevation	0.0004	0.0001	0.000
AADT	0.0067	0.0017	0.000
No_Trucks	-0.0311	0.0059	0.000
Constant	1.0589	0.4213	0.013
MATERIALS			
Age	0.2318	0.0746	0.002
Last_Year	1.3370	0.2877	0.000
Elevation	0.0005	0.0002	0.001
No_Trucks	-0.1064	0.0186	0.000
ESAL	0.0722	0.0155	0.000
Constant	2.9159	0.8084	0.000
STOCKPILE			
Length	-0.0532	0.0110	0.000
Elevation	-0.0006	0.0001	0.000
AADT	0.0581	0.0026	0.000
No_Trucks	-0.3766	0.0212	0.000
ESAL	0.2051	0.0098	0.000
Constant	3.7831	0.2864	0.000

Total hours model has four variables: last year, length, elevation, AADT, and number of trucks. Traffic flow AADT shows a positive impact since the variable is positive. The Materials model has five significant variables: age, last year, elevation, number of trucks and ESAL. The last cost component in this stage is stockpile. The model for stockpile cost also has five significant variables: length, elevation, AADT, number of trucks, and ESAL.

Segment 5-2

From Table 5.5.2, it can be seen that total maintenance cost has six variables last year, district, elevation, temperature, AADT, and number of trucks. The Last year variable is positive suggesting last year maintenance was more expensive than the actual year and more maintenance is needed as roads age. The District variable was positive indicating that the total routine maintenance cost in District 1 is higher than other districts. Elevation is significant. Its sign is positive, implying that the roads with higher elevation incurred higher maintenance costs. The variable for temperature is significant and is positive, which is counterintuitive and needs to have more investigation. Traffic flow AADT shows a positive impact. Maintenance activities differ with the conditions of infrastructure that depends on the amount of the daily traffic passing through. Greater numbers of trucks traveling each day on the roads results in greater deterioration, which triggers more maintenance activities, and therefore higher maintenance cost. The Number of trucks variable is negative implying some of the highway segments have a lesser amount of trucks. The Labor cost component has five significant variables: last year, elevation, temperature, AADT, and number of trucks that are already included in total cost. The Equipment cost component has six crucial factors: age, last year, length, elevation, AADT, and number of trucks. The age factor is negative suggesting each year routine maintenance cost in this stage becomes more costly. The length variable is significant implying that maintenance cost for a highway segment depends on the length of the roadway segment, i.e., the longer a pavement section is the higher the cost is.

Table 5.5.2 Regression Models for Roads in Priority Category 5: Stage 2.

Stage 2							
Total Cost	Coefficient	Standard Error	Significance P>|t|	Total Hours	Coefficient	Standard Error	Significance P>|t|
Last_Year	1.4071	0.1082	0	Last_Year	0.9219	0.0932	0
District	0.2372	0.112	0.035	District	0.2665	0.0964	0.006
Elevation	0.0002	0.0001	0	Elevation	0.0002	0	0
Temperatu	0.1626	0.0818	0.047	Temperature	0.1735	0.0704	0.014
AADT	0.0053	0.001	0	No_Trucks	-0.0083	0.0022	0
No_Trucks	-0.0107	0.0025	0	AADT	0.0038	0.0008	0
Constant	4.8445	0.3733	0	Constant	0.5532	0.3213	0.086
Labor Cost				Materials			
Last_Year	0.9527	0.0919	0	Last_Year	2.4604	0.1867	0
Elevation	0.0002	0	0	Length	0.0377	0.0169	0.026
Temperatu	0.1071	0.0479	0.026	AADT	0.01	0.0017	0
AADT	0.0043	0.0008	0	No_Trucks	-0.0163	0.0043	0
No_Trucks	-0.0076	0.0021	0	Constant	4.0099	0.2441	0
Constant	4.4156	0.2153	0				
Labor Cost				Materials			
Age	-0.0989	0.0303	0.001	Age	0.1595	0.0375	0
Last_Year	1.0755	0.1308	0	Last_Year	0.4274	0.1666	0.011
Length	0.0309	0.0112	0.006	District	1.032	0.2032	0
Elevation	0.0002	0.0001	0	Temperature	0.4193	0.1198	0.001
AADT	0.0052	0.0011	0	No_Trucks	0.1091	0.0206	0
No_Trucks	-0.0097	0.0028	0.001	ESAL	-0.1076	0.0205	0
Constant	3.9437	0.3056	0	Constant	1.0343	0.7029	0.144

The manpower cost component has six variables having the same variables as total cost component. Material cost component has four variables last year, length, AADT, and number of trucks. The stockpile component has six variables age, last year, district, temperature, number of trucks and ESAL.

Segment 5-3

Table 5.5.3 presents the results for the cost models for the third life cycle stage. The variable last year is positive implying that more expenditure was incurred in the last year, the year before chip seal. The District variable was positive indicating that the total routine maintenance cost in District 1 is higher than other districts. Elevation is significant. Its sign is positive, implying that the roads with higher elevation incurred higher maintenance costs.

The variable for temperature is significant and is positive, which is counterintuitive and needs to have more investigation. Traffic flow AADT shows a positive impact. As stated earlier maintenance activities differ with the conditions of infrastructure that depends on the amount of the daily traffic passing through. Greater number of trucks traveling each day on the roads results in greater deterioration, which triggers more maintenance activities, therefore higher maintenance cost. These observations also can be found in other maintenance cost components, including labor cost, stockpile cost, equipment cost, and materials cost. Labor cost models have five significant variables: last year, elevation, temperature, AADT, and number of trucks. The Equipment model has six: age, last year, length, elevation, AADT, and number of trucks. Further, the total hours model has six influential variables. All the variables are the same with labor cost component having age as an additional factor. The Materials model has four variables last year, length, AADT, and number of trucks.

Table 5.5.3 Regression Models for Roads in Priority Category 5: Stage 3.

Stage 3							
Total Cost	Coefficient	Standard Error	Significance P>|t|	Total Hour	Coefficient	Standard Error	Significance P>|t|
Last_Year	1.407	0.108231	0	Last_Year	0.9219	0.0932	0
District	0.2372	0.1119	0.035	District	0.2665	0.0964	0.006
Elevation	0.0002	0.0001	0	Elevation	0.0002	0	0
Temperatu	0.1626	0.0818	0.047	Temperatu	0.1735	0.0704	0.014
AADT	0.0053	0.001	0	No_Truck	-0.0083	0.0022	0
No_Truck	-0.0107	0.0025	0	AADT	0.0038	0.0008	0
Constant	4.8445	0.3733	0	Constant	0.5532	0.3213	0.086
Labor Cost				Materials			
Last_Year	0.9527	0.0919	0	Last_Year	2.4604	0.1867	0
Elevation	0.0002	0	0	Length	0.0377	0.0169	0.026
Temperatu	0.1071	0.0479	0.026	AADT	0.01	0.0017	0
AADT	0.0043	0.0008	0	No_Truck	-0.0163	0.0043	0
No_Truck	-0.0076	0.0021	0	Constant	4.0099	0.2441	0
Constant	4.4156	0.2153	0				
Labor Cost				Materials			
Age	-0.0989	0.0303	0.001	Age	0.1595	0.0375	0
Last_Year	1.0755	0.1301	0	Last_Year	0.4274	0.1666	0.011
Length	0.0309	0.0112	0.006	District	1.0321	0.2033	0
Elevation	0.0002	0.0001	0	Temperatu	0.4193	0.1198	0.001
AADT	0.0052	0.0011	0	No_Truck	0.1091	0.0206	0
No_Truck	-0.0097	0.0028	0.001	ESAL	-0.1076	0.0205	0
Constant	3.9437	0.3056	0	Constant	1.0343	0.7029	0.144

The last stockpile model has six variables age, last year, district, temperature, number of trucks, and ESAL that are crucial to model development.

Based on Table 5.5.4, the After Flush stage has the most variables influencing the cost model and the least amount of variables can be found in After Chip stage. In Stage 1, the age variable is found in the total cost and materials cost components. The variable is positive meaning the maintenance cost increase every year. The Last Year is the factor observed in all the cost components besides stockpile cost component. Since last year is positive it indicates that last year maintenance was more expensive. The variable that exists in all of the components in Stage 1 is elevation and number of trucks. The Number of trucks variable is negative implying the routine maintenance costs is low when truck traffic is low on a road, which is counterintuitive. In the After Flush Stage 2 model the variables that appeared in all cost components are as follow: last year and number of trucks. It indicates those variables are crucial to the After Flush stage maintenance cost model development. The Elevation factor is positive and found in all the components besides materials and stockpile. In higher elevation, maintenance work tends to be in greater demand. Temperature is observed also in all components but equipment and materials. AADT is one of the variables contained in total cost, labor cost, equipment, total hours, and materials.

Since the variable is positive, it means routine maintenance cost is higher on roads where traffic is higher. Other variables that can be found in stage are district, length, ESAL. Length factor is found only in materials cost component. The factor is positive indicating routine maintenance costs increased with time. The Stage 3 model has the fewest number of variables. The total cost and labor cost only have one significant variable of age which is positive. It means that with years the maintenance cost increases. The Equipment cost component also has only one variable last year which is also positive. It indicates that the last year maintenance cost was higher than the previous year. The stockpile cost component has the highest number of variables influencing maintenance cost including: length, district, temperature, and number of trucks.

Table 5.5.4 Routine Maintenance Treatment Stages in Category 5.

After Construction			
TOTAL COST	Coefficient	Standard Error	e P>|t|
Age	0.1160	0.0437	0.009
Last_Year	0.8923	0.1680	0.000
Elevation	0.0043	0.0001	0.000
No_Trucks	-0.0122	0.0036	0.001
Constant	4.8363	0.4583	0.000
LABOR COST			
Last_Year	0.7657	0.1486	0.000
Elevation	0.0003	0.0001	0.000
AADT	0.0049	0.0022	0.027
No_Trucks	-0.0535	0.0184	0.004
ESAL	0.0232	0.0117	0.048
Constant	4.4674	0.4229	0.000
EQUIPMENT			
Last_Year	0.8864	0.1750	0.000
Elevation	0.0007	0.0001	0.000
No_Trucks	-0.0146	0.0041	0.000
Constant	2.5413	0.4832	0.000
TOTAL HOURS	Coefficient	Standard Error	e P>|t|
Last_Year	0.8835	0.1494	0.000
Length	-0.0480	0.0183	0.009
Elevation	0.0004	0.0001	0.000
AADT	0.0067	0.0017	0.000
No_Trucks	-0.0311	0.0059	0.000
Constant	1.0589	0.4213	0.013
MATERIALS			
Age	0.2318	0.0746	0.002
Last_Year	1.3370	0.2877	0.000
Elevation	0.0005	0.0002	0.001
No_Trucks	-0.1064	0.0186	0.000
ESAL	0.0722	0.0155	0.000
Constant	2.9159	0.8084	0.000
STOCKPILE			
Length	-0.0532	0.0110	0.000
Elevation	-0.0006	0.0001	0.000
AADT	0.0581	0.0026	0.000
No_Trucks	-0.3766	0.0212	0.000
ESAL	0.2051	0.0098	0.000
Constant	3.7831	0.2864	0.000

After Flush Seal			
TOTAL COST	Coefficient	Standard Error	e P>|t|
Last_Year	1.407	0.108231	0
District 3	0.2372	0.1119	0.035
Elevation	0.0002	0.0001	0.000
Temperature	0.1626	0.0818	0.047
AADT	0.0053	0.0010	0.000
No_Trucks	-0.0107	0.0025	0.000
Constant	4.8445	0.3733	0.000
LABOR COST			
Last_Year	0.9527	0.0919	0.000
Elevation	0.0002	0.0000	0.000
Temperature	0.1071	0.0479	0.026
AADT	0.0043	0.0008	0.000
No_Trucks	-0.0076	0.0021	0.000
Constant	4.4156	0.2153	0.000
EQUIPMENT			
Age	-0.0989	0.0303	0.001
Last_Year	1.0755	0.1301	0.000
Length	0.0309	0.0112	0.006
Elevation	0.0002	0.0001	0.000
AADT	0.0052	0.0011	0.000
No_Trucks	-0.0097	0.0028	0.001
Constant	3.9437	0.3056	0.000
TOTAL HOURS	Coefficient	Standard Error	e P>|t|
Last_Year	0.9219	0.0932	0.000
District 3	0.2665	0.0964	0.006
Elevation	0.0002	0.0000	0.000
Temperature	0.1735	0.0704	0.014
No_Trucks	-0.0083	0.0022	0.000
AADT	0.0038	0.0008	0.000
Constant	0.5532	0.3213	0.086
MATERIALS			
Last_Year	2.4604	0.1867	0.000
Length	0.0377	0.0169	0.026
AADT	0.0100	0.0017	0.000
No_Trucks	-0.0163	0.0043	0.000
Constant	4.0099	0.2441	0.000
STOCKPILE			
Age	0.1595	0.0375	0.000
Last_Year	0.4274	0.1666	0.011
District 3	1.0321	0.2033	0.000
Temperature	0.4193	0.1198	0.001
No_Trucks	0.1091	0.0206	0.000
ESAL	-0.1076	0.0205	0.000
Constant	1.0343	0.7029	0.144

After Chip Seal			
TOTAL COST	Coefficient	Standard Error	Significance P>|t|
Age	0.1830	0.0805	0.025
Constant	7.2834	0.2597	0.000
LABOR COST			
Age	0.1967	0.0789	0.014
Constant	6.3154	0.2547	0.000
EQUIPMENT			
Last_Year	0.7803	0.3307	0.020
Constant	6.3178	0.1671	0.000
MANPOWER			
Last_Year	0.7504	0.2942	0.012
Elevation	0.0004	0.0002	0.072
Temperature	-0.5011	0.2375	0.038
Constant	2.2609	0.8511	0.009
MATERIALS			
Last_Year	0.6187	0.2727	0.026
Length	0.0517	0.0249	0.041
Constant	5.9078	0.1970	0.000
STOCKPILE			
Length	0.0611	0.0264	0.023
District 3	1.2115	0.3403	0.001
Temperature	1.3210	0.3534	0.000
No_Trucks	-0.0519	0.0131	0.000
Constant	-5.8112	1.3490	0.000

The profile of the total maintenance cost is presented Figure 5.5.2. The figure included three stages: 5-1 (After Construction), 5-2 (After Flush), and 5-3 (After Chip). Each stage involves the same cost components total cost, labor cost, materials cost, total hours cost, equipment cost, and stockpile cost.

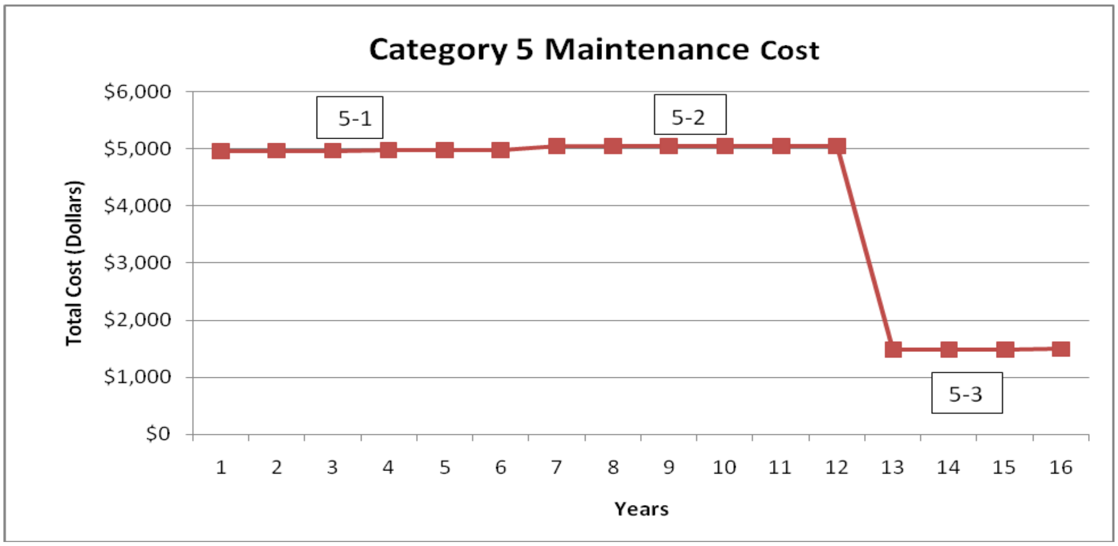


Figure 5.5.2 Total Maintenance Costs for a 16-Year Life Cycle for Category 5 Roads.

