NDOT Research Report

Report No. 113-08-803

Impact of System Expansion on Maintenance Resources

September 2012

Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712

Disclaimer

IMPACT OF SYSTEM EXPANSION ON MAINTENANCE RESOURCES

FINAL REPORT

Submitted to

Nevada Department of Transportation

Research Division

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CHAPTER 1

INTRODUCTION

Over the past decade or so, the population in Nevada has increased dramatically, especially within and near the urban areas. With this increase has come the need to expand the transportation system, particularly roadways. This expansion includes the construction of some new roadways; however, the greatest need is to improve nearly all existing major roadways. These improvements typically have included additional lanes, turning lanes, sound walls, shoulder widening, upgrading older cross-section standards, adding guardrails, and more landscaping. New and improved existing roadways have to be maintained, which adds to the demand on maintenance manpower, equipment, and materials.

In terms of evaluating transportation projects, maintenance and operating costs consist of the agency cost, user cost, and social cost. Obviously, the costs for maintenance resources (i.e., manpower, equipment, and materials) are part of the agency cost. Estimating the demand on maintenance resources is necessary when NDOT maintenance districts submit their requests to headquarters; the submissions then are integrated and a request sent to state legislators for approval. Currently, NDOT's Maintenance Division is responsible for the following maintenance activities:

1) Flexible Pavement
2) Rigid Pavement
3) Misc. Concrete
4) Roadside infrastructure
5) Roadside Cleanup
6) Roadside Facilities
7) Roadside Appurtenances
8) Traffic Services
9) Snow and Ice Control
10) Bridges
11) Stockpile Production

Ideally, the decision rests on the additional number of positions needed and the funding increase for equipment and materials for all these maintenance activities over the life cycles of the highway system expansions. The decision could fully or partially meet the estimated demand for maintenance resources over these life cycles.

The basic focus of this research project is developing a marginal maintenance cost mechanism for new construction projects. This mechanism will identify the total expected short-term and long-term maintenance burden required for each construction project. NDOT's short-term and long-term maintenance schedule has been specified as shown in Figure 1.1. There is one life cycle segment for the roads in Category 1, and three segments for the roads in Category 2. Linear regression models were developed to estimate the annual maintenance costs broken down into man power, materials, equipment and stockpile for each of the segments in the life cycle in all the categories.

In this study, the following steps were followed: a literature review on estimating maintenance costs, a survey with state DOTs other than NDOT was conducted on the practice for estimating maintenance costs, data was collected, and linear regression models were developed for estimating annual maintenance costs.

This report consists of seven chapters. The first chapter provides an introduction on the background and objective of the study. In the second chapter, a literature review is presented. The third chapter describes the survey conducted with other state DOTs. The fourth chapter presents a methodology for developing linear regression models. Chapter 5 provides a detailed description of the data collection process. Chapter 6 describes the development of the linear regression models to estimate annual maintenance costs. Finally, Chapter 7 summarizes the development of the models and identifies the research needed in the future.

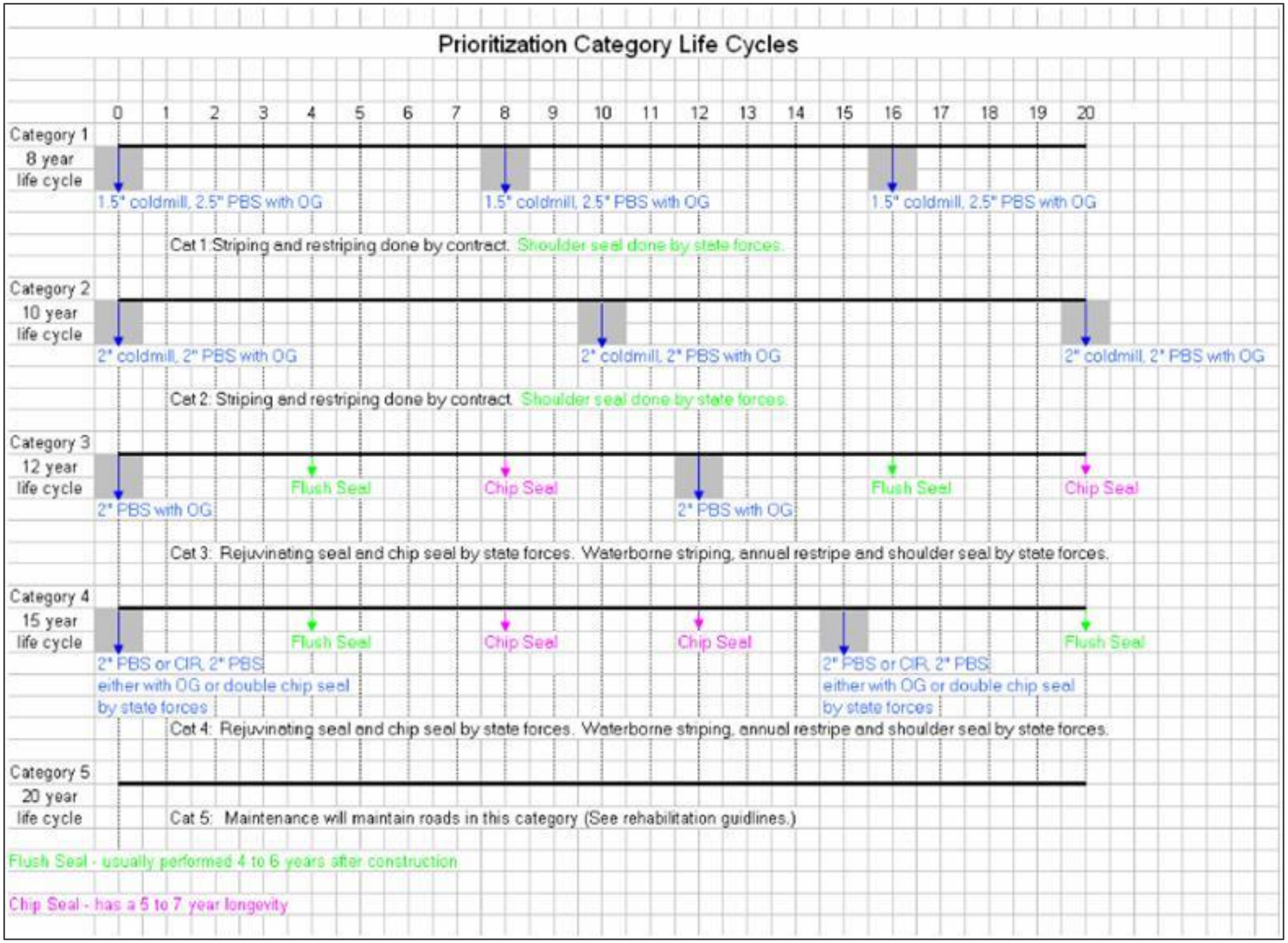


Figure 1.1 Life Cycle of Roads in NDOT.

CHAPTER 2

LITERATURE REVIEW

According to Anani (2008), maintenance costs are incurred for maintenance activities that are triggered when pavement conditions reach a critical condition; for example, pavement deteriorates as more vehicles run on it as well as other environmental factors. The marginal cost for maintenance can be defined as the increase in the total maintenance costs resulting from an additional unit of traffic loading. In Anani (2008), maintenance, rehabilitation and reconstruction (MR&R) costs models are classified into five approaches:

1) The pavement management system (PMS) direct approach,
2) The 'simple roughness' approach,
3) The econometric approach,
4) The cost allocation approach, and
5) The 'perpetual overlay' indirect approach.

Among these five approaches, the most relevant ones to this study are the PMS approach and the econometric approach. A PMS usually consists of a database that records the history of MR&R work on a roadway system and a pavement performance model that can produce the roadway surface condition, given the MR&R history, future maintenance policies, and traffic usage of a roadway segment. Optimization procedures usually are applied to search for the optimal MR&R schedule. As a product of the optimization procedure, maintenance costs also can be derived.

The econometric approach estimates a function that relates the total maintenance cost to influencing factors, such as traffic load, road geometry, pavement structure, and climate. It should be noted that there are only a few studies on estimating MR&R costs. However, the costs in these studies usually have mixed maintenance costs along with rehabilitation and reconstruction costs. The most relevant study is Gibby et al. (1990), in which a regression modeling approach was taken to study the impact of heavy trucks on maintenance cost. In their study, more than 1,100 mile sections of highway were randomly sampled. Data – including annual average daily traffic (AADT), maintenance costs, highway geometric information, and weather various different sources – were collected and integrated into a single database, which was used to develop a regression model. The annual maintenance costs were related to AADTs of heavy trucks and passenger cars, age of pavement, presence or absence of a shoulder, temperature, location maintenance, existence of bridges, functional classification, and the district where a pavement section was located. The regression models were expressed as:

$$\text{TotalCost} = \beta_1 (\text{HT\_AADT})^{\beta 2} (\text{P\&L\_AADT})^{\beta 3} (\text{AGE})^{\beta 4} (\text{AATEMP})^{\beta 6} (\text{SHOULDER})^{\beta 5} \ldots$$
$$(e^{\text{NOSHOULDER'}})^{\beta 7} (e^{\text{MOUNTAIN'}})^{\beta 8} (e^{\text{BRIDGE'}})^{\beta 9} (e^{\text{MNCOLLCTR'}})^{\beta 10} \ldots$$
$$(e^{\text{DISTRICT2'}})^{\beta 11} (e^{\text{DISTRICT11'}})^{\beta 12}$$

The variables in this model are presented in Table 2.1.

Table 2.1 Variables in a Regression Model to Estimate Total Annual Maintenance Cost

Variable	Description
TOTAL_COST	The dependent 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)

It was found that the maintenance cost incurred by heavy trucks was much higher than for passenger cars, which presented a significant implication to such transportation policies as taxation.