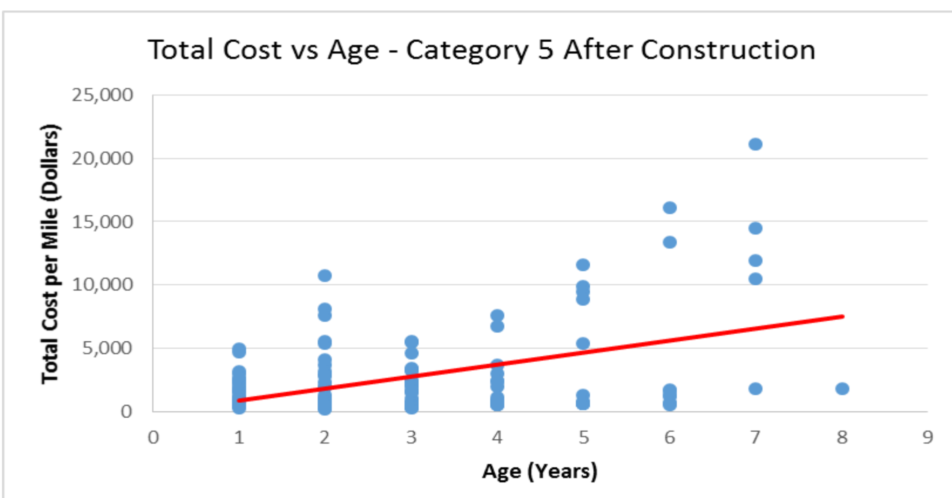


Figure 5.5.3 Total Routine Maintenance Costs vs Age - Category 5 After Construction.

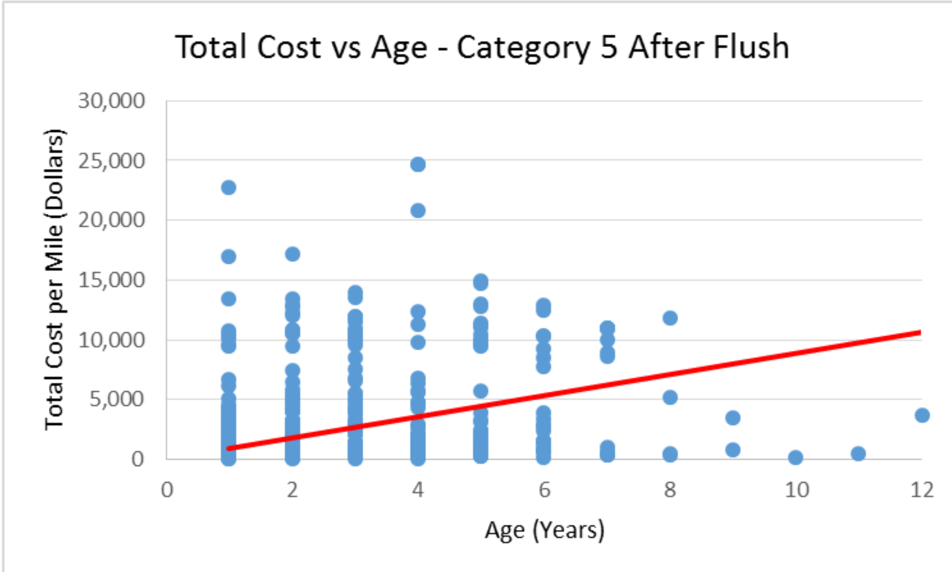


Figure 5.5.4 Total Routine Maintenance Costs vs Age - Category 5 After Flush.

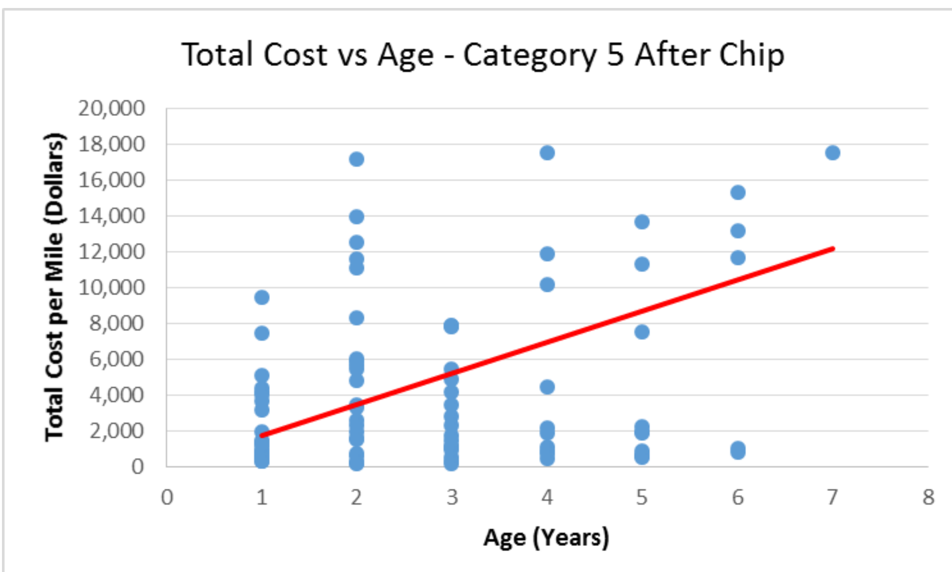


Figure 5.5.5 Total Routine Maintenance Costs vs Age - Category 5 After Chip.

5.6 Summary

Figure 5.6.1 demonstrates a summary of annual routine maintenance cost for five prioritization categories. Categories 1 and 2 show straight trend line while other categories have theirs trend lines split into sections which corresponds to the segments of the maintenance activity life-cycle for a given prioritization category.

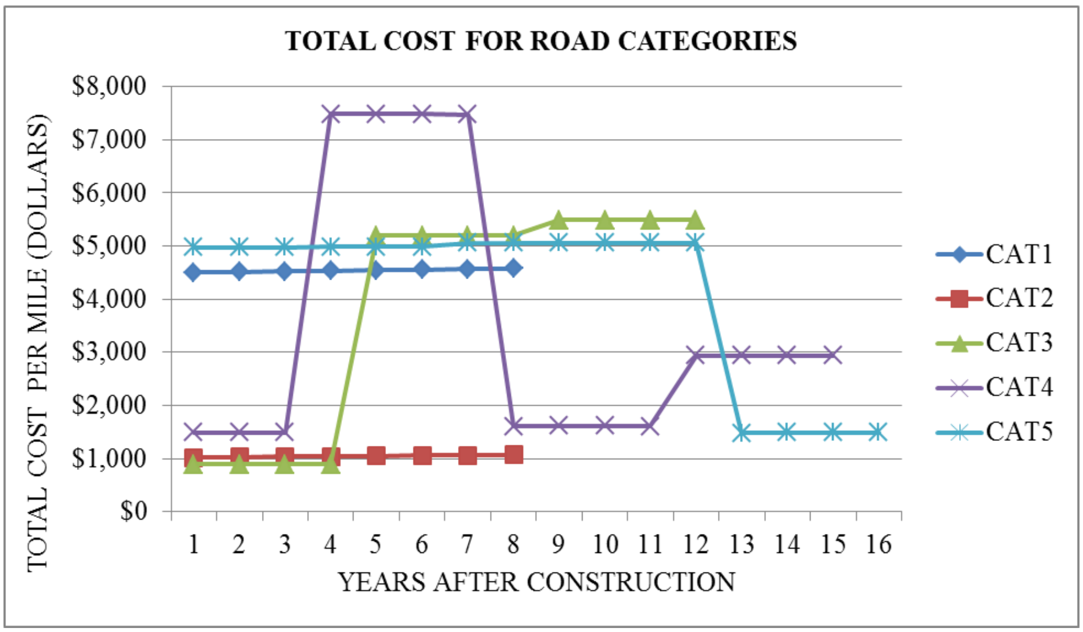


Figure 5.6 Annual Total Cost per Mile for Categories 1, 2, 3, 4, and 5.

The maintenance cost on the graph is displayed for each year in a total of 16 years. It can be seen from the figure that during the first life cycle stage, the roads in Category 4 incurred the highest total cost. The roads in Category 2 incurred the least maintenance costs throughout the whole pavement life. It can also be seen that the total maintenance costs in Categories 1 and 2 are constant while those of other categories are not. The total maintenance costs of Categories 3, 4 and 5 fluctuate through the whole pavement life cycle.

CHAPTER 6

CONCLUSIONS AND FUTURE STUDY NEEDS

6.1 Conclusions

The objective of this research was to estimate the annual highway routine maintenance cost that is important to developing budgets for maintenance of highway facilities that has been growing in Nevada. Five prioritization categories of highways used by NDOT were considered.

Multiple linear regression models were developed for total maintenance costs including five maintenance cost components: labor, equipment, materials, manpower and stockpile. The factors that influence the costs considered in this study are: history of maintenance on a road, maintenance treatments, traffic flow, geographic and jurisdiction locations, pavement structure, and climate. Specifically, the variables for these influencing factors are: elevation, age of the pavement, last year pavement construction work, average daily traffic (ADT), number of trucks, single axial load (ESAL), district work was done, and weather conditions. It was found that all considered variables affect the routine maintenance costs in certain ways.

Linear regression models for five highway prioritization categories classified for the NDOT roadway maintenance were developed. Each category has different numbers of stages and each stage has a different duration.

The analysis indicates that road age is a noteworthy factor for a number of life cycle stages. For stages where the roadway age does not appear to be significant, the roadway cost estimate stays constant. Maintenance activities may be scheduled at the times that are close to the time when a preventive maintenance or reconstruction is scheduled. This practice is reflected in the cost model that the annual maintenance cost may decline with time and suddenly increase at the end of their life cycle stages. Ground elevation is another variable that was repeatedly included in the cost models. It implies that roadways in higher elevations are likely to have higher costs due to special safety features or extreme weather conditions. Maintenance activities differ with conditions of infrastructure which depend on the amount of the daily traffic passing through. The regression models developed in this study indicate that the greater number of trucks traveling each day on the roads results in greater deterioration, which caused more maintenance activities, and higher maintenance cost. Furthermore, the district variable represented cost variation of three NDOT districts in the state of Nevada. The cost variation can be visible since each district adopted different maintenance practices in terms of the materials and equipment used.

The analyses indicate the best estimate of the highway routine maintenance cost. The development of cost estimate models uniquely integrated the life cycle concept of pavement which reflects the infrastructure conditions. The life cycle component varied with each prioritization category including maintenance activities. Variables used in the statistical analysis provide the basis for the models to be incorporated with NDOT's pavement management and maintenance management systems to estimate future maintenance costs that would farther be submitted to the Nevada legislation.

6.2 Future Study

Several research needs in the cost estimate model are apparent from this view.

First, future studies need to target larger data sample size. For instance, the data for analysis should include additional PMS data years. The sample size is crucial in statistical analysis which leads to model development.

Second, it is needed to understand the interrelationship between the cost components and the interrelationship between cost components and total cost. This understanding can be achieved by communicating with NDOT professionals about their maintenance process, particularly which equipment or materials play what roles in which life cycle stage. In addition, advanced statistical models can be developed to identify the interrelationship, making the models provide more information on estimating costs.

APPENDIX

Table 5.1.A Regression Models for Roads in Priority Category 1

Total Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lntot AGE PAVEMENT NO_TRUCKS ELEV WEATHER PERC_TRUCKS
(obs=201)
```

	lntot	AGE	PAVEMENT	NO_TRU~S	ELEV	WEATHER	PERC_T~S
lntot	1.0000						
AGE	0.4150	1.0000					
PAVEMENT	-0.2345	-0.4875	1.0000				
NO_TRUCKS	0.3017	0.2225	-0.5372	1.0000			
ELEV	-0.4460	-0.1119	0.0333	-0.1559	1.0000		
WEATHER	0.5584	0.1475	-0.1675	0.3325	-0.5710	1.0000	
PERC_TRUCKS	-0.5086	-0.4773	0.3737	0.1477	0.0230	-0.0790	1.0000

```
. regress lntot AGE  PAVEMENT NO_TRUCKS  ELEV WEATHER   PERC_TRUCKS
```

Source	SS	df	MS
Model	199.271264	6	33.2118773
Residual	102.440622	194	.528044444
Total	301.711886	200	1.50855943

Number of obs =	201
F(6, 194) =	62.90
Prob > F =	0.0000
R-squared =	0.6605
Adj R-squared =	0.6500
Root MSE =	.72667

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.0269101	.0105898	2.54	0.012	.0060241	.0477961
PAVEMENT	.895953	.1653664	5.42	0.000	.5698062	1.2221
NO_TRUCKS	.0003502	.0000507	6.91	0.000	.0002503	.0004501
ELEV	-.0006072	.0001615	-3.76	0.000	-.0009256	-.0002887
WEATHER	1.49752	.2690652	5.57	0.000	.9668516	2.028189
PERC_TRUCKS	-.0956822	.0087695	-10.91	0.000	-.1129781	-.0783864
_cons	3.00124	1.324037	2.27	0.025	.3898836	5.612596

Table 5.1.A Regression Models for Roads in Priority Category 1 (continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnlabor AGE AC ELEV WEATHER URBAN NO_TRUCKS PERC_TRUCKS
(obs=201)

	lnlabor	AGE	AC	ELEV	WEATHER	URBAN	NO_TRU~S	PERC_T~S
lnlabor	1.0000							
AGE	0.4070	1.0000						
AC	-0.2194	-0.4875	1.0000					
ELEV	-0.4602	-0.1119	0.0333	1.0000				
WEATHER	0.5731	0.1475	-0.1675	-0.5710	1.0000			
URBAN	0.2698	0.3645	-0.5156	-0.1176	0.2007	1.0000		
NO_TRUCKS	0.2906	0.2225	-0.5372	-0.1559	0.3325	0.3701	1.0000	
PERC_TRUCKS	-0.5055	-0.4773	0.3737	0.0230	-0.0790	-0.3898	0.1477	1.0000

. regress lnlabor AGE AC ELEV WEATHER URBAN NO_TRUCKS PERC_TRUCKS

Source	SS	df	MS
Model	178.657396	7	25.5224852
Residual	84.7367712	193	.439050628
Total	263.394167	200	1.31697084

Number of obs =	201
F(7, 193) =	58.13
Prob > F =	0.0000
R-squared =	0.6783
Adj R-squared =	0.6666
Root MSE =	.66261

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.0250733	.0096598	2.60	0.010	.0060209	.0441256
AC	.7995312	.1535276	5.21	0.000	.4967238	1.102339
ELEV	-.0006045	.0001474	-4.10	0.000	-.0008953	-.0003138
WEATHER	1.483417	.2453608	6.05	0.000	.9994845	1.96735
URBAN	-.261127	.1218106	-2.14	0.033	-.5013778	-.0208761
NO_TRUCKS	.0003423	.0000476	7.19	0.000	.0002484	.0004363
PERC_TRUCKS	-.0946788	.0083917	-11.28	0.000	-.11123	-.0781277
_cons	2.588496	1.209792	2.14	0.034	.2023846	4.974607

Table 5.1.A Regression Models for Roads in Priority Category 1 (continued)

Equipment Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lneq  AGE PAVEMENT ELEV WEATHER NO_TRUCKS PERC_TRUCKS
(obs=201)
```

	lneq	AGE	PAVEMENT	ELEV	WEATHER	NO_TRU~S	PERC_T~S
lneq	1.0000						
AGE	0.4122	1.0000					
PAVEMENT	-0.2117	-0.4875	1.0000				
ELEV	-0.4502	-0.1119	0.0333	1.0000			
WEATHER	0.5457	0.1475	-0.1675	-0.5710	1.0000		
NO_TRUCKS	0.2911	0.2225	-0.5372	-0.1559	0.3325	1.0000	
PERC_TRUCKS	-0.4778	-0.4773	0.3737	0.0230	-0.0790	0.1477	1.0000

```
. regress lneq AGE  PAVEMENT  ELEV WEATHER    NO_TRUCKS PERC_TRUCKS
```

Source	SS	df	MS
Model	211.367524	6	35.2279207
Residual	126.837896	194	.65380359
Total	338.205421	200	1.6910271

Number of obs =	201
F(6, 194) =	53.88
Prob > F =	0.0000
R-squared =	0.6250
Adj R-squared =	0.6134
Root MSE =	.80858

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.0339536	.0117836	2.88	0.004	.0107132	.057194
PAVEMENT	.9804464	.1840076	5.33	0.000	.6175343	1.343359
ELEV	-.0006859	.0001797	-3.82	0.000	-.0010403	-.0003315
WEATHER	1.509947	.299396	5.04	0.000	.9194575	2.100436
NO_TRUCKS	.0003586	.0000564	6.36	0.000	.0002474	.0004698
PERC_TRUCKS	-.0945837	.0097581	-9.69	0.000	-.1138292	-.0753382
_cons	1.520007	1.473291	1.03	0.303	-1.385718	4.425732

Table 5.1.A Regression Models for Roads in Priority Category 1 (continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnhrs AGE LENGTH PAVEMENT ELEV WEATHER NO_TRUCKS PERC_TRUCKS
(obs=201)
```

	lnhrs	AGE	LENGTH	PAVEMENT	ELEV	WEATHER	NO_TRU~S	PERC_T~S
lnhrs	1.0000							
AGE	0.4437	1.0000						
LENGTH	-0.4365	-0.3344	1.0000					
PAVEMENT	-0.2930	-0.4875	0.2021	1.0000				
ELEV	-0.4529	-0.1119	0.0150	0.0333	1.0000			
WEATHER	0.5562	0.1475	-0.0703	-0.1675	-0.5710	1.0000		
NO_TRUCKS	0.3743	0.2225	0.0289	-0.5372	-0.1559	0.3325	1.0000	
PERC_TRUCKS	-0.4777	-0.4773	0.6657	0.3737	0.0230	-0.0790	0.1477	1.0000

```
. regress lnhrs AGE  LENGTH PAVEMENT  ELEV WEATHER  NO_TRUCKS PERC_TRUCKS
```

Source	SS	df	MS
Model	191.416444	7	27.3452063
Residual	94.496174	193	.489617482
Total	285.912618	200	1.42956309

Number of obs	= 201
F(7, 193)	= 55.85
Prob > F	= 0.0000
R-squared	= 0.6695
Adj R-squared	= 0.6575
Root MSE	= .69973

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.0300241	.0102036	2.94	0.004	.0098992	.0501491
LENGTH	-.0238673	.0108183	-2.21	0.029	-.0452045	-.0025302
PAVEMENT	.6801899	.1617357	4.21	0.000	.3611934	.9991863
ELEV	-.0006486	.0001555	-4.17	0.000	-.0009554	-.0003418
WEATHER	1.305585	.2591055	5.04	0.000	.7945431	1.816627
NO_TRUCKS	.0003564	.0000495	7.19	0.000	.0002587	.0004541
PERC_TRUCKS	-.0705726	.0107003	-6.60	0.000	-.0916771	-.0494681
_cons	.0084552	1.275286	0.01	0.995	-2.506831	2.523742

Table 5.1.A Regression Models for Roads in Priority Category 1 (continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnma AGE PAVEMENT ELEV WEATHER NO_TRUCKS PERC_TRUCKS
(obs=200)

	lnma	AGE	PAVEMENT	ELEV	WEATHER	NO_TRU~S	PERC_T~S
lnma	1.0000						
AGE	0.4117	1.0000					
PAVEMENT	-0.2580	-0.4861	1.0000				
ELEV	-0.3374	-0.1039	0.0267	1.0000			
WEATHER	0.4593	0.1363	-0.1615	-0.5565	1.0000		
NO_TRUCKS	0.2931	0.2182	-0.5359	-0.1442	0.3210	1.0000	
PERC_TRUCKS	-0.4865	-0.4778	0.3738	0.0221	-0.0799	0.1491	1.0000

. regress lnma AGE PAVEMENT ELEV WEATHER NO_TRUCKS PERC_TRUCKS

Source	SS	df	MS
Model	261.89129	6	43.6485484
Residual	232.453691	193	1.20442327
Total	494.344981	199	2.48414563

Number of obs =	200
F(6, 193) =	36.24
Prob > F =	0.0000
R-squared =	0.5298
Adj R-squared =	0.5152
Root MSE =	1.0975

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.0385476	.016003	2.41	0.017	.0069843	.0701109
PAVEMENT	.9577798	.2497478	3.83	0.000	.4651944	1.450365
ELEV	-.0005093	.0002439	-2.09	0.038	-.0009903	-.0000283
WEATHER	1.606866	.4159731	3.86	0.000	.7864295	2.427303
NO_TRUCKS	.0004356	.0000765	5.69	0.000	.0002847	.0005865
PERC_TRUCKS	-.113235	.0132493	-8.55	0.000	-.1393671	-.0871029
_cons	.5337666	2.032782	0.26	0.793	-3.475554	4.543088

Table 5.1.A Regression Models for Roads in Priority Category 1 (continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate AGE ELEV NO_TRUCKS ESAL lnstock
(obs=37)

	AGE	ELEV	NO_TRU~S	ESAL	lnstock
AGE	1.0000				
ELEV	0.2816	1.0000			
NO_TRUCKS	-0.0133	0.4282	1.0000		
ESAL	0.0159	0.5306	0.9534	1.0000	
lnstock	0.1851	-0.2874	-0.0076	0.0363	1.0000

. regress lnstock AGE ELEV NO_TRUCKS ESAL

Source	SS	df	MS
Model	48.8311211	4	12.2077803
Residual	112.327535	32	3.51023548
Total	161.158657	36	4.47662935

Number of obs =	37
F(4, 32) =	3.48
Prob > F =	0.0181
R-squared =	0.3030
Adj R-squared =	0.2159
Root MSE =	1.8736

lnstock	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.1297734	.0599899	2.16	0.038	.0075779	.2519689
ELEV	-.0032358	.0009505	-3.40	0.002	-.0051718	-.0012998
NO_TRUCKS	-.0011057	.0006186	-1.79	0.083	-.0023657	.0001544
ESAL	.0010604	.000464	2.29	0.029	.0001152	.0020056
_cons	8.28628	1.94444	4.26	0.000	4.325586	12.24697

Table 5.2.A Regression Models for Roads in Priority Category 2

Total Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lntot LENGTH DISTRICT AGE
(obs=93)

	lntot	LENGTH	DISTRICT	AGE
lntot	1.0000			
LENGTH	-0.1639	1.0000		
DISTRICT	0.2913	0.2986	1.0000	
AGE	-0.1308	-0.1978	0.0822	1.0000

. regress lntot LENGTH DISTRICT AGE

Source	SS	df	MS
Model	10.6328465	3	3.54428216
Residual	41.5888214	89	.467290128
Total	52.2216679	92	.567626825

Number of obs	=	93
F(3, 89)	=	7.58
Prob > F	=	0.0001
R-squared	=	0.2036
Adj R-squared	=	0.1768
Root MSE	=	.68359

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LENGTH	-.0585106	.0179904	-3.25	0.002	-.094257	-.0227641
DISTRICT	.7572767	.1855611	4.08	0.000	.3885707	1.125983
AGE	-.0447546	.0189911	-2.36	0.021	-.0824895	-.0070198
_cons	6.92416	.3447124	20.09	0.000	6.239224	7.609097

Table 5.2.A Regression Models for Roads in Priority Category 2 (continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnlabor LENGTH DISTR_NO ELEV LANES
(obs=93)

	lnlabor	LENGTH	DISTR_NO	ELEV	LANES
lnlabor	1.0000				
LENGTH	-0.2618	1.0000			
DISTR_NO	0.2435	0.2986	1.0000		
ELEV	0.3223	0.2770	0.9760	1.0000	
LANES	-0.0051	-0.8327	-0.6049	-0.5921	1.0000

. regress lnlabor LENGTH DISTR_NO ELEV LANES

Source	SS	df	MS
Model	14.4866919	4	3.62167298
Residual	26.7185315	88	.303619676
Total	41.2052234	92	.447882863

Number of obs =	93
F(4, 88) =	11.93
Prob > F =	0.0000
R-squared =	0.3516
Adj R-squared =	0.3221
Root MSE =	.55102

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LENGTH	-.1063372	.0277798	-3.83	0.000	-.1615438	-.0511307
DISTR_NO	-2.236844	.6558401	-3.41	0.001	-3.540189	-.9334998
ELEV	.0012203	.0003119	3.91	0.000	.0006004	.0018401
LANES	-.4190433	.1893156	-2.21	0.029	-.7952682	-.0428184
_cons	7.423424	.7875941	9.43	0.000	5.858246	8.988602

Table 5.2.A Regression Models for Roads in Priority Category 2 (continued)

Equipment Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lneq LYEAR LENGTH ELEV URBAN
(obs=93)

	lneq	LYEAR	LENGTH	ELEV	URBAN
lneq	1.0000				
LYEAR	-0.2848	1.0000			
LENGTH	-0.2086	-0.0595	1.0000		
ELEV	0.2854	0.0582	0.2770	1.0000	
URBAN	-0.2527	0.0677	-0.4527	-0.1847	1.0000

. regress lneq LYEAR LENGTH ELEV URBAN

Source	SS	df	MS
Model	23.7252676	4	5.9313169
Residual	35.6605457	88	.405233474
Total	59.3858133	92	.645497971

Number of obs	=	93
F(4, 88)	=	14.64
Prob > F	=	0.0000
R-squared	=	0.3995
Adj R-squared	=	0.3722
Root MSE	=	.63658

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	-.7672397	.2056641	-3.73	0.000	-1.175954	-.3585255
LENGTH	-.0955713	.0178977	-5.34	0.000	-.1311393	-.0600034
ELEV	.0003488	.0000812	4.30	0.000	.0001874	.0005101
URBAN	-.65202	.1542951	-4.23	0.000	-.958649	-.345391
_cons	5.585863	.3349693	16.68	0.000	4.920182	6.251544

Table 5.2.A Regression Models for Roads in Priority Category 2 (continued)

Material Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnma AADT ELEV LYEAR
(obs=93)

	lnma	AADT	ELEV	LYEAR
lnma	1.0000			
AADT	-0.0397	1.0000		
ELEV	0.4191	-0.4751	1.0000	
LYEAR	-0.2624	0.1207	0.0582	1.0000

. regress lneq LYEAR LENGTH ELEV URBAN

Source	SS	df	MS
Model	23.7252676	4	5.9313169
Residual	35.6605457	88	.405233474
Total	59.3858133	92	.645497971

Number of obs =	93
F(4, 88) =	14.64
Prob > F =	0.0000
R-squared =	0.3995
Adj R-squared =	0.3722
Root MSE =	.63658

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	-.7672397	.2056641	-3.73	0.000	-1.175954	-.3585255
LENGTH	-.0955713	.0178977	-5.34	0.000	-.1311393	-.0600034
ELEV	.0003488	.0000812	4.30	0.000	.0001874	.0005101
URBAN	-.65202	.1542951	-4.23	0.000	-.958649	-.345391
_cons	5.585863	.3349693	16.68	0.000	4.920182	6.251544

Table 5.2.A Regression Models for Roads in Priority Category 2 (continued)

Manpower Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnhrs ELEV DISTRICT LENGTH
(obs=93)

             |    lnhrs     ELEV DISTRICT   LENGTH
-------------+------------------------------------
       lnhrs |   1.0000
        ELEV |   0.3155   1.0000
    DISTRICT |   0.2409   0.9760   1.0000
      LENGTH |  -0.3575   0.2770   0.2986   1.0000


. regress lnhrs LENGTH DISTRICT ELEV

      Source |       SS       df       MS              Number of obs =      93
-------------+------------------------------           F(  3,    89) =   17.83
       Model |  16.3151121     3  5.43837072           Prob > F      =  0.0000
    Residual |  27.1435572    89  .304983789           R-squared     =  0.3754
-------------+------------------------------           Adj R-squared =  0.3544
       Total |  43.4586694    92  .472376841           Root MSE      =  .55225

------------------------------------------------------------------------------
       lnhrs |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      LENGTH |  -.0719182   .0141654    -5.08   0.000    -.1000645   -.043772
    DISTRICT |  -1.940193   .6555099    -2.96   0.004    -3.242677  -.6377085
        ELEV |   .0012535   .0003097     4.05   0.000     .0006381   .0018689
       _cons |   2.548279   .2756304     9.25   0.000     2.000607   3.095951
------------------------------------------------------------------------------
```

Table 5.2.A Regression Models for Roads in Priority Category 2 (continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate AGE ELEV NO_TRUCKS ESAL lnstock
(obs=37)
```

	AGE	ELEV	NO_TRU~S	ESAL	lnstock
AGE	1.0000				
ELEV	0.2816	1.0000			
NO_TRUCKS	-0.0133	0.4282	1.0000		
ESAL	0.0159	0.5306	0.9534	1.0000	
lnstock	0.1851	-0.2874	-0.0076	0.0363	1.0000

```
. regress lnsto AGE LENGTH  ELEV     ESAL
```

Source	SS	df	MS
Model	8.22930499	4	2.05732625
Residual	1.83667198	12	.153055999
Total	10.065977	16	.629123561

Number of obs =	17
F(4, 12) =	13.44
Prob > F =	0.0002
R-squared =	0.8175
Adj R-squared =	0.7567
Root MSE =	.39122

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.6033122	.1050101	5.75	0.000	.3745148	.8321096
LENGTH	.2292798	.0350691	6.54	0.000	.1528709	.3056888
ELEV	.006152	.0009654	6.37	0.000	.0040486	.0082553
ESAL	.0022602	.0006712	3.37	0.006	.0007978	.0037225
_cons	-31.07042	5.320371	-5.84	0.000	-42.66251	-19.47833

Table 5.3.1A Regression Models for Roads in Priority Category 3 – Const.

Total Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lntot LYEAR ELEV NO_TRUCKS PERC_TRUCKS
(obs=21)
```

	lntot	LYEAR	ELEV	NO_TRU~S	PERC_T~S
lntot	1.0000				
LYEAR	0.1503	1.0000			
ELEV	0.1032	-0.2750	1.0000		
NO_TRUCKS	0.3561	-0.1830	-0.2651	1.0000	
PERC_TRUCKS	-0.2417	-0.1347	0.2965	0.1578	1.0000

```
. regress lntot LYEAR ELEV  NO_TRUCKS PERC_TRUCKS
```

Source	SS	df	MS
Model	6.53210331	4	1.63302583
Residual	8.75162264	16	.546976415
Total	15.2837259	20	.764186297

Number of obs =	21
F(4, 16) =	2.99
Prob > F =	0.0511
R-squared =	0.4274
Adj R-squared =	0.2842
Root MSE =	.73958

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.1440854	.0870369	1.66	0.117	-.0404245	.3285953
ELEV	.0003822	.0001731	2.21	0.042	.0000153	.0007491
NO_TRUCKS	.010234	.0034961	2.93	0.010	.0028227	.0176453
PERC_TRUCKS	-.0595685	.0278233	-2.14	0.048	-.1185513	-.0005858
_cons	4.475647	1.158518	3.86	0.001	2.019698	6.931595

Table 5.3.1A Regression Models for Roads in Priority Category 3 Const. (continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnlabor  ELEV AADT
(obs=21)
```

	lnlabor	ELEV	AADT
lnlabor	1.0000		
ELEV	0.0195	1.0000	
AADT	0.5200	-0.4018	1.0000