Sebaaly et al. (2000) conducted a study for NDOT on estimating maintenance costs in late 1990s, for which a review is provided in Appendix 1. In this study, four techniques were used to estimate maintenance costs were discussed (Sebaaly et al., 2000; Hand, 1995). These are:

1. Correlating annual maintenance costs to Present Service Index (PSI) levels.
2. Correlating annual maintenance costs to the probability of their occurrence.
3. Establishing an overall annual maintenance cost for each treatment.

4. Establishing a fixed period cumulative annual maintenance cost for each treatment.

The first technique correlates annual maintenance costs to pavement performance, represented as the PSI level. This technique was proposed based on the understanding that the cost of maintenance varies with the nature of the maintenance activities that are triggered by the pavement conditions. Recognizing the fact that there is a time element in the pavement performance – i.e., not every maintenance activity occurs every year – makes the maintenance costs fluctuate significantly from year to year. In the second technique, the annual maintenance costs are correlated to the probability of the occurrence of maintenance activities. The third technique calculates the annual maintenance costs by considering the life of a pavement after a certain treatment. With this technique, the annual maintenance costs are the average of the total maintenance costs over the year before next maintenance treatment. In the fourth technique, the annual maintenance costs take into consideration the time since the last treatment. In the study for NDOT (Sebaaly et al., 2000; Hands et al. 1995), the fourth technique was adopted.

Note that the four techniques are not regression models that can consider the different characteristics of pavement, such as traffic load and road functional classification, critical in determining the pavement conditions and maintenance costs.

CHAPTER 3

SURVEY

A survey form was designed and distributed to the maintenance division of 50 state DOTs. In total, 20 state DOTs returned the survey; the response rate was 40%, which can be viewed as satisfactory. The survey, which included 12 questions, is included below.

The objective of the survey was to collect the information on the cost estimation practices for maintenance work that was adopted in each state DOT. The survey starts with questions to clarify the maintenance tasks performed by each DOT. Then, questions were asked on the performance of the roads in order to understand the impact of road performance on costs. To determine the appropriate form of the modeling approach to estimate maintenance costs, questions were asked regarding the methods each DOT adopted to estimate maintenance cost. Overall, the results from the survey were helpful to NDOT in improving the development of maintenance cost practices.

The first and second questions of this survey were:

(1) What are the road maintenance works performed by state force in your state DOT?
(2) What are the road maintenance works performed by contractors in your state DOT?

The responses, which are included in the Appendix, show that the road maintenance works performed by each state's force and contractors were significantly different. Most of the state DOTs contracted out some maintenance tasks. However, Colorado Department of Transportation (CDOT) performs all maintenance of their roadways internally.

The third question is about preventive maintenance.

(3) Please list the preventive maintenances in your state DOT.

The responses indicate that the maintenance activities viewed as preventive are different among the states responded to the survey.

The fourth question inquires about the timing of the preventive maintenance.

(4) Are the timings of these preventive maintenances determined based on field inspections of roadways?

☐ Yes ☐ No

Out of the 20 states that responded, 18 states replied that their preventive maintenance were scheduled based on the results from field inspection of roadways. One state indicated that some preventive maintenance work was assigned according to a fixed schedule.

The fifth question is about whether there are separate budgets for different infrastructures:

(5) Does your state DOT have separated budgets for major highway infrastructures like bridge, lighting, signing, pavement marking, sidewalk, etc.?

☐ Yes ☐ No

If yes, please list these highway infrastructures?

In the responses, 14 states replied that they did have separate budgets for different infrastructures. The infrastructures for which they had separate budgets varied among these 14 states.

The sixth question asks about the method used to budget for new facilities:

(6) Which method do you use to budget for new facilities like bridge, lighting, signing, pavement marking, sidewalk lighting, etc.?

☐ Historic record ☐ Data from other agencies ☐ Others, specify

Eight states chose 'Historic record', nine chose 'Other', one chose both 'Historic record' and 'Others', one indicated 'Data from other agencies' and one chose both 'Historic record' and 'Data from other agencies'. It might be the case that different methods can be adopted for different tasks, even if a facility is not new to a state. For example, graffiti removal might be a new task for some states, while bridges that have graffiti are not new facilities.

The seventh question asks about the trend regarding maintenance costs:

(7) Do you observe that maintenance costs for a roadway section increase with years after a reconstruction, a rehabilitation, or a preventive maintenance?

☐ Yes ☐ No

Among the responses, 15 states answered 'yes', while the remaining states replied 'no'. The response to this question would help validate the maintenance cost data from NDOT. It is expected that the cost data would present such a trend.

The eighth question asks about maintenance cost functions:

(8) Are there equations in your Pavement Management System that relate the costs of roadway maintenance (excluding reconstruction and rehabilitation) to the influencing factors such as ages, traffic loads, pavement conditions, weather, etc.?

☐ Yes ☐ No

Six states indicated that they had maintenance cost functions, while the remaining states had no cost functions.

The ninth question inquires about maintenance cost functions for bridges:

(9) Are there equations in your Bridge Management Systems (BMS) that relate the costs of bridge maintenance (excluding reconstruction and rehabilitation) to the influencing factors such as ages, traffic loads, etc.?

☐ Yes ☐ No

The states that have maintenance cost function for roadways also answered 'yes' to this question.

The tenth question is about separating the cost data for bridges and road surfaces:

(10) In your routine, corrective and/or preventive maintenance database, is it possible to separate the works for pavements and bridges?

☐ Yes ☐ No

Most of the states show that they can separate the costs of these two major facilities. This is a very good practice that NDOT may want to adopt.

In the eleventh question, the type of maintenance cost is inquired:

(11) Do you estimate maintenance costs in terms of man power, equipment, materials, separately?

☐ Yes ☐ No

Among the 20 states that responded, 5 states indicated that they did not separate the costs for manpower, equipment, and materials.

The last question is about the annual fluctuation of maintenance costs:

(12) How does your state DOT deal with the annual fluctuation of maintenance costs (routine, corrective and/or maintenance) because the maintenance activities on a roadway section each year are different?

- Averaging the maintenance costs over the past three years
- Estimate the probability of occurrence of maintenance activities
- Develop advanced statistical regression models
- Others, please specify ____

All these three methods have been adopted in some of these 20 states. About 10 states used other methods. These responses indicate that the fluctuation of annual maintenance costs is a concern, currently, among many state DOTs.

CHAPTER 4

METHODOLOGY

In this study, regression models were developed for different maintenance costs, different maintenance prioritization categories, and different life cycle stages. The maintenance costs are broken down into the costs for manpower, materials, equipment, and stockpile.

In NDOT, five maintenance prioritization categories are developed for various routes -- Categories 1, 2, 3, 4, and 5 – each with different maintenance strategies over the life cycles. Table 4.1 lists the characteristics of these prioritization categories. It can be seen that the Category 5 routes has the largest percentage, 25%.

Table 4.1 NDOT Highway Maintenance Prioritization Categories

Category	ADT & Truck Traffic	% of System	Project Deterioration Rate (Years)
1	Controlled Access	19	8
2	ESAL > 540 or ADT>10,000	20	10
3	540 ≥ ESAL > 405, or 1,600 < ADT ≤ 10,000, & NHS	21	12
4	405 ≥ ESAL > 270, or 400 < ADT ≤ 1,600	15	15
5	ADT ≤ 400	25	20

Figure 4.1 also displays the maintenance strategies for each prioritization category.

For the Category 1 routes, only one life cycle stage is considered: it starts from reconstruction with a 1.5” coldmill, 2.5” PBS with OG and ends at another such reconstruction. Similar to the Category 1 route, only one life cycle stage was considered for Category 2 routes, which starts from an end with a 2” coldmill and a 2.5” PBS with OG. There are three life cycle stages for Category 3: After reconstruction, After Flush Seal, and After Chip Seal. Four life cycle stages are assumed for Category 4: After Reconstruction, After Flush Seal, After First Chip Seal, and After the Second Chip Seal. In other words, there is one more Chip Seal treatment considered for