```
. regress lnlabor ELEV   AADT
```

Source	SS	df	MS
Model	4.34378802	2	2.17189401
Residual	8.71401658	18	.484112032
Total	13.0578046	20	.65289023

Number of obs	=	21
F(2, 18)	=	4.49
Prob > F	=	0.0263
R-squared	=	0.3327
Adj R-squared	=	0.2585
Root MSE	=	.69578

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ELEV	.0001964	.0001515	1.30	0.211	-.000122	.0005147
AADT	.0006064	.0002026	2.99	0.008	.0001808	.0010319
_cons	4.685266	.8628293	5.43	0.000	2.872529	6.498003

Table 5.3.1A Regression Models for Roads in Priority Category 3 Const. (continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnlabor ELEV AADT
(obs=21)

	lnlabor	ELEV	AADT
lnlabor	1.0000		
ELEV	0.0195	1.0000	
AADT	0.5200	-0.4018	1.0000

. regress lnhrs ELEV AADT

Source	SS	df	MS
Model	5.21261801	2	2.60630901
Residual	11.448342	18	.636019001
Total	16.66096	20	.833048002

Number of obs	=	21
F(2, 18)	=	4.10
Prob > F	=	0.0341
R-squared	=	0.3129
Adj R-squared	=	0.2365
Root MSE	=	.79751

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ELEV	.0003016	.0001737	1.74	0.100	-.0000633	.0006665
AADT	.0006459	.0002322	2.78	0.012	.0001581	.0011336
_cons	.8442492	.9889789	0.85	0.405	-1.233518	2.922017

Table 5.3.1A Regression Models for Roads in Priority Category 3 Const. (continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnma LYEAR ELEV PERC_TRUCKS ESAL
(obs=21)

	lnma	LYEAR	ELEV	PERC_T~S	ESAL
lnma	1.0000				
LYEAR	0.2989	1.0000			
ELEV	0.0204	-0.2750	1.0000		
PERC_TRUCKS	-0.1381	-0.1347	0.2965	1.0000	
ESAL	0.2278	-0.1445	-0.2794	0.5357	1.0000

. regress lnma LYEAR ELEV PERC_TRUCKS ESAL

Source	SS	df	MS
Model	18.9064348	4	4.72660871
Residual	23.4085742	16	1.46303588
Total	42.315009	20	2.11575045

Number of obs =	21
F(4, 16) =	3.23
Prob > F =	0.0401
R-squared =	0.4468
Adj R-squared =	0.3085
Root MSE =	1.2096

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.3468922	.1424163	2.44	0.027	.0449831	.6488014
ELEV	.000775	.0003216	2.41	0.028	.0000932	.0014569
PERC_TRUCKS	-.1579648	.0602034	-2.62	0.018	-.2855902	-.0303394
ESAL	.0216152	.007013	3.08	0.007	.0067483	.0364821
_cons	.3680401	1.997316	0.18	0.856	-3.866081	4.602162

Table 5.3.1A Regression Models for Roads in Priority Category 3 Const. (continued)

Equipment Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lneq ELEV NO_TRUCKS PERC_TRUCKS
(obs=21)
```

	lneq	ELEV	NO_TRU~S	PERC_T~S
lneq	1.0000			
ELEV	0.2657	1.0000		
NO_TRUCKS	0.2275	-0.2651	1.0000	
PERC_TRUCKS	-0.2537	0.2965	0.1578	1.0000

```
. regress lneq ELEV  NO_TRUCKS PERC_TRUCKS
```

Source	SS	df	MS
Model	6.33696044	3	2.11232015
Residual	11.1814091	17	.65772995
Total	17.5183696	20	.875918479

Number of obs =	21
F(3, 17) =	3.21
Prob > F =	0.0494
R-squared =	0.3617
Adj R-squared =	0.2491
Root MSE =	.81101

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ELEV	.0004383	.0001795	2.44	0.026	.0000597	.0008169
NO_TRUCKS	.0078508	.0036905	2.13	0.048	.0000645	.0156372
PERC_TRUCKS	-.0696431	.0305074	-2.28	0.036	-.134008	-.0052781
_cons	3.686508	.9926442	3.71	0.002	1.592211	5.780804

Table 5.3.1A Regression Models for Roads in Priority Category 3 Const. (continued)

Stockpile Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate ELEV NO_TRUCKS PERC_TRUCKS ESAL lnsto
(obs=21)
```

	ELEV	NO_TRU~S	PERC_T~S	ESAL	lnsto
ELEV	1.0000				
NO_TRUCKS	-0.2658	1.0000			
PERC_TRUCKS	0.2966	0.1579	1.0000		
ESAL	-0.2794	0.7964	0.5357	1.0000	
lnsto	-0.0922	0.1846	0.1333	-0.0257	1.0000

```
. regress lnsto ELEV  NO_TRUCKS PERC_TRUCKS ESAL
```

Source	SS	df	MS
Model	28.8019504	4	7.20048759
Residual	34.2757755	16	2.14223597
Total	63.0777259	20	3.15388629

Number of obs =	21
F(4, 16) =	3.36
Prob > F =	0.0354
R-squared =	0.4566
Adj R-squared =	0.3208
Root MSE =	1.4636

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ELEV	-.0008527	.000382	-2.23	0.040	-.0016626	-.0000428
NO_TRUCKS	.0417033	.0126579	3.29	0.005	.0148697	.0685369
PERC_TRUCKS	.2784646	.0886838	3.14	0.006	.0904635	.4664658
ESAL	-.0534963	.015517	-3.45	0.003	-.0863908	-.0206018
_cons	2.629672	1.904097	1.38	0.186	-1.406834	6.666178

Table 5.3.2A Regression Models for Roads in Priority Category 3 - Flush Seal

Total Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lntot LYEAR ELEV NO_TRUCKS PERC_TRUCKS
(obs=87)

	lntot	LYEAR	ELEV	NO_TRU~S	PERC_T~S
lntot	1.0000				
LYEAR	-0.2059	1.0000			
ELEV	0.0769	0.0780	1.0000		
NO_TRUCKS	0.1592	-0.0129	-0.2832	1.0000	
PERC_TRUCKS	-0.2254	-0.1269	0.3046	0.3297	1.0000

. regress lntot LYEAR ELEV NO_TRUCKS PERC_TRUCKS

Source	SS	df	MS
Model	15.543163	4	3.88579074
Residual	40.3519287	82	.492096692
Total	55.8950917	86	.649942927

Number of obs =	87
F(4, 82) =	7.90
Prob > F =	0.0000
R-squared =	0.2781
Adj R-squared =	0.2429
Root MSE =	.7015

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	-.5555341	.1793324	-3.10	0.003	-.9122835	-.1987848
ELEV	.0002915	.0000838	3.48	0.001	.0001248	.0004583
NO_TRUCKS	.0075957	.0019203	3.96	0.000	.0037756	.0114158
PERC_TRUCKS	-.0562486	.0120881	-4.65	0.000	-.0802958	-.0322015
_cons	6.275678	.4458052	14.08	0.000	5.38883	7.162527

Table 5.3.2A Regression Models for Roads in Priority Category 3 - Flush Seal (continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnlabor LYEAR TEMP NO_TRUCKS PERC_TRUCKS
(obs=87)
```

	lnlabor	LYEAR	TEMP	NO_TRU~S	PERC_T~S
lnlabor	1.0000				
LYEAR	-0.1929	1.0000			
TEMP	-0.1567	0.0839	1.0000		
NO_TRUCKS	0.1362	-0.0129	-0.0203	1.0000	
PERC_TRUCKS	-0.3466	-0.1269	0.6399	0.3297	1.0000

```
. regress lnlabor LYEAR  TEMP  NO_TRUCKS PERC_TRUCKS
```

Source	SS	df	MS
Model	16.4939594	4	4.12348984
Residual	36.4460799	82	.444464389
Total	52.9400393	86	.615581852

Number of obs =	87
F(4, 82) =	9.28
Prob > F =	0.0000
R-squared =	0.3116
Adj R-squared =	0.2780
Root MSE =	.66668

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	-.5651844	.1735001	-3.26	0.002	-.9103314	-.2200374
TEMP	.37035	.1386356	2.67	0.009	.0945597	.6461403
NO_TRUCKS	.0064506	.0017441	3.70	0.000	.002981	.0099201
PERC_TRUCKS	-.0766201	.0144125	-5.32	0.000	-.1052912	-.0479489
_cons	6.553865	.2331919	28.11	0.000	6.089972	7.017758

Table 5.3.2A Regression Models for Roads in Priority Category 3 - Flush Seal (continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnhrs LYEAR NO_TRUCKS ESAL
(obs=87)
```

	lnhrs	LYEAR	NO_TRU~S	ESAL
lnhrs	1.0000			
LYEAR	-0.1497	1.0000		
NO_TRUCKS	0.1394	-0.0129	1.0000	
ESAL	-0.1181	-0.0543	0.8628	1.0000

```
. regress lnhrs LYEAR   NO_TRUCKS   ESAL
```

Source	SS	df	MS
Model	16.657972	3	5.55265732
Residual	43.3504664	83	.522294776
Total	60.0084384	86	.697772539

Number of obs =	87
F(3, 83) =	10.63
Prob > F =	0.0000
R-squared =	0.2776
Adj R-squared =	0.2515
Root MSE =	.7227

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	-.3679044	.1817438	-2.02	0.046	-.7293856	-.0064232
NO_TRUCKS	.0174837	.003335	5.24	0.000	.0108504	.0241169
ESAL	-.0132925	.0025512	-5.21	0.000	-.0183667	-.0082182
_cons	3.037596	.1765789	17.20	0.000	2.686388	3.388804

Table 5.3.2A Regression Models for Roads in Priority Category 3 - Flush Seal (continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnma AGE LYEAR ELEV PERC_TRUCKS ESAL
(obs=87)

	lnma	AGE	LYEAR	ELEV	PERC_T~S	ESAL
lnma	1.0000					
AGE	0.0774	1.0000				
LYEAR	-0.2122	0.3240	1.0000			
ELEV	0.0451	-0.1005	0.0780	1.0000		
PERC_TRUCKS	-0.0978	-0.2301	-0.1269	0.3046	1.0000	
ESAL	0.1051	-0.1829	-0.0543	-0.2156	0.6497	1.0000

. regress lnma AGE LYEAR ELEV PERC_TRUCKS ESAL

Source	SS	df	MS
Model	24.9979382	5	4.99958763
Residual	80.5531272	81	.994483052
Total	105.551065	86	1.22733797

Number of obs =	87
F(5, 81) =	5.03
Prob > F =	0.0005
R-squared =	0.2368
Adj R-squared =	0.1897
Root MSE =	.99724

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.1191276	.061718	1.93	0.057	-.0036718	.2419269
LYEAR	-.9185798	.2708991	-3.39	0.001	-1.457584	-.3795755
ELEV	.000437	.0001331	3.28	0.002	.0001722	.0007018
PERC_TRUCKS	-.0924199	.0240318	-3.85	0.000	-.1402355	-.0446042
ESAL	.0113262	.0028894	3.92	0.000	.0055771	.0170753
_cons	4.059284	.7043407	5.76	0.000	2.657867	5.460701

Table 5.3.2A Regression Models for Roads in Priority Category 3 - Flush Seal (continued)

Equipment Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lneq LYEAR ELEV NO_TRUCKS PERC_TRUCKS
(obs=87)
```

	lneq	LYEAR	ELEV	NO_TRU~S	PERC_T~S
lneq	1.0000				
LYEAR	-0.2220	1.0000			
ELEV	0.2051	0.0780	1.0000		
NO_TRUCKS	0.0211	-0.0129	-0.2832	1.0000	
PERC_TRUCKS	-0.1995	-0.1269	0.3046	0.3297	1.0000

```
. regress lneq LYEAR   ELEV  NO_TRUCKS PERC_TRUCKS
```

Source	SS	df	MS
Model	19.170877	4	4.79271925
Residual	52.4653884	82	.63982181
Total	71.6362654	86	.832979831

Number of obs =	87
F(4, 82) =	7.49
Prob > F =	0.0000
R-squared =	0.2676
Adj R-squared =	0.2319
Root MSE =	.79989

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	-.668649	.2044858	-3.27	0.002	-1.075436	-.2618616
ELEV	.0003992	.0000956	4.18	0.000	.000209	.0005893
NO_TRUCKS	.0060495	.0021897	2.76	0.007	.0016935	.0104054
PERC_TRUCKS	-.0585913	.0137836	-4.25	0.000	-.0860114	-.0311713
_cons	4.565725	.5083343	8.98	0.000	3.554486	5.576964

Table 5.3.2A Regression Models for Roads in Priority Category 3 - Flush Seal (continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate LYEAR ELEV AADT NO_TRUCKS ESAL lnsto
(obs=87)

	LYEAR	ELEV	AADT	NO_TRU~S	ESAL	lnsto
LYEAR	1.0000					
ELEV	0.0780	1.0000				
AADT	0.1125	-0.4387	1.0000			
NO_TRUCKS	-0.0129	-0.2832	0.5661	1.0000		
ESAL	-0.0543	-0.2156	0.1846	0.8628	1.0000	
lnsto	0.2179	-0.0874	0.0344	0.0975	-0.0352	1.0000

. regress lnsto LYEAR ELEV AADT NO_TRUCKS ESAL

Source	SS	df	MS
Model	20.7761809	5	4.15523619
Residual	58.4238941	81	.721282643
Total	79.200075	86	.920931105

Number of obs =	87
F(5, 81) =	5.76
Prob > F =	0.0001
R-squared =	0.2623
Adj R-squared =	0.2168
Root MSE =	.84928

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.6193973	.2178579	2.84	0.006	.1859285	1.052866
ELEV	-.0002582	.0001025	-2.52	0.014	-.0004621	-.0000543
AADT	-.0012161	.0002968	-4.10	0.000	-.0018066	-.0006256
NO_TRUCKS	.0334167	.0071245	4.69	0.000	.0192412	.0475921
ESAL	-.0210096	.0046032	-4.56	0.000	-.0301685	-.0118508
_cons	1.386547	.6008882	2.31	0.024	.1909675	2.582126

Table 5.3.3A Regression Models for Roads in Priority Category 3 – Chip Seal

Total Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lntot LENGTH DISTRICT
(obs=67)
```

	lntot	LENGTH	DISTRICT
lntot	1.0000		
LENGTH	-0.2691	1.0000	
DISTRICT	0.0917	0.5771	1.0000

```
. regress lntot LENGTH DISTRICT
```

Source	SS	df	MS
Model	6.27429429	2	3.13714714
Residual	32.0095478	64	.500149184
Total	38.2838421	66	.580058213

Number of obs =	67
F(2, 64) =	6.27
Prob > F =	0.0033
R-squared =	0.1639
Adj R-squared =	0.1378
Root MSE =	.70721

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LENGTH	-.0486206	.014094	-3.45	0.001	-.0767767	-.0204646
DISTRICT	.5030989	.1901182	2.65	0.010	.1232942	.8829036
_cons	6.790699	.4148678	16.37	0.000	5.961906	7.619493

Table 5.3.3A Regression Models for Roads in Priority Category 3 – Chip Seal (continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnlabor NO_TRUCKS PERC_TRUCKS
(obs=67)
```

	lnlabor	NO_TRU~S	PERC_T~S
lnlabor	1.0000		
NO_TRUCKS	0.0595	1.0000	
PERC_TRUCKS	-0.3890	0.3899	1.0000

```
. regress lnlabor NO_TRUCKS PERC_TRUCKS
```

Source	SS	df	MS
Model	7.74056787	2	3.87028393
Residual	30.2228803	64	.472232504
Total	37.9634481	66	.57520376

Number of obs	=	67
F(2, 64)	=	8.20
Prob > F	=	0.0007
R-squared	=	0.2039
Adj R-squared	=	0.1790
Root MSE	=	.68719

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
NO_TRUCKS	.0042463	.0020653	2.06	0.044	.0001203	.0083723
PERC_TRUCKS	-.0476946	.011884	-4.01	0.000	-.0714356	-.0239535
_cons	6.92351	.2213924	31.27	0.000	6.481228	7.365792

Table 5.3.3A Regression Models for Roads in Priority Category 3 – Chip Seal (continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnhrs NO_TRUCKS ESAL
(obs=67)
```

	lnhrs	NO_TRU~S	ESAL
lnhrs	1.0000		
NO_TRUCKS	0.0683	1.0000	
ESAL	-0.1572	0.8944	1.0000

```
. regress lnhrs NO_TRUCKS  ESAL
```

Source	SS	df	MS
Model	10.3003971	2	5.15019855
Residual	32.0756549	64	.501182108
Total	42.376052	66	.642061394

Number of obs =	67
F(2, 64) =	10.28
Prob > F =	0.0001
R-squared =	0.2431
Adj R-squared =	0.2194
Root MSE =	.70794

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
NO_TRUCKS	.0188254	.0043813	4.30	0.000	.0100727	.0275781
ESAL	-.0141033	.0031413	-4.49	0.000	-.0203787	-.0078279
_cons	3.011252	.1978104	15.22	0.000	2.61608	3.406424

Table 5.3.3A Regression Models for Roads in Priority Category 3 – Chip Seal (continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnma  ELEV TEMP NO_TRUCKS
(obs=62)
```

	lnma	ELEV	TEMP	NO_TRU~S
lnma	1.0000			
ELEV	0.0611	1.0000		
TEMP	-0.2124	0.6086	1.0000	
NO_TRUCKS	0.1803	-0.3082	-0.0223	1.0000

```
. regress lnma ELEV TEMP NO_TRUCKS
```