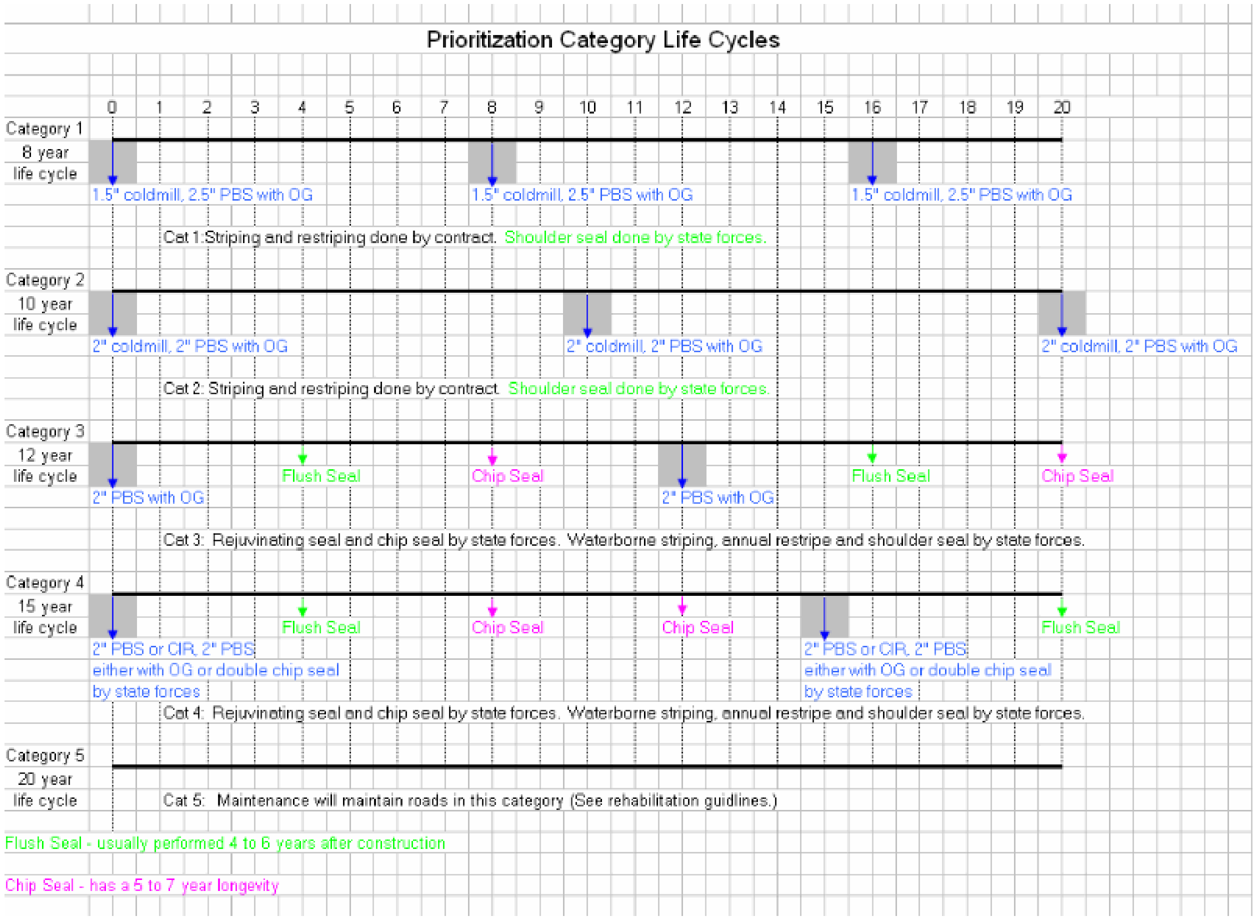


Figure 4.1 Prioritization Category Life Cycles.

Category 4 than for Category 3. There is no clear maintenance treatment patterns adopted for Category 5. In this study, three life cycle stages were considered: a beginning stage, a middle stage, and a last stage.

For Categories 3, 4, and 5, separate regression models were developed for the last year of a life cycle stage. For Categories 1 and 2, the last year was a reconstruction that was not performed by NDOT workforce. As for other categories, the maintenance activities in the last year of each life cycle stage include routine, corrective and the preventive maintenance, all of which have dramatically different ranges of costs. If these costs are put together in a lump sum, however, the estimation may not be accurate.

Linear regression models were developed for each life cycle stage of five different maintenance prioritization categories. The models can be written as:

$$Y_i = \beta_1 + \beta_2 X_{2i} + \beta_3 X_{3i} + \cdots + \beta_k X_{ki} + \varepsilon_i, \quad \forall i$$

where

The relation between Y and X is linear.

The X's are deterministic.

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

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

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

ε_i is normally distributed, $\forall$ i

No linear relationship exists between any subset of the X_i.

The dependent variables Y_i are the maintenance costs for manpower, materials, equipment, stockpile, and work hours. The independent variables are the factors that influence the costs, and include the age after the start of a life cycle stage, the pavement surface type, total traffic volume, truck flow volume, urban/rural area, and elevation.

CHAPTER 5

DATA COLLECTION

5.1 Data Collection Procedure

In this study, the ultimate goal of data collection was to extract maintenance cost data, road segment characteristics, and traffic flow data, based on which the correlations among them that can be modeled. The first step was to develop an inventory of roads maintained by NDOT that could be used as a population for sampling. Samples of road segments could be selected from this population of roads. In the second step, time-space diagrams were developed for the selected roads, in which the history of maintenance activities on each selected road could be presented. The third step was to utilize the time-space diagrams to identify the road sections that showed the same time series of maintenance treatments. It was assumed that each of these sections experienced the same maintenance treatments, between which the road characteristics were unchanged and the traffic loads were uniform over the entire road sections. The fourth step was to extract maintenance data. In the last step, the road characteristics data were collected for the identified homogenous sections. This sequence of steps is presented in Figure 5.1.

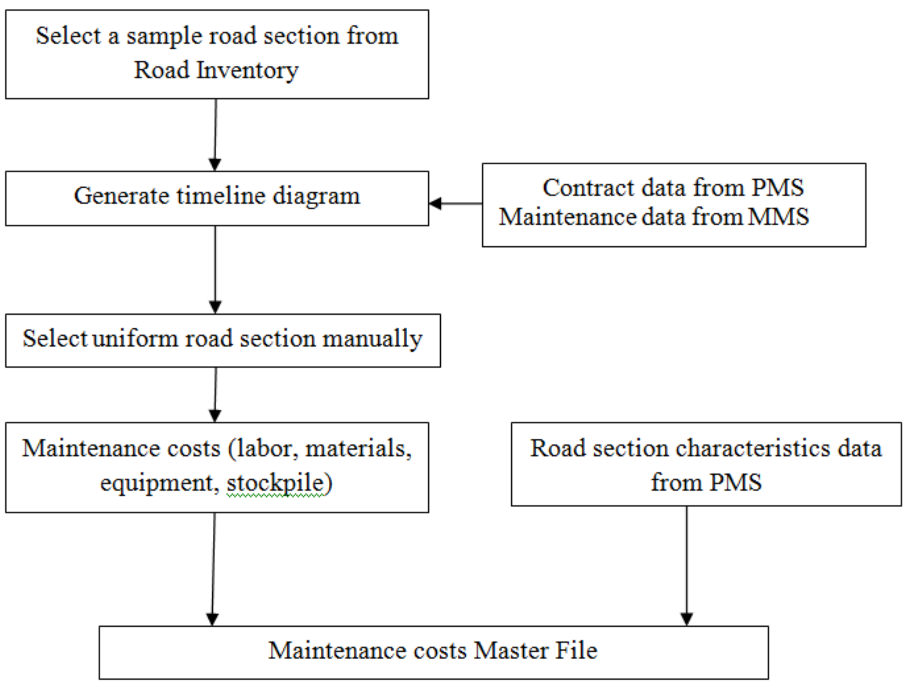


Figure 5.1 Procedure for Data Collection.

5.2 Road Inventory

In developing the inventory of roads maintained by NDOT, the roads in the five maintenance prioritization categories in each county of Nevada were identified based on the 2007 PMS data. Figure 5.2 shows the inventory of roads maintained by NDOT in 2007, broken down into the five categories. The inventories of roads in other counties of Nevada are listed in Appendix 4.

When this study was conducted, 2007 PMS data were the most updated available. In the PMS data, there is one field for maintenance prioritization, as shown in Figure 5.3; this field indicates the prioritization category to which a road segment belongs. This field can be used to extract the road inventory data in Figure 5.2. Note that one road could be divided into multiple sections, each with different maintenance prioritization. For example, SR 115 had two sections, as shown in Figure 5.3, one in Category 4 and the other in Category 5.

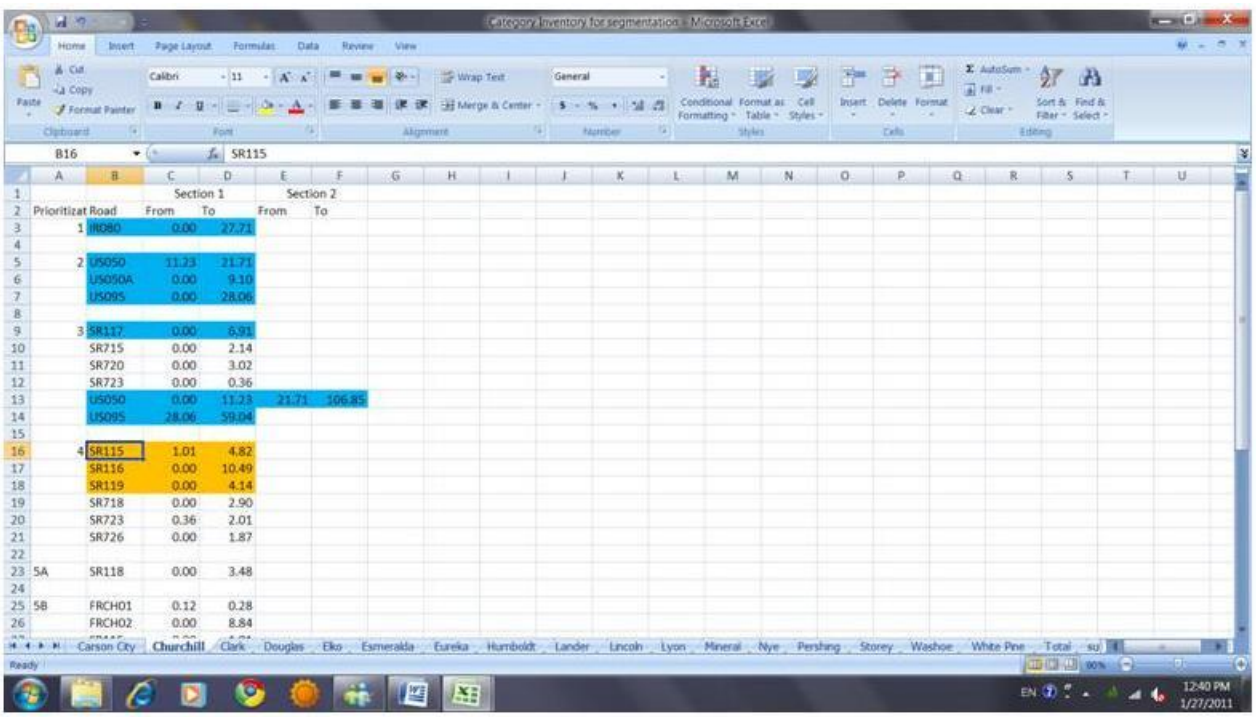


Figure 5.2 Road Inventory for Churchill County from PMS 2007 Data.

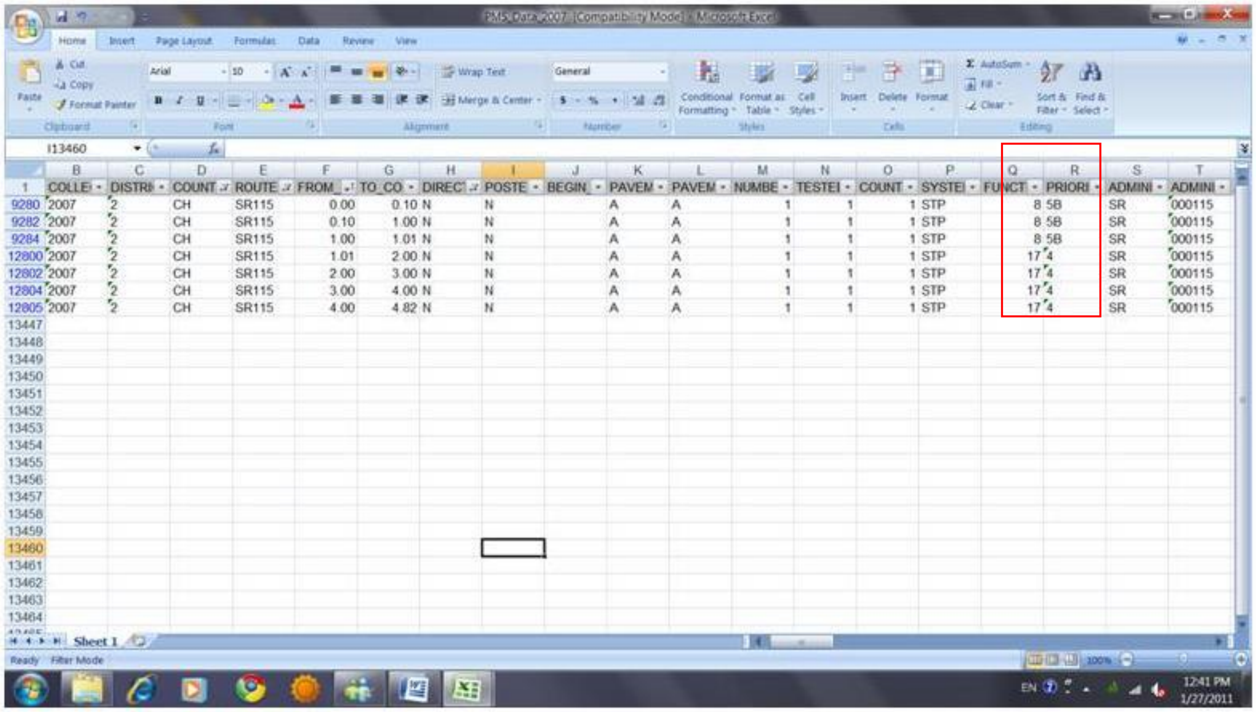


Figure 5.3 Maintenance Prioritization Category from PMS 2007 Data.

The inventory of the roads for all the counties in Nevada is summarized in Figure 5.4. The percentages of these five categories of roads are ordered increasingly as 1, 4, 2, 3, and 5. These numbers are consistent with those of NDOT official statistics.

	Carson Cit	Churchill	Clark	Douglas	Elko	Esmeralda	Eureka	Humboldt	Lander	Lincoln	Lyon	Mineral	Nye	Pershing	Storey	Washoe	White Pine		
Prioritizati	total	total	total	total	total	total	total	total	total	total	total	total	total	total	total	total	total		
1	9.05	27.71	205.86	0	132.73	0	25.7	61.38	26.97	0	15.91	0	6.86	75.09	0	88.59	0	675.85	0.123878
2	22.32	47.64	274.44	12.32	81.77	98	0	38.44	0	0	29.73	93.44	109.93	0	0	77.96	0	885.99	0.162396
3	16.88	139.78	147.58	26.09	117.63	0	53.71	50.51	63.58	103.07	102.86	35.21	48.71	0	10.66	76.48	242.22	1234.97	0.226361
4	2.95	24.86	63.78	19.21	114.71	0	40.85	24.2	40.8	146.02	76.5	11.14	138.37	1.69	3.12	113.12	35.64	856.96	0.157075
5A	0	3.48	35.67	0	101.77	18.8	20.24	89.2	72.23	1.81	7.47	3.24	59.47	7.11	0	1.29	34.09	455.87	0.083558
5B	0	25.7	16.58	0	88.74	84.58	42.19	72.64	14.15	87.14	0.92	55.09	141.07	18.92	0	1.35	2.04	651.11	0.119344
5C	1.08	76.37	27.2	0.94	86.55	38.4	17.27	9.47	72.42	17.31	10.72	4.73	78.23	105.74	0	18.36	130.21	695	0.127389
																		5455.75	

Figure 5.4 Road Mileage for All Nevada Counties According to Prioritization Categories.

5.3 Time-Space Diagram for Maintenance Work

Time-space diagrams present the maintenance tasks performed on a road. Figure 5.5 presents the time-space diagrams for I-80 from 0.00 – 27.17 in Churchill County; the diagram is zoomed into one road segment. Figure 5.6 shows the time-space diagram that covers the entire I-80 in Churchill County.

From Figure 5.5 it can be seen that the columns present the year's maintenances, rehabilitations, or reconstructions that were performed; the rows show the locations where these happened on a road. The yellow columns are those of rehabilitation and reconstruction projects that were recorded in the PMS database as multiple works performed in a year on the road. The purple columns are those of maintenance works performed under a flexible pavement program that consisted of the following tasks:

- Base & Surface Repair
- Hand Patching
- Machine Patching
- Maintenance Overlay, Inlay (Scheduled Betterment)
- Roadway Capital Improvements (Scheduled Betterment)
- Sand
- Fog/Flush
- Chip
- Scrub/Slurry
- Crack Filling
- Cold Milling

The other maintenance tasks, such as snow removal, are not presented in the diagram. From the colors of the columns, the road segments that experienced the same maintenance tasks can be distinguished. From these diagrams, the road segments that experienced homogenous maintenance can be identified, particularly preventive maintenance.

The time space diagrams for Prioritization Categories 3, 4 and 5 are presented with minor differences from those for Categories 1 and 2.

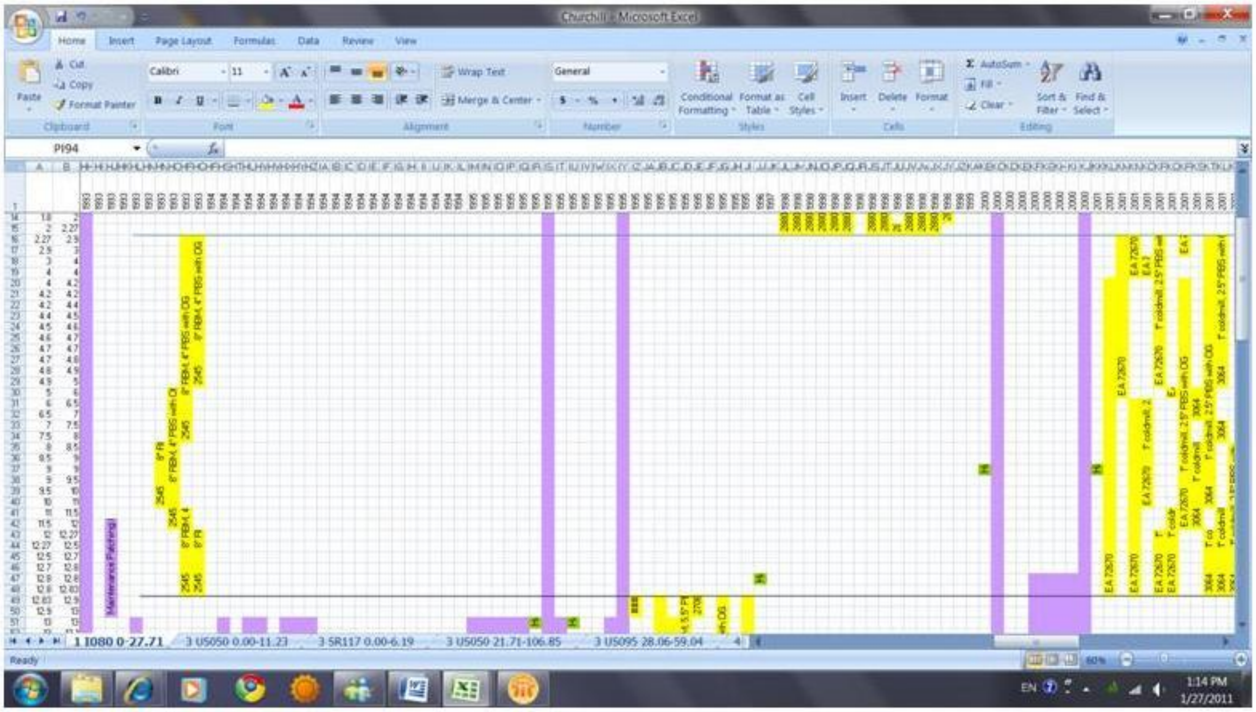


Figure 5.5 Time Space Diagram for I-80 of Category 1 from 0.00 to 27.71 (zoomed in).