Source	SS	df	MS
Model	10.602	3	3.53400001
Residual	47.0221271	58	.81072633
Total	57.6241272	61	.944657823

Number of obs	=	62
F(3, 58)	=	4.36
Prob > F	=	0.0078
R-squared	=	0.1840
Adj R-squared	=	0.1418
Root MSE	=	.9004

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ELEV	.000404	.0001458	2.77	0.008	.0001121	.0006959
TEMP	-.6368337	.2045108	-3.11	0.003	-1.046206	-.2274609
NO_TRUCKS	.0064585	.0026866	2.40	0.019	.0010807	.0118362
_cons	4.807919	.6913504	6.95	0.000	3.424031	6.191807

Table 5.3.3A Regression Models for Roads in Priority Category 3 – Chip Seal (continued)

Equipment Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lneq  DISTRICT PERC_TRUCKS
(obs=67)
```

	lneq	DISTRICT	PERC_T~S
lneq	1.0000		
DISTRICT	0.1419	1.0000	
PERC_TRUCKS	-0.2353	0.4364	1.0000

```
. regress lneq DISTRICT     PERC_TRUCKS
```

Source	SS	df	MS
Model	6.61968699	2	3.3098435
Residual	44.5885999	64	.696696874
Total	51.2082869	66	.775883135

Number of obs =	67
F(2, 64) =	4.75
Prob > F =	0.0119
R-squared =	0.1293
Adj R-squared =	0.1021
Root MSE =	.83468

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
DISTRICT	.4747031	.2036754	2.33	0.023	.0678148	.8815915
PERC_TRUCKS	-.0418422	.0147736	-2.83	0.006	-.0713559	-.0123285
_cons	5.601589	.4707352	11.90	0.000	4.661187	6.54199

Table 5.3.3A Regression Models for Roads in Priority Category 3 – Chip Seal (continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate AGE ELEV lnsto
(obs=67)
```

	AGE	ELEV	lnsto
AGE	1.0000		
ELEV	-0.0831	1.0000	
lnsto	0.1805	-0.1855	1.0000

```
. regress lnsto AGE  ELEV
```

Source	SS	df	MS
Model	.764329399	2	.382164699
Residual	11.5953965	64	.18117807
Total	12.3597259	66	.187268574

Number of obs	= 67
F(2, 64)	= 2.11
Prob > F	= 0.1297
R-squared	= 0.0618
Adj R-squared	= 0.0325
Root MSE	= .42565

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.0419571	.0306637	1.37	0.176	-.0193007	.1032149
ELEV	-.0000712	.0000504	-1.41	0.163	-.0001719	.0000295
_cons	.3069394	.2695205	1.14	0.259	-.2314896	.8453684

Table 5.4.1A Regression Models for Roads in Priority Category 4 - After Const.

Total Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lntot LYEAR AADT ESAL
(obs=97)
```

	lntot	LYEAR	AADT	ESAL
lntot	1.0000			
LYEAR	0.4641	1.0000		
AADT	0.2634	0.1316	1.0000	
ESAL	-0.1415	0.1030	0.4080	1.0000

```
. regress lntot LYEAR     AADT    ESAL
```

Source	SS	df	MS
Model	19.4690863	3	6.48969544
Residual	36.9393469	93	.397197278
Total	56.4084332	96	.587587846

Number of obs =	97
F(3, 93) =	16.34
Prob > F =	0.0000
R-squared =	0.3451
Adj R-squared =	0.3240
Root MSE =	.63024

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.8256329	.1543776	5.35	0.000	.5190696	1.132196
AADT	.0010279	.0002821	3.64	0.000	.0004677	.0015881
ESAL	-.0096519	.0027291	-3.54	0.001	-.0150712	-.0042325
_cons	7.01172	.1372293	51.09	0.000	6.73921	7.28423

Table 5.4.1A Regression Models for Roads in Priority Category 4 - After Const. (Continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnlabor LYEAR ELEV NO_TRUCKS ESAL DIST2
(obs=97)
```

	lnlabor	LYEAR	ELEV	NO_TRU~S	ESAL	DIST2
lnlabor	1.0000					
LYEAR	0.3734	1.0000				
ELEV	0.2632	0.0294	1.0000			
NO_TRUCKS	-0.1455	0.0846	-0.4947	1.0000		
ESAL	-0.1694	0.1030	-0.3790	0.9267	1.0000	
DIST2	0.1507	-0.0618	-0.1623	0.0643	0.1632	1.0000

```
. regress lnlabor LYEAR   ELEV   NO_TRUCKS  ESAL DIST2
```

Source	SS	df	MS
Model	16.8106164	5	3.36212329
Residual	36.0620827	91	.396286623
Total	52.8726991	96	.550757282

Number of obs =	97
F(5, 91) =	8.48
Prob > F =	0.0000
R-squared =	0.3179
Adj R-squared =	0.2805
Root MSE =	.62951

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.710389	.1543174	4.60	0.000	.4038564	1.016922
ELEV	.0002533	.0000773	3.28	0.001	.0000997	.0004069
NO_TRUCKS	.0270238	.0109686	2.46	0.016	.005236	.0488115
ESAL	-.0211725	.0072303	-2.93	0.004	-.0355346	-.0068103
DIST2	.4607353	.1383665	3.33	0.001	.1858873	.7355834
_cons	4.622466	.4983412	9.28	0.000	3.632573	5.61236

Table 5.4.1A Regression Models for Roads in Priority Category 4 - After Const. (Continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnhrs LYEAR ELEV NO_TRUCKS ESAL DIST2
(obs=97)
```

	lnhrs	LYEAR	ELEV	NO_TRU~S	ESAL	DIST2
lnhrs	1.0000					
LYEAR	0.4297	1.0000				
ELEV	0.2420	0.0294	1.0000			
NO_TRUCKS	-0.0997	0.0846	-0.4947	1.0000		
ESAL	-0.1390	0.1030	-0.3790	0.9267	1.0000	
DIST2	0.1406	-0.0618	-0.1623	0.0643	0.1632	1.0000

```
. regress lnhrs LYEAR  ELEV   NO_TRUCKS  ESAL  DIST2
```

Source	SS	df	MS
Model	20.433887	5	4.0867774
Residual	35.7594681	91	.392961188
Total	56.1933551	96	.585347449

Number of obs =	97
F(5, 91) =	10.40
Prob > F =	0.0000
R-squared =	0.3636
Adj R-squared =	0.3287
Root MSE =	.62687

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.8320969	.1536686	5.41	0.000	.5268532	1.137341
ELEV	.0002669	.000077	3.47	0.001	.0001139	.0004198
NO_TRUCKS	.0337088	.0109224	3.09	0.003	.0120127	.0554049
ESAL	-.0247923	.0071999	-3.44	0.001	-.0390941	-.0104905
DIST2	.4781939	.1377847	3.47	0.001	.2045014	.7518864
_cons	1.146021	.4962459	2.31	0.023	.1602893	2.131752

Table 5.4.1A Regression Models for Roads in Priority Category 4 - After Const. (Continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnma LYEAR DISTRICT AADT
(obs=96)

	lnma	LYEAR	DISTRICT	AADT
lnma	1.0000			
LYEAR	0.6164	1.0000		
DISTRICT	0.2878	0.0782	1.0000	
AADT	0.3262	0.1300	-0.0158	1.0000

. regress lnma LYEAR DISTRICT AADT

Source	SS	df	MS
Model	36.0895022	3	12.0298341
Residual	35.722767	92	.388290945
Total	71.8122692	95	.755918623

Number of obs =	96
F(3, 92) =	30.98
Prob > F =	0.0000
R-squared =	0.5026
Adj R-squared =	0.4863
Root MSE =	.62313

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	1.159882	.1531137	7.58	0.000	.8557849	1.463979
DISTRICT	.3246571	.0966719	3.36	0.001	.1326583	.5166559
AADT	.0008858	.0002558	3.46	0.001	.0003777	.0013939
_cons	4.764602	.2352068	20.26	0.000	4.297461	5.231743

Table 5.4.1A Regression Models for Roads in Priority Category 4 - After Const. (Continued)

Equipment Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lneq LYEAR ELEV NO_TRUCKS ESAL DIST2
(obs=97)
```

	lneq	LYEAR	ELEV	NO_TRU~S	ESAL	DIST2
lneq	1.0000					
LYEAR	0.2380	1.0000				
ELEV	0.2617	0.0294	1.0000			
NO_TRUCKS	-0.1145	0.0846	-0.4947	1.0000		
ESAL	-0.1488	0.1030	-0.3790	0.9267	1.0000	
DIST2	0.0607	-0.0618	-0.1623	0.0643	0.1632	1.0000

```
. regress lneq LYEAR  ELEV  NO_TRUCKS  ESAL  DIST2
```

Source	SS	df	MS
Model	15.6175938	5	3.12351875
Residual	65.2337384	91	.716854268
Total	80.8513322	96	.842201377

Number of obs	=	97
F(5, 91)	=	4.36
Prob > F	=	0.0013
R-squared	=	0.1932
Adj R-squared	=	0.1488
Root MSE	=	.84667

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.5561298	.2075514	2.68	0.009	.1438544	.9684051
ELEV	.0003223	.000104	3.10	0.003	.0001157	.0005289
NO_TRUCKS	.0343586	.0147523	2.33	0.022	.0050549	.0636623
ESAL	-.0247739	.0097245	-2.55	0.013	-.0440905	-.0054573
DIST2	.3765915	.186098	2.02	0.046	.0069306	.7462523
_cons	3.779967	.6702511	5.64	0.000	2.448595	5.111338

Table 5.4.1A Regression Models for Roads in Priority Category 4 - After Const. (Continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnsto AGE LYEAR LENGTH ELEV TEMP NO_TRUCKS ESAL DIST2
(obs=12)

	lnsto	AGE	LYEAR	LENGTH	ELEV	TEMP	NO_TRU~S	ESAL	DIST2
lnsto	1.0000								
AGE	-0.0552	1.0000							
LYEAR	0.3852	0.3021	1.0000						
LENGTH	0.1932	0.2400	-0.1097	1.0000					
ELEV	-0.3302	0.6471	-0.1367	0.6272	1.0000				
TEMP	0.4719	-0.3618	0.1625	0.3738	-0.4264	1.0000			
NO_TRUCKS	0.0940	-0.2225	0.3462	-0.0623	-0.4726	0.7550	1.0000		
ESAL	-0.2165	-0.2136	0.1587	-0.1875	-0.3879	0.5400	0.9276	1.0000	
DIST2	-0.5709	0.2703	0.0286	-0.6749	0.1471	-0.8591	-0.3272	-0.0863	1.0000

. regress lnsto AGE LYEAR LENGTH ELEV TEMP NO_TRUCKS ESAL DIST2

Source	SS	df	MS
Model	8.48883923	8	1.0611049
Residual	.072662155	3	.024220718
Total	8.56150139	11	.778318308

Number of obs =	12
F(8, 3) =	43.81
Prob > F =	0.0051
R-squared =	0.9915
Adj R-squared =	0.9689
Root MSE =	.15563

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	1.1901	.1311966	9.07	0.003	.7725735	1.607626
LYEAR	-1.245036	.2302904	-5.41	0.012	-1.977923	-.5121494
LENGTH	1.581587	.1796949	8.80	0.003	1.009718	2.153457
ELEV	-.014663	.0016262	-9.02	0.003	-.0198384	-.0094877
TEMP	-4.887966	.9079756	-5.38	0.013	-7.77755	-1.998383
NO_TRUCKS	.1724459	.050178	3.44	0.041	.0127573	.3321346
ESAL	-.0678523	.0199266	-3.41	0.042	-.1312677	-.004437
DIST2	26.49822	3.532628	7.50	0.005	15.25582	37.74061
_cons	41.2227	4.107304	10.04	0.002	28.15142	54.29397

Table 5.4.2A Regression Models for Roads in Priority Category 4 - After Flush

Total Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lntot AGE LYEAR DISTRICT ELEV TEMP PERC_TRUCKS
(obs=78)
```

	lntot	AGE	LYEAR	DISTRICT	ELEV	TEMP	PERC_T~S
lntot	1.0000						
AGE	0.2350	1.0000					
LYEAR	0.6587	0.5305	1.0000				
DISTRICT	-0.3061	-0.0473	0.0020	1.0000			
ELEV	0.3070	-0.0182	0.0160	-0.3771	1.0000		
TEMP	0.0114	-0.0775	0.0565	-0.2795	0.6246	1.0000	
PERC_TRUCKS	-0.2397	-0.3388	0.0209	0.1035	-0.3472	0.0752	1.0000

```
. regress lntot AGE LYEAR  DISTRICT ELEV TEMP PERC_TRUCKS
```

Source	SS	df	MS
Model	65.8014315	6	10.9669052
Residual	27.4731283	71	.38694547
Total	93.2745598	77	1.21135792

Number of obs	= 78
F(6, 71)	= 28.34
Prob > F	= 0.0000
R-squared	= 0.7055
Adj R-squared	= 0.6806
Root MSE	= .62205

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	-.236474	.0649962	-3.64	0.001	-.3660727	-.1068754
LYEAR	2.144686	.2024357	10.59	0.000	1.741041	2.548331
DISTRICT	-.391052	.100595	-3.89	0.000	-.5916328	-.1904712
ELEV	.0003949	.000127	3.11	0.003	.0001416	.0006481
TEMP	-.4724195	.1347916	-3.50	0.001	-.7411864	-.2036526
PERC_TRUCKS	-.0235862	.0097111	-2.43	0.018	-.0429496	-.0042228
_cons	7.681544	.76916	9.99	0.000	6.147882	9.215205

Table 5.4.2A Regression Models for Roads in Priority Category 4 - After Flush (Continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnlabor AGE LYEAR LENGTH DISTRICT ELEV TEMP PERC_TRUCKS
(obs=78)
```

	lnlabor	AGE	LYEAR	LENGTH	DISTRICT	ELEV	TEMP	PERC_T~S
lnlabor	1.0000							
AGE	0.2274	1.0000						
LYEAR	0.5270	0.5305	1.0000					
LENGTH	-0.2778	-0.0311	0.0016	1.0000				
DISTRICT	-0.3589	-0.0473	0.0020	0.0825	1.0000			
ELEV	0.3489	-0.0182	0.0160	0.1762	-0.3771	1.0000		
TEMP	-0.0415	-0.0775	0.0565	0.3697	-0.2795	0.6246	1.0000	
PERC_TRUCKS	-0.3121	-0.3388	0.0209	0.0967	0.1035	-0.3472	0.0752	1.0000

```
. regress lnlabor AGE LYEAR LENGTH DISTRICT ELEV TEMP   PERC_TRUCKS
```

Source	SS	df	MS
Model	51.7257212	7	7.38938874
Residual	25.6051087	70	.365787267
Total	77.3308298	77	1.00429649

Number of obs =	78
F(7, 70) =	20.20
Prob > F =	0.0000
R-squared =	0.6689
Adj R-squared =	0.6358
Root MSE =	.6048

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	-.1560025	.0632992	-2.46	0.016	-.2822488	-.0297563
LYEAR	1.542002	.1971177	7.82	0.000	1.148863	1.935141
LENGTH	-.0400732	.0160911	-2.49	0.015	-.0721658	-.0079806
DISTRICT	-.3618926	.0998497	-3.62	0.001	-.5610365	-.1627487
ELEV	.0004823	.0001235	3.91	0.000	.000236	.0007286
TEMP	-.4785546	.137896	-3.47	0.001	-.7535795	-.2035297
PERC_TRUCKS	-.0194655	.0094622	-2.06	0.043	-.0383372	-.0005937
_cons	6.368793	.7483418	8.51	0.000	4.876272	7.861313

Table 5.4.2A Regression Models for Roads in Priority Category 4 - After Flush (Continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnhrs LYEAR LENGTH DISTRICT ELEV TEMP
(obs=78)
```

	lnhrs	LYEAR	LENGTH	DISTRICT	ELEV	TEMP
lnhrs	1.0000					
LYEAR	0.5661	1.0000				
LENGTH	-0.3226	0.0016	1.0000			
DISTRICT	-0.3388	0.0020	0.0825	1.0000		
ELEV	0.2437	0.0160	0.1762	-0.3771	1.0000	
TEMP	-0.1364	0.0565	0.3697	-0.2795	0.6246	1.0000