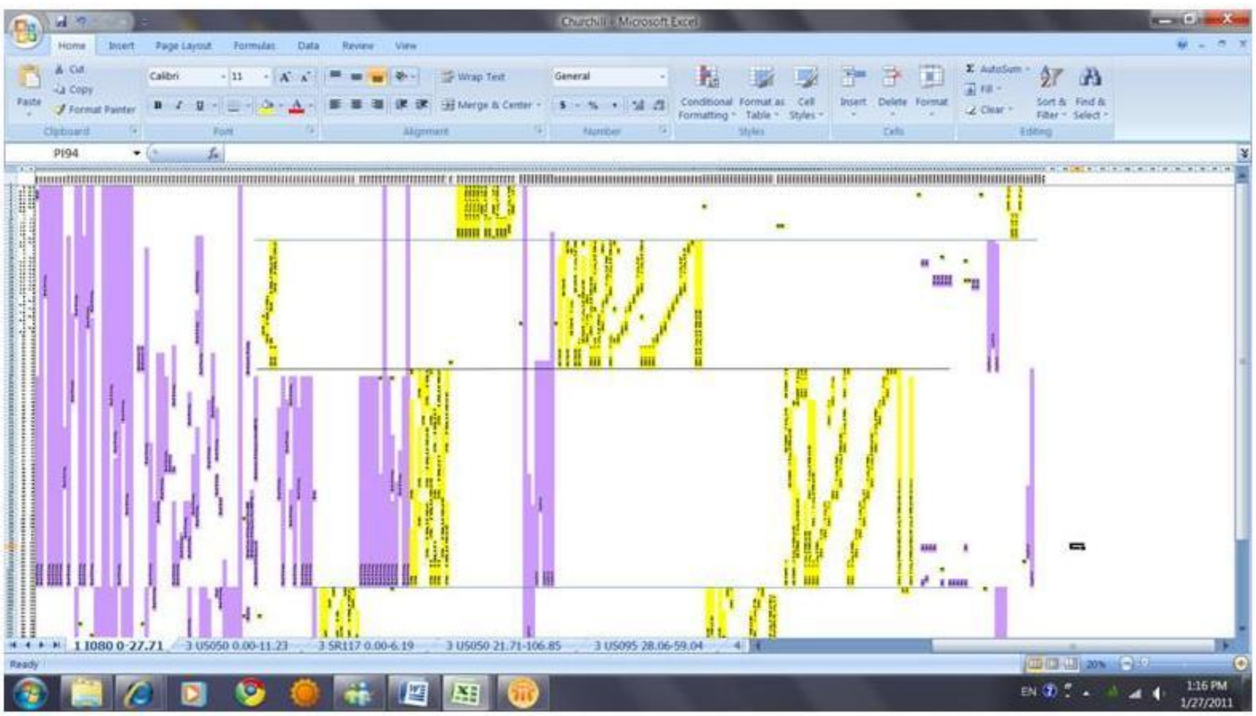


Figure 5.6 Time Space Diagram for I-80 of Category 1 from 0.00 to 27.71 (zoomed out).

In addition to the yellow and purple strips, orange strips were marked on the time space diagrams to distinguish the preventive maintenance tasks, see Figure 5.7: Fog/Flush, Chip, and Sand Seals.

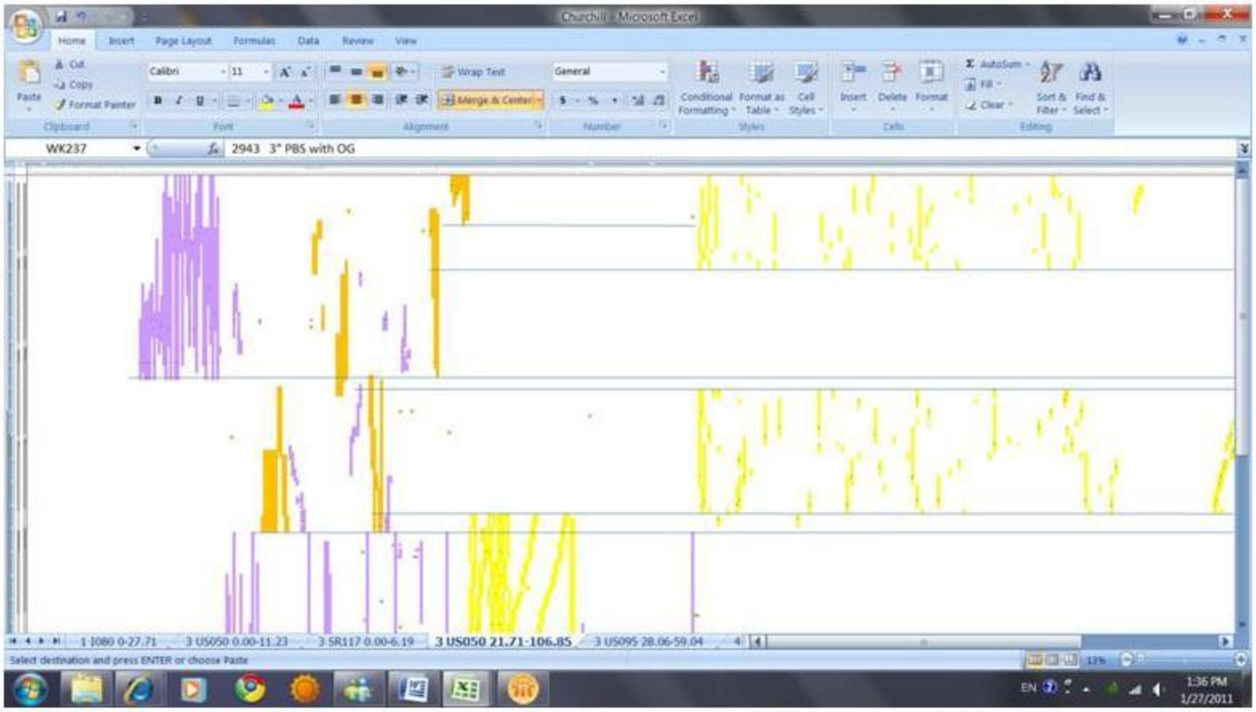


Figure 5.7 Time Space Diagram for US 50 (Category 3) in Churchill County.

Time space diagrams were developed based on running an MS Excel program written using Macro. The data from the PMS and MMS databases were utilized as the base of the program. The contracting works on rehabilitation and reconstruction, represented as yellow strips, are included in the PMS database. The maintenance works, depicted as purple and orange strips, are from the MMS database. The procedures adopted in coding the Macro program are presented in Figures 5.8 and 5.9.

Data file MMS:

1. Loop through each segment

   a. find the year

   b. find mileage points

   c. if the current task is different from previous task, or the corresponding cells are colored already, insert a year column

   d. put task in the corresponding slots (change corresponding cell color and text in excel)

2. merge any contiguous cells with same color and same text, turn text up.

Figure 5.8 Procedure Using MMS Data for Macro of the Time-Space Diagrams.

Data file AllData:

1. Loop through each sement

   a. Find the year

   b. Find mileage points

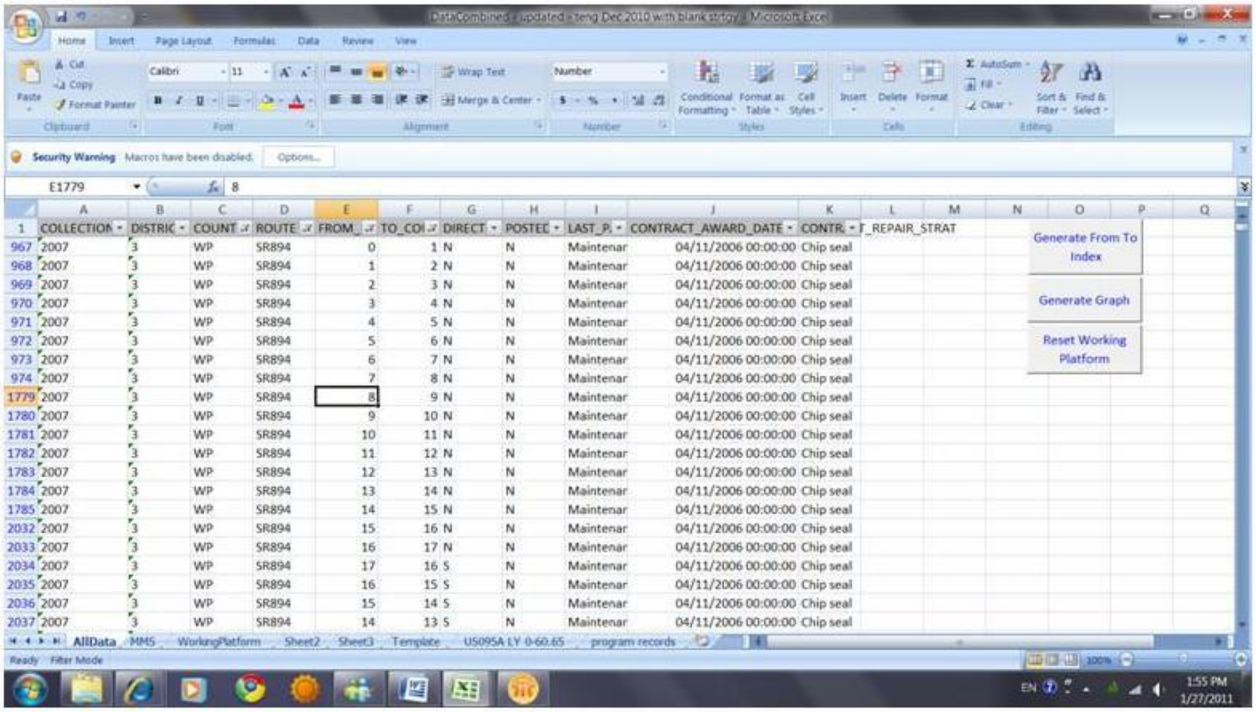
   c. If the current "Contract Repair Strat" is different from previous one in this year column, or the corresponding cells are colored already, insert a year column

   d. Put "Contract" and "Contract Repair Strat" in the cells and color

2. merge any contiguous cells with same color and same text, turn text up.

Figure 5.9 Procedure Using PMS Data of Macro of the Time-Space Diagrams.

Figure 5.10 presents the interface of the MS Excel program. The PMS and MMS data are stored in the spread sheets named 'Alldata' and 'MMS'. For an identified road, such information as the county, the road name, and the beginning and ending mile posts needs to specified using the filtering function in MS Excel. The 'FROM' should be entered as '≤' the ending milepost, while the 'TO' should be input as '≥' the beginning milepost for a road segment. In this way, all the maintenance works related to the road segment concerned can be included.