```
. regress lnhrs LYEAR  LENGTH DISTRICT ELEV TEMP
```

Source	SS	df	MS
Model	52.9190743	5	10.5838149
Residual	26.739045	72	.371375625
Total	79.6581193	77	1.03452103

Number of obs =	78
F(5, 72) =	28.50
Prob > F =	0.0000
R-squared =	0.6643
Adj R-squared =	0.6410
Root MSE =	.60941

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	1.37743	.1611215	8.55	0.000	1.05624	1.698619
LENGTH	-.0460229	.0161704	-2.85	0.006	-.0782581	-.0137877
DISTRICT	-.3705877	.1000224	-3.71	0.000	-.5699787	-.1711968
ELEV	.0005204	.000106	4.91	0.000	.000309	.0007318
TEMP	-.6163722	.1294435	-4.76	0.000	-.8744132	-.3583312
_cons	2.666096	.5811334	4.59	0.000	1.507627	3.824564

Table 5.4.2A Regression Models for Roads in Priority Category 4 - After Flush (Continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnma AGE LYEAR DISTRICT TEMP
(obs=78)
```

	lnma	AGE	LYEAR	DISTRICT	TEMP
lnma	1.0000				
AGE	0.1874	1.0000			
LYEAR	0.6797	0.5305	1.0000		
DISTRICT	-0.1727	-0.0473	0.0020	1.0000	
TEMP	-0.0314	-0.0775	0.0565	-0.2795	1.0000

```
. regress lnma AGE LYEAR  DISTRICT  TEMP
```

Source	SS	df	MS
Model	110.654299	4	27.6635748
Residual	85.8858506	73	1.1765185
Total	196.54015	77	2.55246948

Number of obs =	78
F(4, 73) =	23.51
Prob > F =	0.0000
R-squared =	0.5630
Adj R-squared =	0.5391
Root MSE =	1.0847

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	-.3097851	.1017204	-3.05	0.003	-.5125135	-.1070566
LYEAR	3.102206	.3405961	9.11	0.000	2.423399	3.781013
DISTRICT	-.4882199	.1689013	-2.89	0.005	-.8248397	-.1516002
TEMP	-.359703	.1769238	-2.03	0.046	-.7123115	-.0070944
_cons	8.107597	.6315258	12.84	0.000	6.848968	9.366226

Table 5.4.2A Regression Models for Roads in Priority Category 4 - After Flush (Continued)

Equipment Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lneq AGE LYEAR DISTRICT ELEV TEMP NO_TRUCKS ESAL
(obs=78)
```

	lneq	AGE	LYEAR	DISTRICT	ELEV	TEMP	NO_TRU~S	ESAL
lneq	1.0000							
AGE	0.0206	1.0000						
LYEAR	0.3827	0.5305	1.0000					
DISTRICT	-0.4400	-0.0473	0.0020	1.0000				
ELEV	0.4377	-0.0182	0.0160	-0.3771	1.0000			
TEMP	0.0929	-0.0775	0.0565	-0.2795	0.6246	1.0000		
NO_TRUCKS	-0.2404	-0.1462	0.0736	0.1266	-0.5097	-0.2583	1.0000	
ESAL	-0.2129	-0.1853	0.0404	0.2765	-0.3961	-0.0904	0.8345	1.0000

```
. regress lneq AGE LYEAR  DISTRICT ELEV TEMP  NO_TRUCKS  ESAL
```

Source	SS	df	MS
Model	67.6093899	7	9.65848427
Residual	42.6176523	70	.608823604
Total	110.227042	77	1.43152003

Number of obs	=	78
F(7, 70)	=	15.86
Prob > F	=	0.0000
R-squared	=	0.6134
Adj R-squared	=	0.5747
Root MSE	=	.78027

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	-.2949175	.0762021	-3.87	0.000	-.4468978	-.1429372
LYEAR	1.695137	.2519931	6.73	0.000	1.192553	2.197721
DISTRICT	-.7111463	.1372243	-5.18	0.000	-.9848316	-.4374609
ELEV	.0005963	.000154	3.87	0.000	.0002891	.0009034
TEMP	-.7376608	.1634484	-4.51	0.000	-1.063648	-.4116733
NO_TRUCKS	-.0206603	.0072708	-2.84	0.006	-.0351615	-.0061591
ESAL	.0137681	.0063527	2.17	0.034	.001098	.0264381
_cons	6.478311	1.006946	6.43	0.000	4.470021	8.486602

Table 5.4.2A Regression Models for Roads in Priority Category 4 - After Flush Continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnsto AGE DISTRICT TEMP
(obs=17)
```

	lnsto	AGE	DISTRICT	TEMP
lnsto	1.0000			
AGE	0.4222	1.0000		
DISTRICT	0.5307	-0.2659	1.0000	
TEMP	-0.0619	0.2471	0.2432	1.0000

```
. regress lnsto AGE   DISTRICT   TEMP
```

Source	SS	df	MS
Model	18.8157902	3	6.27193006
Residual	4.83381069	13	.371831592
Total	23.6496009	16	1.47810005

Number of obs =	17
F(3, 13) =	16.87
Prob > F =	0.0001
R-squared =	0.7956
Adj R-squared =	0.7484
Root MSE =	.60978

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.8152766	.1482904	5.50	0.000	.4949147	1.135639
DISTRICT	1.822346	.2980004	6.12	0.000	1.178556	2.466137
TEMP	-.8932113	.2695889	-3.31	0.006	-1.475623	-.3107998
_cons	-1.45719	.9774176	-1.49	0.160	-3.568773	.654392

Table 5.4.3A Regression Models for Roads in Priority Category 4 - After Chip1

Total Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lntot ESAL AGE
(obs=89)

             |    lntot     ESAL      AGE
-------------+---------------------------
       lntot |   1.0000
        ESAL |  -0.3594   1.0000
         AGE |   0.1803   0.0913   1.0000


. regress lntot AGE      ESAL

      Source |       SS       df       MS              Number of obs =      89
-------------+------------------------------           F(  2,    86) =    9.12
       Model |  13.2457454     2  6.6228727            Prob > F      =  0.0003
    Residual |  62.4546073    86  .726216364           R-squared     =  0.1750
-------------+------------------------------           Adj R-squared =  0.1558
       Total |  75.7003527    88  .86023128            Root MSE      =  .85218

------------------------------------------------------------------------------
       lntot |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         AGE |   .0984699   .0450783     2.18   0.032     .0088572    .1880826
        ESAL |  -.0210853   .0054712    -3.85   0.000    -.0319617   -.010209
       _cons |   7.409676   .2375515    31.19   0.000     6.937439    7.881913
------------------------------------------------------------------------------
```

Table 5.4.3A Regression Models for Roads in Priority Category 4 - After Chip1 (Continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate AGE  NO_TRUCKS ESAL lnlabor
(obs=89)
```

	AGE	NO_TRU~S	ESAL	lnlabor
AGE	1.0000			
NO_TRUCKS	-0.0385	1.0000		
ESAL	0.0913	0.9354	1.0000	
lnlabor	0.2150	-0.2716	-0.3600	1.0000

```
. regress lnlabor AGE   NO_TRUCKS   ESAL
```

Source	SS	df	MS
Model	20.0058739	3	6.66862462
Residual	52.5372602	85	.618085414
Total	72.5431341	88	.824353796

Number of obs =	89
F(3, 85) =	10.79
Prob > F =	0.0000
R-squared =	0.2758
Adj R-squared =	0.2502
Root MSE =	.78618

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.1612536	.0444267	3.63	0.000	.0729214	.2495857
NO_TRUCKS	.0486229	.0154652	3.14	0.002	.0178738	.0793719
ESAL	-.0660357	.0152333	-4.33	0.000	-.0963236	-.0357479
_cons	6.381765	.2283358	27.95	0.000	5.927772	6.835758

Table 5.4.3A Regression Models for Roads in Priority Category 4 - After Chip1 (Continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnhrs  AGE ELEV
(obs=89)
```

	lnhrs	AGE	ELEV
lnhrs	1.0000		
AGE	0.1999	1.0000	
ELEV	0.2715	-0.0296	1.0000

```
. regress lnhrs ELEV       AGE
```

Source	SS	df	MS
Model	8.96832981	2	4.48416491
Residual	67.6829193	86	.78701069
Total	76.6512492	88	.871036922

Number of obs	=	89
F(2, 86)	=	5.70
Prob > F	=	0.0047
R-squared	=	0.1170
Adj R-squared	=	0.0965
Root MSE	=	.88714

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ELEV	.0001823	.0000665	2.74	0.007	.00005	.0003146
AGE	.0959699	.0467519	2.05	0.043	.0030302	.1889096
_cons	1.687678	.3694637	4.57	0.000	.9532083	2.422147

Table 5.4.3A Regression Models for Roads in Priority Category 4 - After Chip1 (Continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnma TEMP
(obs=88)

	lnma	TEMP
lnma	1.0000	
TEMP	-0.3742	1.0000

. regress lnma TEMP

Source	SS	df	MS
Model	16.5414894	1	16.5414894
Residual	101.596884	86	1.18135912
Total	118.138373	87	1.35791234

Number of obs =	88
F(1, 86) =	14.00
Prob > F =	0.0003
R-squared =	0.1400
Adj R-squared =	0.1300
Root MSE =	1.0869

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
TEMP	-.3907019	.1044117	-3.74	0.000	-.5982655	-.1831383
_cons	6.202785	.2513581	24.68	0.000	5.703102	6.702469

Table 5.4.3A Regression Models for Roads in Priority Category 4 - After Chip1 (Continued)

Equipment Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lneq AGE NO_TRUCKS ESAL
(obs=89)
```

	lneq	AGE	NO_TRU~S	ESAL
lneq	1.0000			
AGE	0.1885	1.0000		
NO_TRUCKS	-0.2909	-0.0385	1.0000	
ESAL	-0.3698	0.0913	0.9354	1.0000

```
. regress lneq AGE   NO_TRUCKS   ESAL
```

Source	SS	df	MS
Model	24.8972955	3	8.2990985
Residual	75.0231739	85	.882625576
Total	99.9204694	88	1.13545988

Number of obs =	89
F(3, 85) =	9.40
Prob > F =	0.0000
R-squared =	0.2492
Adj R-squared =	0.2227
Root MSE =	.93948

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.167707	.0530894	3.16	0.002	.062151	.273263
NO_TRUCKS	.0491978	.0184808	2.66	0.009	.0124531	.0859426
ESAL	-.0706651	.0182036	-3.88	0.000	-.1068587	-.0344714
_cons	5.964231	.2728589	21.86	0.000	5.421714	6.506747

Table 5.4.3A Regression Models for Roads in Priority Category 4 - After Chip1 (Continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate NO_TR ESAL lnsto
(obs=89)

	NO_TR	ESAL	lnsto
NO_TR	1.0000		
ESAL	0.9354	1.0000	
lnsto	0.2331	0.1442	1.0000

. regress lnsto NO_TR ESAL

Source	SS	df	MS
Model	9.90066837	2	4.95033419
Residual	91.2451981	86	1.06099068
Total	101.145866	88	1.14938485

Number of obs	=	89
F(2, 86)	=	4.67
Prob > F	=	0.0119
R-squared	=	0.0979
Adj R-squared	=	0.0769
Root MSE	=	1.03

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
NO_TR	.05142	.0189672	2.71	0.008	.0137144	.0891255
ESAL	-.0379406	.0186186	-2.04	0.045	-.0749531	-.0009281
_cons	-.1219156	.2456961	-0.50	0.621	-.6103433	.3665121

Table 5.4.4A Regression Models for Roads in Priority Category 4 - After Chip2

Total Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lntot LYEAR LENGTH ELEV TEMP DIST1
(obs=110)
```

	lntot	LYEAR	LENGTH	ELEV	TEMP	DIST1
lntot	1.0000					
LYEAR	0.6607	1.0000				
LENGTH	0.0755	0.0097	1.0000			
ELEV	-0.0179	0.0664	0.2045	1.0000		
TEMP	0.1225	0.0538	-0.4609	0.0003	1.0000	
DIST1	0.1752	0.0549	-0.4520	0.1807	0.9269	1.0000

```
. regress lntot LYEAR LENGTH ELEV TEMP    DIST1
```

Source	SS	df	MS
Model	71.73214	5	14.346428
Residual	63.8201433	104	.613655224
Total	135.552283	109	1.24359893

Number of obs =	110
F(5, 104) =	23.38
Prob > F =	0.0000
R-squared =	0.5292
Adj R-squared =	0.5065
Root MSE =	.78336

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	1.833821	.1874925	9.78	0.000	1.462017	2.205626
LENGTH	.0439113	.0154274	2.85	0.005	.0133183	.0745044
ELEV	-.0002154	.0000702	-3.07	0.003	-.0003546	-.0000761
TEMP	-.5283168	.2034104	-2.60	0.011	-.9316872	-.1249463
DIST1	1.721629	.4677684	3.68	0.000	.7940263	2.649231
_cons	8.061696	.478116	16.86	0.000	7.113574	9.009818

Table 5.4.4A Regression Models for Roads in Priority Category 4 - After Chip2 (Continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate LYEAR AADT PERC_TRUCKS DIST1
(obs=110)

	LYEAR	AADT	PERC_T~S	DIST1
LYEAR	1.0000			
AADT	0.0769	1.0000		
PERC_TRUCKS	-0.0472	-0.2625	1.0000	
DIST1	0.0549	-0.1376	0.4059	1.0000

. regress lnlabor LYEAR AADT PERC_TRUCKS DIST1

Source	SS	df	MS
Model	38.7010407	4	9.67526017
Residual	50.2961235	105	.4790107
Total	88.9971642	109	.816487745

Number of obs =	110
F(4, 105) =	20.20
Prob > F =	0.0000
R-squared =	0.4349
Adj R-squared =	0.4133
Root MSE =	.69211

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	1.248038	.1661118	7.51	0.000	.9186687	1.577407
AADT	-.0011846	.0004583	-2.59	0.011	-.0020932	-.000276
PERC_TRUCKS	-.0265551	.0069258	-3.83	0.000	-.0402876	-.0128225
DIST1	.4187281	.1458818	2.87	0.005	.1294715	.7079848
_cons	6.844238	.2003567	34.16	0.000	6.446968	7.241508

Table 5.4.4A Regression Models for Roads in Priority Category 4 - After Chip2 (Continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate LYEAR DISTRICT AADT PERC_TRUCKS lnhrs
(obs=110)

	LYEAR	DISTRICT	AADT	PERC_T~S	lnhrs
LYEAR	1.0000				
DISTRICT	-0.0205	1.0000			
AADT	0.0769	0.0836	1.0000		
PERC_TRUCKS	-0.0472	-0.2285	-0.2625	1.0000	
lnhrs	0.5913	-0.1399	-0.0786	-0.1979	1.0000

. regress lnhrs LYEAR DISTRICT AADT PERC_TRUCKS

Source	SS	df	MS
Model	39.8195309	4	9.95488272
Residual	51.3186212	105	.488748773
Total	91.1381521	109	.836129836

Number of obs	= 110
F(4, 105)	= 20.37
Prob > F	= 0.0000
R-squared	= 0.4369
Adj R-squared	= 0.4155
Root MSE	= .69911

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	1.340976	.1672998	8.02	0.000	1.009252	1.672701
DISTRICT	-.2349579	.103148	-2.28	0.025	-.4394813	-.0304345
AADT	-.0010741	.0004627	-2.32	0.022	-.0019915	-.0001567
PERC_TRUCKS	-.0216962	.0065979	-3.29	0.001	-.0347786	-.0086138
_cons	4.021273	.2776015	14.49	0.000	3.47084	4.571705

Table 5.4.4A Regression Models for Roads in Priority Category 4 - After Chip2 (Continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate LYEAR LENGTH DISTRICT lneq
(obs=110)
```

	LYEAR	LENGTH	DISTRICT	lneq
LYEAR	1.0000			
LENGTH	0.0097	1.0000		
DISTRICT	-0.0205	0.4151	1.0000	
lneq	0.4839	0.1105	-0.2388	1.0000

```
. regress lnnma LYEAR LENGTH DISTRICT
```

Source	SS	df	MS
Model	128.602143	3	42.8673811
Residual	151.13946	106	1.42584396
Total	279.741603	109	2.56643672

Number of obs =	110
F(3, 106) =	30.06
Prob > F =	0.0000
R-squared =	0.4597
Adj R-squared =	0.4444
Root MSE =	1.1941

lnnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	2.466831	.2847462	8.66	0.000	1.902294	3.031368
LENGTH	.0475155	.0217886	2.18	0.031	.0043175	.0907135
DISTRICT	-.6710021	.1884322	-3.56	0.001	-1.044587	-.2974169
_cons	6.22569	.3158628	19.71	0.000	5.599461	6.851918

Table 5.4.4A Regression Models for Roads in Priority Category 4 - After Chip2 (Continued)

Equipment Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lneq LYEAR LENGTH DISTRICT NO_TRUCKS
(obs=110)

	lneq	LYEAR	LENGTH	DISTRICT	NO_TRU~S
lneq	1.0000				
LYEAR	0.4839	1.0000			
LENGTH	0.1105	0.0097	1.0000		
DISTRICT	-0.2388	-0.0205	0.4151	1.0000	
NO_TRUCKS	-0.2529	-0.0186	-0.3021	-0.1631	1.0000

. regress lneq LYEAR ELEV NO_TRUCKS ESAL DIST2

Source	SS	df	MS
Model	15.6175938	5	3.12351875
Residual	65.2337384	91	.716854268
Total	80.8513322	96	.842201377

Number of obs =	97
F(5, 91) =	4.36
Prob > F =	0.0013
R-squared =	0.1932
Adj R-squared =	0.1488
Root MSE =	.84667

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.5561298	.2075514	2.68	0.009	.1438544	.9684051
ELEV	.0003223	.000104	3.10	0.003	.0001157	.0005289
NO_TRUCKS	.0343586	.0147523	2.33	0.022	.0050549	.0636623
ESAL	-.0247739	.0097245	-2.55	0.013	-.0440905	-.0054573
DIST2	.3765915	.186098	2.02	0.046	.0069306	.7462523
_cons	3.779967	.6702511	5.64	0.000	2.448595	5.111338

Table 5.4.4A Regression Models for Roads in Priority Category 4 - After Chip2 (Continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate AGE LENGTH ELEV TEMP NO_TRUCKS PERC_TRUCKS ESAL DIST1
(obs=110)
```

	AGE	LENGTH	ELEV	TEMP	NO_TRU~S	PERC_T~S	ESAL	DIST1
AGE	1.0000							
LENGTH	-0.0352	1.0000						
ELEV	-0.1556	0.2045	1.0000					
TEMP	-0.1925	-0.4609	0.0003	1.0000				
NO_TRUCKS	-0.2193	-0.3021	0.0068	0.3728	1.0000			
PERC_TRUCKS	-0.2274	-0.2760	0.1803	0.4590	0.6988	1.0000		
ESAL	-0.1306	-0.2837	-0.0007	0.3628	0.9603	0.6256	1.0000	
DIST1	-0.1962	-0.4520	0.1807	0.9269	0.3137	0.4059	0.2856	1.0000

```
. regress lnsto AGE  LENGTH ELEV TEMP  NO_TRUCKS PERC_TRUCKS ESAL DIST1
```

Source	SS	df	MS
Model	107.651414	8	13.4564268
Residual	223.453894	101	2.21241479
Total	331.105308	109	3.03766337

Number of obs =	110
F(8, 101) =	6.08
Prob > F =	0.0000
R-squared =	0.3251
Adj R-squared =	0.2717
Root MSE =	1.4874

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.239226	.0784062	3.05	0.003	.0836892	.3947627
LENGTH	-.0785296	.0302553	-2.60	0.011	-.1385481	-.0185112
ELEV	.0006951	.0001439	4.83	0.000	.0004096	.0009806
TEMP	1.938398	.4304056	4.50	0.000	1.084589	2.792207
NO_TRUCKS	.0863577	.0214371	4.03	0.000	.0438323	.1288831
PERC_TRUCKS	-.0869636	.0212588	-4.09	0.000	-.1291353	-.0447918
ESAL	-.0577581	.0169261	-3.41	0.001	-.0913349	-.0241814
DIST1	-4.746338	.9424559	-5.04	0.000	-6.615917	-2.876759
_cons	-4.528344	1.099818	-4.12	0.000	-6.710087	-2.346602

Table 5.5.1A Regression Models for Roads in Priority Category 5-1

Total Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lntot AGE LYEAR ELEV NO_TRUCKS
(obs=159)
```

	lntot	AGE	LYEAR	ELEV	NO_TRU~S
lntot	1.0000				
AGE	0.3100	1.0000			
LYEAR	0.4606	0.3906	1.0000		
ELEV	0.2884	-0.1161	0.0518	1.0000	
NO_TRUCKS	-0.1829	-0.0618	0.0126	0.1391	1.0000

```
. regress lntot AGE LYEAR   ELEV  NO_TRUCKS
```

Source	SS	df	MS
Model	62.1471337	4	15.5367834
Residual	108.929789	154	.707336295
Total	171.076923	158	1.08276534

Number of obs	=	159
F(4, 154)	=	21.97
Prob > F	=	0.0000
R-squared	=	0.3633
Adj R-squared	=	0.3467
Root MSE	=	.84103

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.1159946	.0436563	2.66	0.009	.0297522	.2022371
LYEAR	.8923423	.1679856	5.31	0.000	.5604887	1.224196
ELEV	.0004304	.0000879	4.90	0.000	.0002568	.000604
NO_TRUCKS	-.0121785	.003588	-3.39	0.001	-.0192666	-.0050904
_cons	4.836265	.4583481	10.55	0.000	3.930804	5.741726

Table 5.5.1A Regression Models for Roads in Priority Category 5-1 (continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnlabor LYEAR ELEVATION AADT NO_TRUCKS ESAL
(obs=159)
```

	lnlabor	LYEAR	ELEVAT~N	AADT	NO_TRU~S	ESAL
lnlabor	1.0000					
LYEAR	0.3705	1.0000				
ELEVATION	0.3022	0.0518	1.0000			
AADT	-0.0915	0.0673	0.1368	1.0000		
NO_TRUCKS	-0.2073	0.0126	0.1391	0.8080	1.0000	
ESAL	-0.1652	-0.0045	0.1993	0.6374	0.9440	1.0000

```
. regress lnlabor LYEAR ELEVATION AADT NO_TRUCKS ESAL
```

Source	SS	df	MS
Model	44.1826117	5	8.83652234
Residual	99.906016	153	.652980497
Total	144.088628	158	.91195334

Number of obs =	159
F(5, 153) =	13.53
Prob > F =	0.0000
R-squared =	0.3066
Adj R-squared =	0.2840
Root MSE =	.80807

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.7657338	.1485627	5.15	0.000	.4722348	1.059233
ELEVATION	.0003346	.0000879	3.81	0.000	.0001609	.0005083
AADT	.004946	.0022151	2.23	0.027	.0005699	.0093222
NO_TRUCKS	-.053462	.0184092	-2.90	0.004	-.089831	-.0170931
ESAL	.0232371	.01166	1.99	0.048	.0002018	.0462724
_cons	4.467349	.4228828	10.56	0.000	3.631906	5.302792

Table 5.5.1A Regression Models for Roads in Priority Category 5-1 (continued)

Manpower Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lnhrs LYEAR LENGTH ELEV AADT NO_TRUCKS
(obs=159)
```

	lnhrs	LYEAR	LENGTH	ELEV	AADT	NO_TRU~S
lnhrs	1.0000					
LYEAR	0.4167	1.0000				
LENGTH	-0.0212	0.0498	1.0000			
ELEV	0.2358	0.0518	0.2954	1.0000		
AADT	0.0268	0.0673	0.0424	0.1368	1.0000	
NO_TRUCKS	-0.1738	0.0126	-0.0631	0.1391	0.8080	1.0000

```
. regress lnhrs LYEAR LENGTH   ELEV  AADT NO_TRUCKS
```

Source	SS	df	MS
Model	54.1314808	5	10.8262962
Residual	100.972129	153	.659948557
Total	155.10361	158	.981668418

Number of obs =	159
F(5, 153) =	16.40
Prob > F =	0.0000
R-squared =	0.3490
Adj R-squared =	0.3277
Root MSE =	.81237

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.8834783	.1493915	5.91	0.000	.5883419	1.178615
LENGTH	-.0480238	.0182775	-2.63	0.009	-.0841326	-.011915
ELEV	.0003707	.0000883	4.20	0.000	.0001963	.0005451
AADT	.0066544	.0016778	3.97	0.000	.0033398	.0099691
NO_TRUCKS	-.0310785	.0059436	-5.23	0.000	-.0428206	-.0193364
_cons	1.058874	.4212846	2.51	0.013	.2265886	1.89116

Table 5.5.1A Regression Models for Roads in Priority Category 5-1 (continued)

Materials Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lnma AGE LYEAR ELEV NO_TRUCKS ESAL
(obs=159)
```

	lnma	AGE	LYEAR	ELEV	NO_TRU~S	ESAL
lnma	1.0000					
AGE	0.3202	1.0000				
LYEAR	0.3968	0.3906	1.0000			
ELEV	0.2337	-0.1161	0.0518	1.0000		
NO_TRUCKS	-0.2211	-0.0618	0.0126	0.1391	1.0000	
ESAL	-0.1024	-0.0688	-0.0045	0.1993	0.9440	1.0000

```
. regress lnma AGE LYEAR   ELEV   NO_TRUCKS  ESAL
```

Source	SS	df	MS
Model	207.195314	5	41.4390629
Residual	316.109427	153	2.06607469
Total	523.304742	158	3.31205533

Number of obs	=	159
F(5, 153)	=	20.06
Prob > F	=	0.0000
R-squared	=	0.3959
Adj R-squared	=	0.3762
Root MSE	=	1.4374

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.2318011	.074622	3.11	0.002	.0843786	.3792235
LYEAR	1.33736	.2876719	4.65	0.000	.7690378	1.905681
ELEV	.0005001	.0001537	3.25	0.001	.0001965	.0008037
NO_TRUCKS	-.1063657	.0186356	-5.71	0.000	-.1431819	-.0695495
ESAL	.0722052	.01545	4.67	0.000	.0416824	.1027281
_cons	2.915926	.8083612	3.61	0.000	1.318936	4.512917

Table 5.5.1A Regression Models for Roads in Priority Category 5-1 (continued)

Equipment Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lneq LYEAR ELEV NO_TRUCKS
(obs=159)
```

	lneq	LYEAR	ELEV	NO_TRU~S
lneq	1.0000			
LYEAR	0.3495	1.0000		
ELEV	0.4303	0.0518	1.0000	
NO_TRUCKS	-0.1688	0.0126	0.1391	1.0000

```
. regress lneq LYEAR  ELEV NO_TRUCKS
```

Source	SS	df	MS
Model	75.1589433	3	25.0529811
Residual	141.656812	155	.913914918
Total	216.815755	158	1.37225162

Number of obs =	159
F(3, 155) =	27.41
Prob > F =	0.0000
R-squared =	0.3466
Adj R-squared =	0.3340
Root MSE =	.95599

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.8864039	.1749598	5.07	0.000	.5407906	1.232017
ELEV	.0006719	.0000989	6.79	0.000	.0004765	.0008673
NO_TRUCKS	-.0145971	.0040727	-3.58	0.000	-.0226423	-.006552
_cons	2.541259	.4832225	5.26	0.000	1.586707	3.49581

Table 5.5.1A Regression Models for Roads in Priority Category 5-1 (continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnsto LENGTH ELEV AADT NO_TRUCKS ESAL
(obs=23)
```

	lnsto	LENGTH	ELEV	AADT	NO_TRU~S	ESAL
lnsto	1.0000					
LENGTH	-0.1309	1.0000				
ELEV	0.0417	0.5208	1.0000			
AADT	0.5600	0.0966	0.2585	1.0000		
NO_TRUCKS	0.4430	0.1387	0.3812	0.8340	1.0000	
ESAL	0.3364	0.2259	0.4761	0.0307	0.4911	1.0000

```
. regress lnsto LENGTH  ELEV  AADT NO_TRUCKS  ESAL
```

Source	SS	df	MS
Model	8.02231796	5	1.60446359
Residual	.200425272	17	.011789722
Total	8.22274323	22	.373761056

Number of obs =	23
F(5, 17) =	136.09
Prob > F =	0.0000
R-squared =	0.9756
Adj R-squared =	0.9685
Root MSE =	.10858

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LENGTH	-.0532194	.0109589	-4.86	0.000	-.0763406	-.0300982
ELEV	-.0005957	.0000757	-7.87	0.000	-.0007554	-.0004361
AADT	.0580587	.0026274	22.10	0.000	.0525154	.0636021
NO_TRUCKS	-.3765994	.02122	-17.75	0.000	-.4213697	-.331829
ESAL	.2050533	.0098063	20.91	0.000	.1843639	.2257427
_cons	3.783136	.2863566	13.21	0.000	3.178976	4.387295

Table 5.5.2A Regression Models for Roads in Priority Category 5-2

Total Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lntot LYEAR DISTRICT  ELEV TEMP AADT NO_TRUCKS
(obs=448)
```

	lntot	LYEAR	DISTRICT	ELEV	TEMP	AADT	NO_TRU~S
lntot	1.0000						
LYEAR	0.5044	1.0000					
DISTRICT	0.1047	0.0213	1.0000				
ELEV	0.2156	0.0251	0.2700	1.0000			
TEMP	0.0510	0.0261	-0.6788	0.0565	1.0000		
AADT	0.2110	0.0793	0.2368	0.0955	-0.0731	1.0000	
NO_TRUCKS	0.0675	0.1501	0.2941	0.0698	-0.1125	0.6312	1.0000

```
. regress lntot LYEAR  DISTRICT ELEV TEMP AADT NO_TRUCKS
```

Source	SS	df	MS
Model	224.35595	6	37.3926583
Residual	418.009027	441	.947866274
Total	642.364977	447	1.43705811

Number of obs	=	448
F(6, 441)	=	39.45
Prob > F	=	0.0000
R-squared	=	0.3493
Adj R-squared	=	0.3404
Root MSE	=	.97358

lntot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	1.40713	.108231	13.00	0.000	1.194417	1.619842
DISTRICT	.2372211	.1119491	2.12	0.035	.017201	.4572412
ELEV	.0001826	.0000513	3.56	0.000	.0000817	.0002835
TEMP	.1626083	.081763	1.99	0.047	.0019148	.3233018
AADT	.0052989	.0009784	5.42	0.000	.0033761	.0072218
NO_TRUCKS	-.0106704	.0025446	-4.19	0.000	-.0156715	-.0056692
_cons	4.844473	.3733005	12.98	0.000	4.110804	5.578143

Table 5.5.2A Regression Models for Roads in Priority Category 5-2 (continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnlabor LYEAR ELEV TEMP AADT NO_TRUCKS
(obs=448)

	lnlabor	LYEAR	ELEV	TEMP	AADT	NO_TRU~S
lnlabor	1.0000					
LYEAR	0.4203	1.0000				
ELEV	0.2736	0.0251	1.0000			
TEMP	0.1160	0.0261	0.0565	1.0000		
AADT	0.2019	0.0793	0.0955	-0.0731	1.0000	
NO_TRUCKS	0.0536	0.1501	0.0698	-0.1125	0.6312	1.0000

. regress lnlabor LYEAR ELEV TEMP AADT NO_TRUCKS

Source	SS	df	MS
Model	128.147173	5	25.6294346
Residual	302.157231	442	.683613645
Total	430.304404	447	.962649674

Number of obs	=	448
F(5, 442)	=	37.49
Prob > F	=	0.0000
R-squared	=	0.2978
Adj R-squared	=	0.2899
Root MSE	=	.82681

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.9527239	.0919136	10.37	0.000	.772082	1.133366
ELEV	.0002425	.0000397	6.11	0.000	.0001645	.0003204
TEMP	.1070661	.0478921	2.24	0.026	.0129415	.2011907
AADT	.0043357	.0008288	5.23	0.000	.0027068	.0059646
NO_TRUCKS	-.0075938	.0021214	-3.58	0.000	-.0117631	-.0034246
_cons	4.415569	.2153393	20.51	0.000	3.992352	4.838785

Table 5.5.2A Regression Models for Roads in Priority Category 5-2 (continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnhrs LYEAR DISTRICT ELEV TEMP NO_TRUCKS AADT
(obs=448)
```

	lnhrs	LYEAR	DISTRICT	ELEV	TEMP	NO_TRU~S	AADT
lnhrs	1.0000						
LYEAR	0.4019	1.0000					
DISTRICT	0.1420	0.0213	1.0000				
ELEV	0.3022	0.0251	0.2700	1.0000			
TEMP	0.0552	0.0261	-0.6788	0.0565	1.0000		
NO_TRUCKS	0.0553	0.1501	0.2941	0.0698	-0.1125	1.0000	
AADT	0.1882	0.0793	0.2368	0.0955	-0.0731	0.6312	1.0000