	COLLECTION	DISTRIC	COUNT	ROUTE	FROM_	TO_CO	DIRECT	POSTED	LAST_P.	CONTRACT_AWARD_DATE	CONTR.	T_REPAIR_STRAT
967	2007	3	WP	SR894	0	1	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
968	2007	3	WP	SR894	1	2	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
969	2007	3	WP	SR894	2	3	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
970	2007	3	WP	SR894	3	4	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
971	2007	3	WP	SR894	4	5	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
972	2007	3	WP	SR894	5	6	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
973	2007	3	WP	SR894	6	7	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
974	2007	3	WP	SR894	7	8	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
1779	2007	3	WP	SR894	8	9	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
1780	2007	3	WP	SR894	9	10	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
1781	2007	3	WP	SR894	10	11	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
1782	2007	3	WP	SR894	11	12	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
1783	2007	3	WP	SR894	12	13	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
1784	2007	3	WP	SR894	13	14	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
1785	2007	3	WP	SR894	14	15	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
2032	2007	3	WP	SR894	15	16	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
2033	2007	3	WP	SR894	16	17	N	N	Maintenar	04/11/2006 00:00:00	Chip seal	
2034	2007	3	WP	SR894	17	16	S	N	Maintenar	04/11/2006 00:00:00	Chip seal	
2035	2007	3	WP	SR894	16	15	S	N	Maintenar	04/11/2006 00:00:00	Chip seal	
2036	2007	3	WP	SR894	15	14	S	N	Maintenar	04/11/2006 00:00:00	Chip seal	
2037	2007	3	WP	SR894	14	13	S	N	Maintenar	04/11/2006 00:00:00	Chip seal	

Figure 5.10 MS Excel Program Interface for the Time-Space Diagram Macro.

Figure 5.11 shows the relationship between a road segment and its associated maintenance works. It can be seen that there are four possible maintenance works that were performed: (1) within the segment, (2) through the segment, (3) overlay the segment on the left, and (4) overlay the segment on the right.

Figure 5.11 Four Cases (Marked as Yellow) to Count Costs for a Route Segment (Marked as Red).

With these inputs, which make the relevant data active in the program, the following steps are carried out.

1) The first step is to reset a working spreadsheet by clicking on the ‘Reset Working Platform’ button.
2) Then, click on the ‘Generate From To Index’ button to generate the frame of the time-space diagram, i.e., years vs. locations.
3) The last step is to generate the time-space diagram by clicking on the ‘Generate Graph’ button.

Depending on the amount of rehabilitation, construction, and maintenance works performed on a road segment, the program could last as short as a few minutes or as long as a few hours to complete.

5.4 Selecting Homogenous Road Segments

With the time-space diagrams developed for selected road sections, road segments that show homogenous maintenance treatments in history were identified. The horizontal lines in Figure 5.5 were drawn to delineate such a homogenous segment starting from 2.27 to 12.83. Figure 5.6 present multiple such segments identified from the diagram.

The identification of the homogenous road segments used the maintenance policy as shown in Figure 4.1. For a homogeneous segment in Categories 1 or 2, there should be no rehabilitation performed on any division in it during the time duration between these two rehabilitations. As far as a homogeneous segment in other categories, there should be no preventive maintenance or rehabilitation performed within the segment during the time period between rehabilitation and any preventive maintenance.

As shown in Figure 5.12, four segments were identified for I-80 from 0.00 to 27.71 in Churchill County: 0.00-2.27, 2.27-12.83, 12.83-22.46, and 22.46-27.27, each with a time period starting and ending with a rehabilitation. Similarly, two segments were identified for SR 317 from 0.00 to 6.91 in Churchill County: 0.00 – 42 4.22 - 6.91.

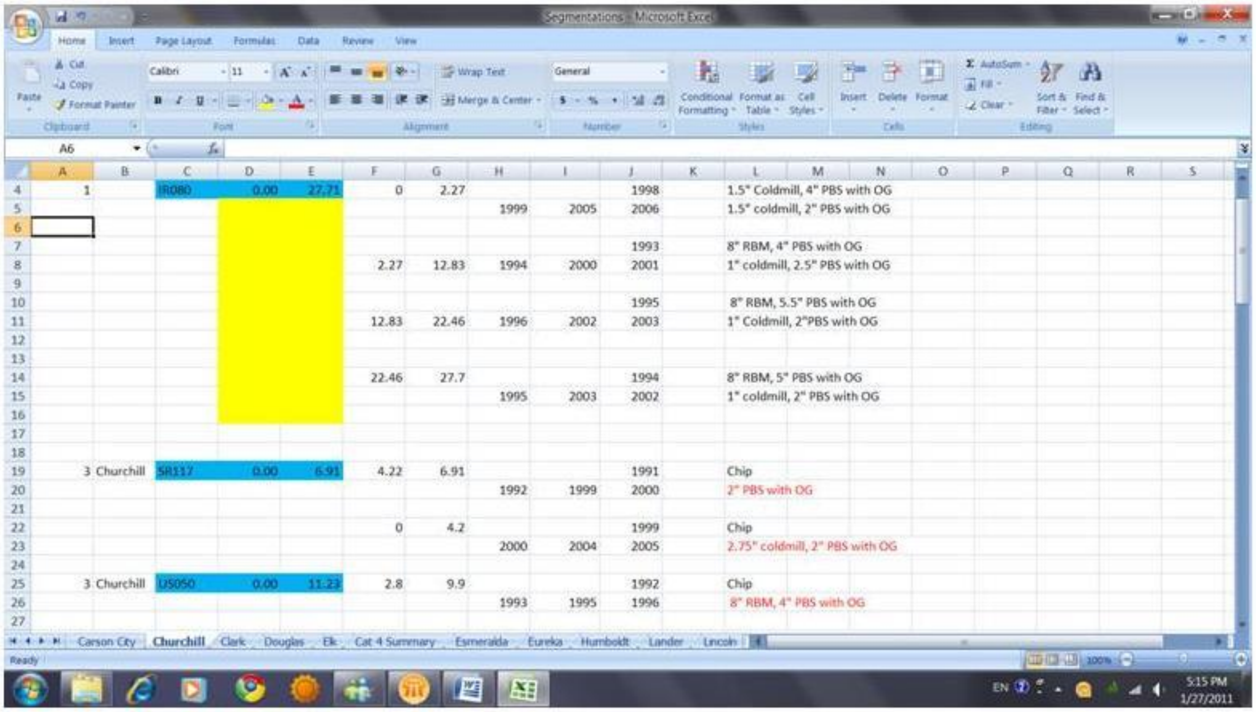


Figure 5.12 Identified Road Segments for Roads in Churchill County.

5.5 Deriving Traffic Flow and Road Characteristics Data

5.5.1 Traffic flow data

The mile-by-mile traffic flow data available in the PMS database vary over a given road segment. Thus, averaging has to be performed for the mile-by-mile traffic flow data. The procedure to derive the average ADT data starts by copying and pasting the road characteristics data to a separate worksheet. The average of the ADT is first calculated for one year. The spreadsheet formula is then copied and pasted to other years. The averages of ADTs of these years are put together, then copied and pasted to the cost data file.

Figure 5.13 shows the filtered data for the road segment East US 50 from 43.71 to 59.96 in Churchill. This segment was identified for US 50 in Churchill County from 21.71 to 106.85, which is presented in Figure 5.14. It should be noted that when filtering the data, the criterion for the ‘FROM’ column should be “less than or equal to 43.71” and the ‘TO’ column should be “less than or equal to 59.96”. Figure 5.15 shows that the traffic flow data is moved to a separate spreadsheet, in which their averages are derived and clustered together before moving to the master file for cost data.

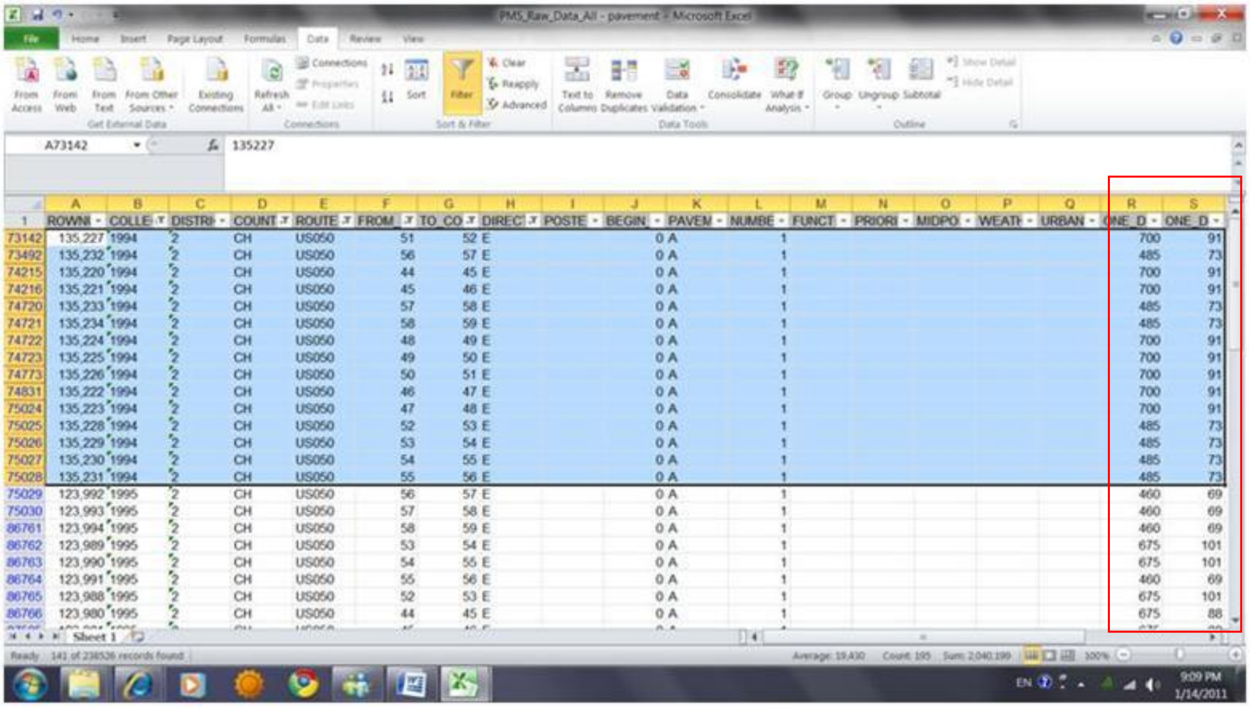


Figure 5.13 Road Characteristics Data from NDOT PMS Data.

3	Churchill	US050	21.71	106.85	43.71	59.96			1993		chip						
							1994	1998	1999		1.5" coldmill, 2.5" PBS with OG				1994	3	7
															1995	3	7
															1996	3	7
															1997	3	7
															1998	3	7
															1999	3	7
							2000	2001	2002		fog/flush				2000	1	10
															2001	1	10
															2002	1	10

Figure 5.14 Identified Road Segments for US 50 in Churchill County of Nevada.

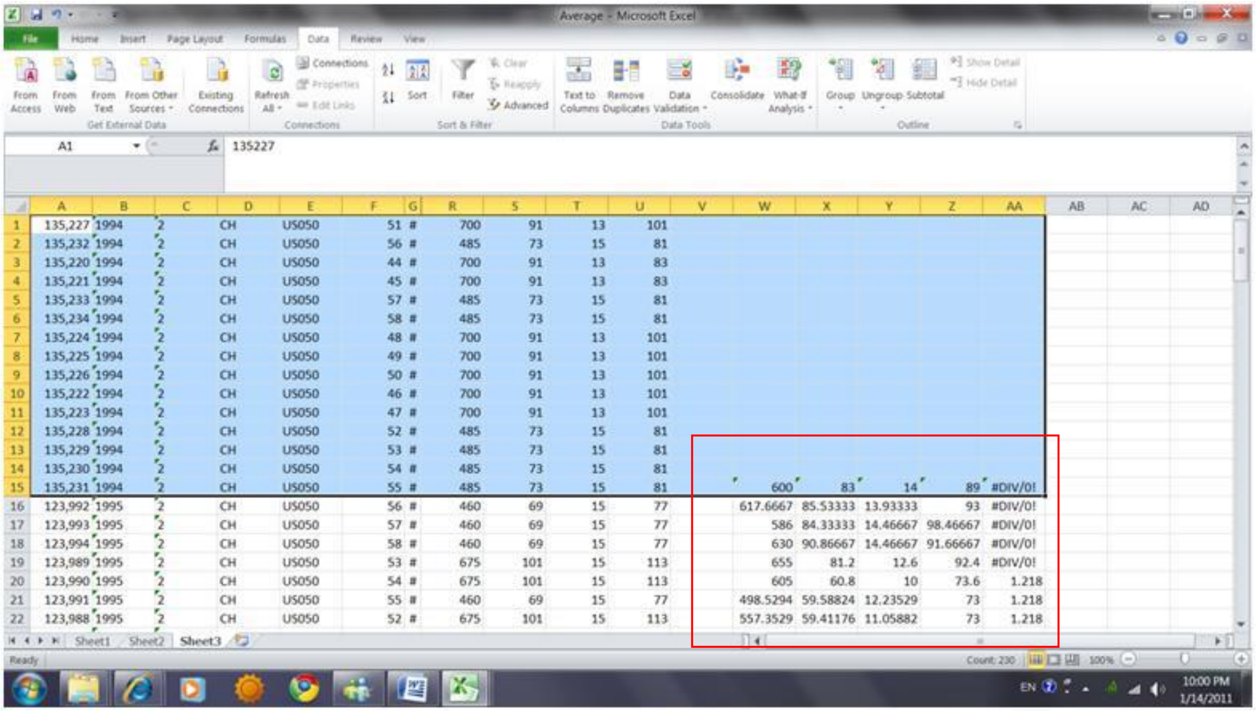


Figure 5.15 Traffic Flow Data from the NDOT PMS database, Copied and Pasted to a Different Spreadsheet.

5.5.2 Midpoint Elevation Data

When the length of road segment is long, the midpoint elevations of the mile-by-mile midpoint elevations on the road segment may be different; thus, the average of these mile-by-mile midpoint evaluation data needs to be derived. Usually, the most recent years of the road characteristics data also have the complete mile-by-mile midpoint elevation data. These data can be copied and pasted to a separate spreadsheet.

In this study, a template was developed. These mile-by-mile data can be inserted into the template, and the average of the mile-by-mile midpoint elevation can be read from the template right away. Figure 5.16 displays such a template as well as the average midpoint elevation.

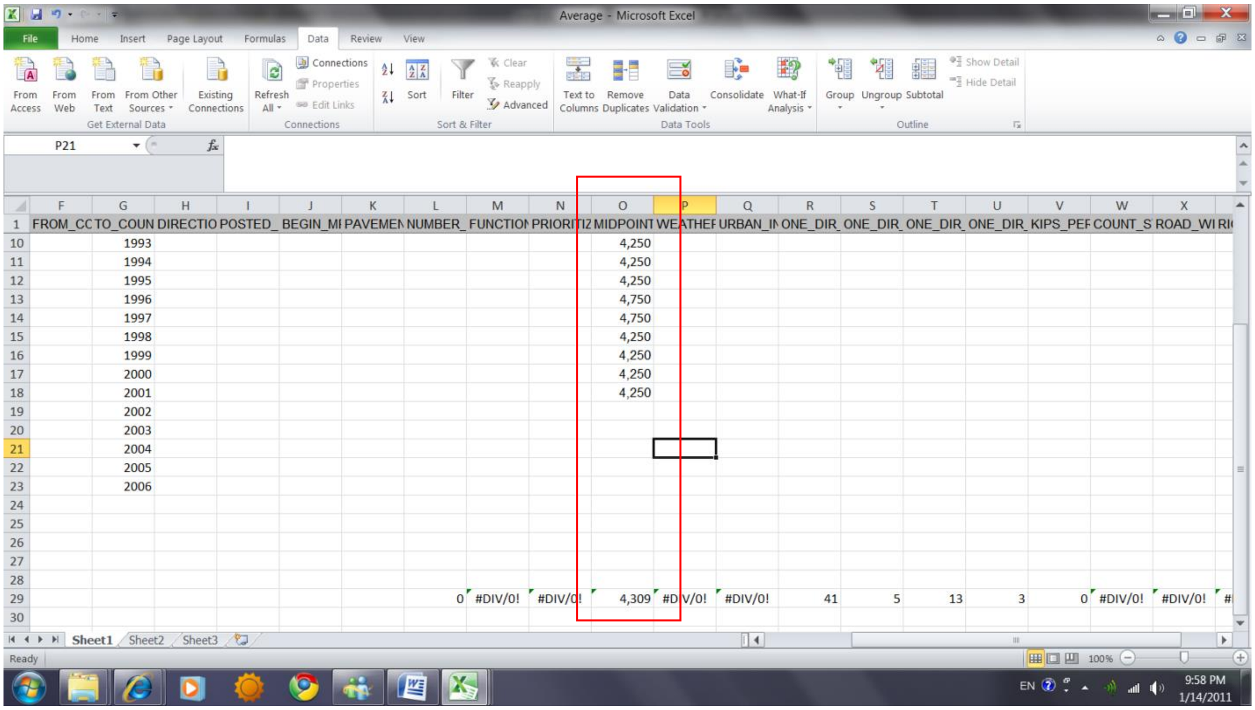
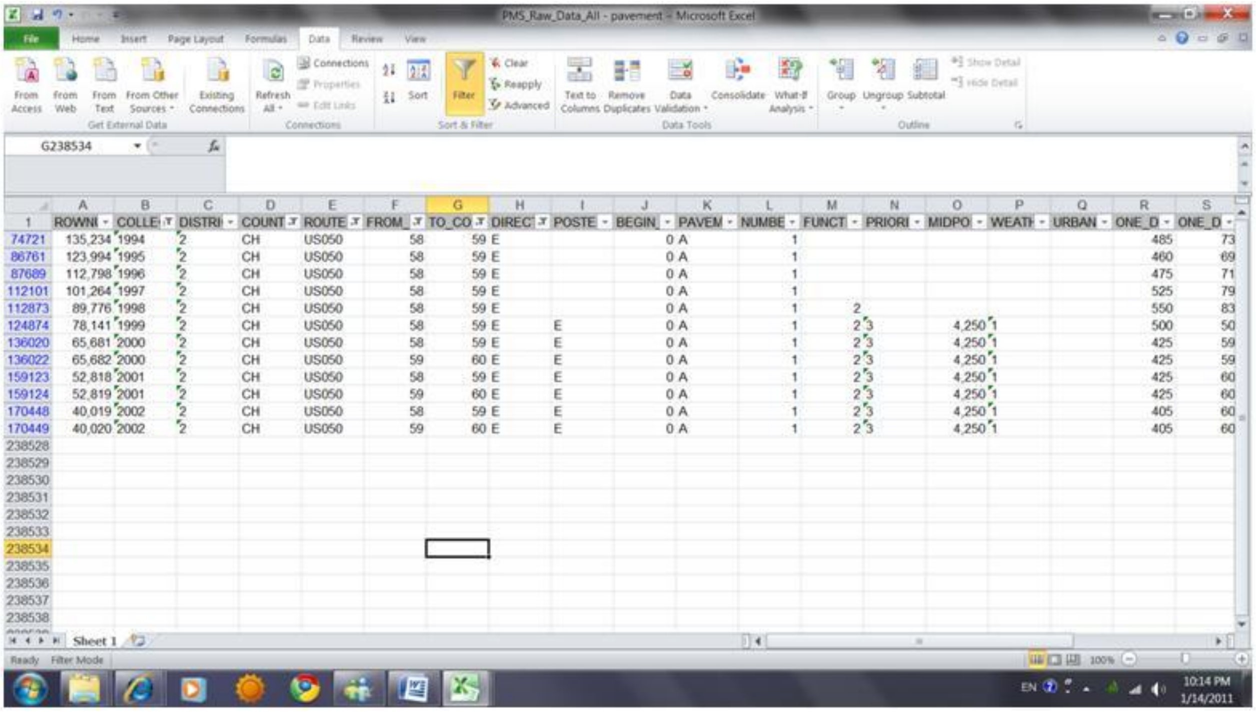


Figure 5.16 Template for Calculating the Average of Midpoint Elevation.