```
. regress lnhrs LYEAR DISTRICT ELEV TEMP NO_TRUCKS AADT
```

Source	SS	df	MS
Model	129.746003	6	21.6243338
Residual	309.71931	441	.70231136
Total	439.465313	447	.983143876

Number of obs =	448
F(6, 441) =	30.79
Prob > F =	0.0000
R-squared =	0.2952
Adj R-squared =	0.2856
Root MSE =	.83804

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.9219267	.0931629	9.90	0.000	.7388282	1.105025
DISTRICT	.2665415	.0963634	2.77	0.006	.0771529	.45593
ELEV	.0002287	.0000442	5.18	0.000	.0001419	.0003156
TEMP	.1734937	.0703798	2.47	0.014	.0351722	.3118152
NO_TRUCKS	-.0083077	.0021904	-3.79	0.000	-.0126126	-.0040029
AADT	.003759	.0008422	4.46	0.000	.0021038	.0054141
_cons	.5532449	.321329	1.72	0.086	-.0782815	1.184771

Table 5.5.2A Regression Models for Roads in Priority Category 5-2 (continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnma LYEAR LENGTH AADT NO_TRUCKS
(obs=446)
```

	lnma	LYEAR	LENGTH	AADT	NO_TRU~S
lnma	1.0000				
LYEAR	0.5190	1.0000			
LENGTH	0.0574	0.0176	1.0000		
AADT	0.1941	0.0787	-0.2934	1.0000	
NO_TRUCKS	0.0540	0.1493	-0.2335	0.6310	1.0000

```
. regress lnma LYEAR LENGTH   AADT NO_TRUCKS
```

Source	SS	df	MS
Model	596.47556	4	149.11889
Residual	1241.79996	441	2.81587292
Total	1838.27552	445	4.13095622

Number of obs =	446
F(4, 441) =	52.96
Prob > F =	0.0000
R-squared =	0.3245
Adj R-squared =	0.3183
Root MSE =	1.6781

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	2.460389	.1867097	13.18	0.000	2.093437	2.82734
LENGTH	.0377066	.0168997	2.23	0.026	.0044926	.0709205
AADT	.0100314	.0017108	5.86	0.000	.0066691	.0133937
NO_TRUCKS	-.016253	.0042987	-3.78	0.000	-.0247015	-.0078044
_cons	4.009854	.2441138	16.43	0.000	3.530083	4.489625

Table 5.5.2A Regression Models for Roads in Priority Category 5-2 (continued)

Equipment Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lneq AGE LYEAR LENGTH ELEV AADT NO_TRUCKS
(obs=448)
```

	lneq	AGE	LYEAR	LENGTH	ELEV	AADT	NO_TRU~S
lneq	1.0000						
AGE	-0.0600	1.0000					
LYEAR	0.3222	0.3341	1.0000				
LENGTH	0.1162	-0.0323	0.0158	1.0000			
ELEV	0.2275	-0.0457	0.0251	0.0743	1.0000		
AADT	0.1688	-0.1297	0.0793	-0.2938	0.0955	1.0000	
NO_TRUCKS	0.0216	-0.0499	0.1501	-0.2343	0.0698	0.6312	1.0000

```
. regress lneq AGE LYEAR LENGTH  ELEV  AADT NO_TRUCKS
```

Source	SS	df	MS
Model	156.023058	6	26.003843
Residual	534.518568	441	1.21206024
Total	690.541626	447	1.54483585

Number of obs =	448
F(6, 441) =	21.45
Prob > F =	0.0000
R-squared =	0.2259
Adj R-squared =	0.2154
Root MSE =	1.1009

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	-.098873	.0302746	-3.27	0.001	-.1583734	-.0393725
LYEAR	1.075484	.13077	8.22	0.000	.8184745	1.332494
LENGTH	.0308779	.0111894	2.76	0.006	.0088868	.052869
ELEV	.0002391	.0000531	4.51	0.000	.0001348	.0003434
AADT	.0052312	.0011377	4.60	0.000	.0029952	.0074672
NO_TRUCKS	-.0097231	.0028206	-3.45	0.001	-.0152666	-.0041796
_cons	3.943676	.3056014	12.90	0.000	3.343059	4.544292

Table 5.5.2A Regression Models for Roads in Priority Category 5-2 (continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

Dependent Variable: stockpile

```
. correlate lnsto AGE LYEAR DISTRICT TEMP NO_TRUCKS  ESAL
(obs=140)
```

	lnsto	AGE	LYEAR	DISTRICT	TEMP	NO_TRU~S	ESAL
lnsto	1.0000						
AGE	0.3571	1.0000					
LYEAR	0.3602	0.4130	1.0000				
DISTRICT	0.2624	-0.0753	0.0263	1.0000			
TEMP	0.0877	0.0928	-0.0545	-0.5149	1.0000		
NO_TRUCKS	0.1903	-0.0389	0.2577	0.1223	0.1524	1.0000	
ESAL	0.1553	-0.0296	0.2497	0.1160	0.1557	0.9950	1.0000

```
. regress lnsto AGE LYEAR  DISTRICT TEMP  NO_TRUCKS  ESAL
```

Source	SS	df	MS
Model	58.9603967	6	9.82673278
Residual	74.8132101	133	.562505339
Total	133.773607	139	.962400049

Number of obs =	140
F(6, 133) =	17.47
Prob > F =	0.0000
R-squared =	0.4407
Adj R-squared =	0.4155
Root MSE =	.75

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.1594967	.0374966	4.25	0.000	.0853298	.2336635
LYEAR	.4274298	.1665487	2.57	0.011	.0980029	.7568567
DISTRICT	1.032086	.2031803	5.08	0.000	.6302035	1.433969
TEMP	.4192842	.1198237	3.50	0.001	.1822776	.6562908
NO_TRUCKS	.1090529	.0206237	5.29	0.000	.0682599	.1498458
ESAL	-.1076391	.0204871	-5.25	0.000	-.1481617	-.0671164
_cons	1.034327	.7029167	1.47	0.144	-.3560153	2.424669

Table 5.5.3A Regression Models for Roads in Priority Category 5-3

Total Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lntot AGE
(obs=94)

             |    lntot      AGE
-------------+------------------
       lntot |   1.0000
         AGE |   0.2307   1.0000


. regress lntot AGE

      Source |       SS       df       MS              Number of obs =      94
-------------+------------------------------           F(  1,    92) =    5.17
       Model |  8.14379664     1  8.14379664           Prob > F      =  0.0253
    Residual |  144.906453    92  1.57507014           R-squared     =  0.0532
-------------+------------------------------           Adj R-squared =  0.0429
       Total |   153.05025    93  1.64570161           Root MSE      =   1.255

------------------------------------------------------------------------------
       lntot |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         AGE |    .183007    .080483     2.27   0.025     .0231608    .3428533
       _cons |   7.283439   .2597357    28.04   0.000     6.767581    7.799297
------------------------------------------------------------------------------
```

Table 5.5.3A Regression Models for Roads in Priority Category 5-3 (continued)

Labor Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

. correlate lnlabor AGE
(obs=94)

	lnlabor	AGE
lnlabor	1.0000	
AGE	0.2515	1.0000

. regress lnlabor AGE

Source	SS	df	MS
Model	9.40695142	1	9.40695142
Residual	139.318583	92	1.51433243
Total	148.725535	93	1.5991993

Number of obs =	94
F(1, 92) =	6.21
Prob > F =	0.0145
R-squared =	0.0633
Adj R-squared =	0.0531
Root MSE =	1.2306

lnlabor	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AGE	.1966884	.078916	2.49	0.014	.0399545	.3534223
_cons	6.315375	.2546785	24.80	0.000	5.809562	6.821189

Table 5.5.3A Regression Models for Roads in Priority Category 5-3 (continued)

Manpower Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate LYEAR ELEV TEMP
(obs=94)
```

	LYEAR	ELEV	TEMP
LYEAR	1.0000		
ELEV	0.1087	1.0000	
TEMP	0.0889	0.6096	1.0000

```
. regress lnhrs LYEAR   ELEV TEMP
```

Source	SS	df	MS
Model	17.6895421	3	5.89651405
Residual	137.482547	90	1.52758386
Total	155.172089	93	1.66851709

Number of obs =	94
F(3, 90) =	3.86
Prob > F =	0.0120
R-squared =	0.1140
Adj R-squared =	0.0845
Root MSE =	1.236

lnhrs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.7504377	.2942209	2.55	0.012	.1659166	1.334959
ELEV	.0003659	.0002007	1.82	0.072	-.0000328	.0007645
TEMP	-.5010887	.2375427	-2.11	0.038	-.9730088	-.0291687
_cons	2.260878	.8511249	2.66	0.009	.5699697	3.951786

Table 5.5.3A Regression Models for Roads in Priority Category 5-3 (continued)

Materials Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate lnma LYEAR LENGTH
(obs=94)
```

	lnma	LYEAR	LENGTH
lnma	1.0000		
LYEAR	0.2325	1.0000	
LENGTH	0.2138	0.0307	1.0000

```
. regress lnma LYEAR LENGTH
```

Source	SS	df	MS
Model	12.9505999	2	6.47529994
Residual	120.807991	91	1.32756034
Total	133.75859	93	1.43826441

Number of obs =	94
F(2, 91) =	4.88
Prob > F =	0.0097
R-squared =	0.0968
Adj R-squared =	0.0770
Root MSE =	1.1522

lnma	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.6186886	.2726721	2.27	0.026	.0770589	1.160318
LENGTH	.0517458	.0249284	2.08	0.041	.0022285	.1012631
_cons	5.9078	.1969609	29.99	0.000	5.516561	6.299038

Table 5.5.3A Regression Models for Roads in Priority Category 5-3 (continued)

Equipment Cost

```
********* ORDINARY LEAST SQUARES ESTIMATION *********
```

```
. correlate lneq LYEAR
(obs=94)
```

	lneq	LYEAR
lneq	1.0000	
LYEAR	0.2389	1.0000

```
. regress lneq LYEAR
```

Source	SS	df	MS
Model	10.8825736	1	10.8825736
Residual	179.812009	92	1.95447836
Total	190.694583	93	2.05047939

Number of obs	=	94
F(1, 92)	=	5.57
Prob > F	=	0.0204
R-squared	=	0.0571
Adj R-squared	=	0.0468
Root MSE	=	1.398

lneq	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LYEAR	.7803242	.3306928	2.36	0.020	.1235398	1.437109
_cons	6.317837	.1670961	37.81	0.000	5.98597	6.649705

Table 5.5.3A Regression Models for Roads in Priority Category 5-3 (continued)

Stockpile Cost

********* ORDINARY LEAST SQUARES ESTIMATION *********

```
. correlate LENGTH DISTRICT TEMP NO_TRUCKS PERC_TRUCKS lnsto
(obs=94)
```

	LENGTH	DISTRICT	TEMP	NO_TRU~S	PERC_T~S	lnsto
LENGTH	1.0000					
DISTRICT	-0.2048	1.0000				
TEMP	0.3697	-0.7317	1.0000			
NO_TRUCKS	0.0886	0.0938	0.3704	1.0000		
PERC_TRUCKS	0.0324	0.2270	0.1654	0.8655	1.0000	
lnsto	0.3112	0.0726	0.1355	-0.0312	0.0792	1.0000

```
. regress lnsto LENGTH DISTRICT  TEMP  NO_TRUCKS PERC_TRUCKS
```

Source	SS	df	MS
Model	42.6571643	5	8.53143286
Residual	109.89541	88	1.24881148
Total	152.552574	93	1.64035026

Number of obs =	94
F(5, 88) =	6.83
Prob > F =	0.0000
R-squared =	0.2796
Adj R-squared =	0.2387
Root MSE =	1.1175

lnsto	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
LENGTH	.0611144	.0264343	2.31	0.023	.0085817	.1136471
DISTRICT	1.211451	.3403451	3.56	0.001	.5350867	1.887815
TEMP	1.320977	.353427	3.74	0.000	.6186147	2.023338
NO_TRUCKS	-.0519288	.0131024	-3.96	0.000	-.0779671	-.0258904
PERC_TRUCKS	.0929227	.0319594	2.91	0.005	.0294102	.1564353
_cons	-5.81124	1.348964	-4.31	0.000	-8.492023	-3.130458

REFERENCES

1. Venukanthan, K. S. (1999) *Analyses and Procedures for Pavement Management System.* A Master Thesis, Department of Civil Engineering, University of Nevada.
2. Venukanthan K. S., Sebaaly, Fernandez G. (2001) *Development of Performance Models from PMS Data.* 5th International Conference on Managing Pavements, University of Nevada.
3. Panthi, K. (2009) *A Methodological Framework for Modeling Pavement Maintenance Cost for Projects with Performance-based Contracts*. FIU Electronics Theses and Dissertations, Paper 120.
4. Transportation Research Circular. (2012) Maintenance Management 2012. Presentations from the 2012 ASHTO-TRB Maintenance Management Conference, Seattle, Washington.
5. Anani, S. (2008) B. *Revisiting the Estimation of Highway Maintenance Marginal Cost.* Doctoral dissertation, Department of Civil and Environmental Engineering, University of California, Berkeley.
6. Texas Department of Transportation. *Construction and Materials Tips*. Journal third quarter. Retrieved: October 21, 2013.
7. Haas R., Hudson R. W., Zaniewski J., (1994) Modern Pavement Management. Krieger Publishing Company, Malabar, Florida.
8. McKierran B. (2012) Managing for Results, Citi Tech Systems.
9. Teng, H. (2011) *Impact of System Expansion on Maintenance Resources.* NDOT, Report, Las Vegas, Nevada.

10. Pavement Management System, <http://www.eastgatecog.org/Portals/Eastgate/Uploaded_Documents/LRTP-chapter4_PMS.pdf> Retrieved October 23, 2013.

11. Nevada Department of Transportation. (2011) *Contract maintenance on Nevada Highways.* Maintenance and Asset management Division, Carson City, Nevada.

12. United States Department of Transportation. (2005) *Memorandum: Pavement Preservation Definitions*. Federal Highway Administration, Retrieved 23 October 2013.

13. Texas Department of Transportation. (2013) *An AHP-based Approach to Prioritizing Resources for Highway Routine Maintenance*. Technical Report, Center for Transportation Research at the University of Texas, Austin, Texas.

14. Balducci, P. (2009) *Nevada Highway Cost Allocation Study*. Compilation Report, Batelle, Pacific Northwest Division, Richland, Washington.

15. Hoover, K.D. (2005) *The Methodology of Econometrics*. Department of Economics, University of California. Prepared for the Palgrave Handbooks of Econometrics, volume 1: Theoretical Econometrics.

16. Edward E. Leamer (2008). *Specification Problems in Econometrics*. The New Palgrave Dictionary of Economics. Second Edition.

17. Kennedy, P. (2003). *A guide to econometrics*. Cambridge, Mass: MIT Press.

18. Rozenkrantz, W.A. (1997). Introduction to Probability and Statistics for Scientists and Engineers. McGraw-Hill.

19. Gibby, R., Kitamura, R., Zhao, H. (1990) Evaluation of Truck Impacts on Pavement Maintenance Costs. *Transportation Research Record*. 1262, 48-56.

20. Hand, A.J. (1995). Development of Life-Cycle Cost Analysis Procedures for Nevada's Flexible Pavements. A Master Thesis, Department of Civil Engineering, University of Nevada.

21. Sebaaly, P.E., Venukanthen, S., Siddharthan, R., Hand, A., and Epps, J. (2000). Development of Pavement Network Optimization System. *Research Report No. 1198-1*, Report to Nevada Department of Transportation, Carson City, NV.

22. Ministry of Transportation of Ontario. (1990) Pavement design and Rehabilitation Manual. SDO-90-01.

23. Chong, G.J., Sewer S.W., Macey K. (1989). Pavement Maintenance Guidelines: Distress, Maintenance Alternatives and Performance Standards. Ministry of Transportation, Ontario, Report SP-001.

24. Volovski M. (2011). Econometric Models for Pavement Routine Maintenance Expenditure. Mid-Continent Transportation Research Symposium, Ames, Iowa. Purdue University, West Lafayette, Indiana.

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