5.5.3 Data for Other Road Characteristics

Other road characteristics data – such as number of lanes, the type of road surface, and whether the road is urban or rural – do not vary over the length of a road segment. These data are collected as follows. A shorter road section of one mile long within the road segment can be chosen. As a result, only one record of the road characteristics for the road segment is displayed in MS Excel. These one-year records are shown together, which makes it convenient to be moved to the cost data master file. Figure 5.17 presents the road characteristics over a given time period.



	ROWNI	COLLE	DISTRI	COUNT	ROUTE	FROM_	TO_CO	DIREC	POSTE	BEGIN	PAVEM	NUMBE	FUNCT	PRIORI	MIDPO	WEATH	URBAN	ONE_D	ONE_D
74721	135,234	1994	2	CH	US050	58	59	E		0	A	1						485	73
86761	123,994	1995	2	CH	US050	58	59	E		0	A	1						460	69
87689	112,798	1996	2	CH	US050	58	59	E		0	A	1						475	71
112101	101,264	1997	2	CH	US050	58	59	E		0	A	1						525	79
112873	89,776	1998	2	CH	US050	58	59	E		0	A	1	2					550	83
124874	78,141	1999	2	CH	US050	58	59	E	E	0	A	1	2	3	4,250	1		500	50
136020	65,681	2000	2	CH	US050	58	59	E	E	0	A	1	2	3	4,250	1		425	59
136022	65,682	2000	2	CH	US050	59	60	E	E	0	A	1	2	3	4,250	1		425	59
159123	52,818	2001	2	CH	US050	58	59	E	E	0	A	1	2	3	4,250	1		425	60
159124	52,819	2001	2	CH	US050	59	60	E	E	0	A	1	2	3	4,250	1		425	60
170448	40,019	2002	2	CH	US050	58	59	E	E	0	A	1	2	3	4,250	1		405	60
170449	40,020	2002	2	CH	US050	59	60	E	E	0	A	1	2	3	4,250	1		405	60

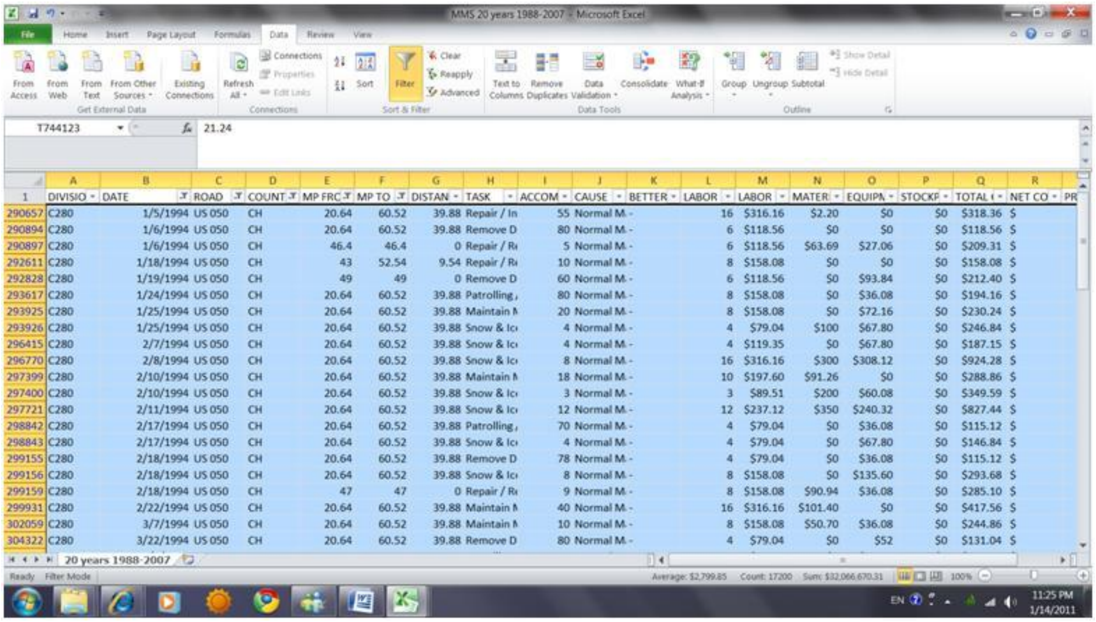
Figure 5.17 Road Characteristics for a Chosen Road Segment from 1994 to 2002.

It was found in the data collection that road segment characteristics may not be uniform within a segment and over a time period. Sometimes, traffic flows are kept constant over any point of a road segment for which no average is needed. It also happens that the midpoint elevations are the same mile-by-mile within the road segment, for which no average is needed to derive the evaluation for a chosen road segment. This case highly likely happen for road segments having shorter distances and/or in rural areas. Care should be taken that the number of sections within a road segment varies over the years. The range of time period for averaging a road segment characteristic in the spreadsheet has been adjusted accordingly.

5.6 Maintenance Cost Data

Maintenance cost data were extracted from the NDOT MMS database. To facilitate the data extraction, a MS Spreadsheet program was developed. Given a chosen road segment with specific beginning and ending mileposts and time period, the corresponding maintenance cost data can been pooled together, and copied and pasted to a template in the MS Excel program. The data that are moved are used as a base to derive the cost data for manpower, equipment, materials, and stockpile.

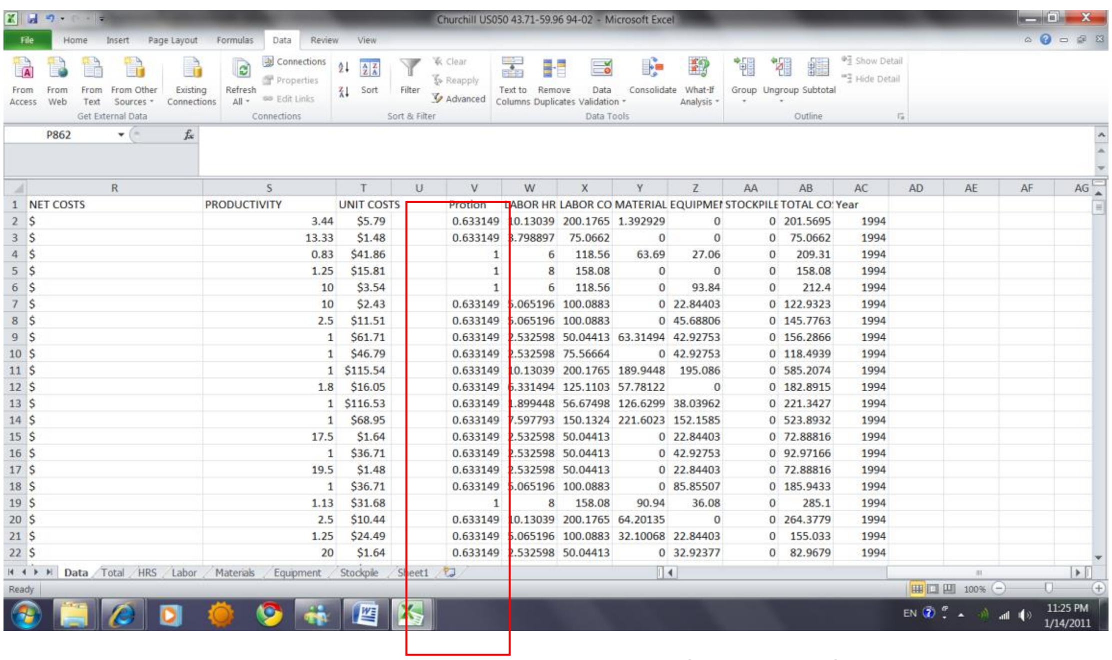
Figure 5.18 shows the filtered maintenance data for US 50 from 43.71 to 59.96 in Churchill. These cost data are for maintenance activities relevant to a specific road segment.



	DIVISIO	DATE	ROAD	COUNT	MP FRC	MP TO	DISTAN	TASK	ACCOM	CAUSE	BETTER	LABOR	LABOR	MATER	EQUIPN	STOCKP	TOTAL	NET CO
290657	C280	1/5/1994	US 050	CH	20.64	60.52	39.88	Repair / In	55	Normal M	-	16	$316.16	$2.20	$0	$0	$318.36	$
290894	C280	1/6/1994	US 050	CH	20.64	60.52	39.88	Remove D	80	Normal M	-	6	$118.56	$0	$0	$0	$118.56	$
290897	C280	1/6/1994	US 050	CH	46.4	46.4	0	Repair / R	5	Normal M	-	6	$118.56	$63.69	$27.06	$0	$209.31	$
292611	C280	1/18/1994	US 050	CH	43	52.54	9.54	Repair / R	10	Normal M	-	8	$158.08	$0	$0	$0	$158.08	$
292828	C280	1/19/1994	US 050	CH	49	49	0	Remove D	60	Normal M	-	6	$118.56	$0	$93.84	$0	$212.40	$
293617	C280	1/24/1994	US 050	CH	20.64	60.52	39.88	Patrolling,	80	Normal M	-	8	$158.08	$0	$36.08	$0	$194.16	$
293925	C280	1/25/1994	US 050	CH	20.64	60.52	39.88	Maintain M	20	Normal M	-	8	$158.08	$0	$72.16	$0	$230.24	$
293926	C280	1/25/1994	US 050	CH	20.64	60.52	39.88	Snow & Ice	4	Normal M	-	4	$79.04	$100	$67.80	$0	$246.84	$
296415	C280	2/7/1994	US 050	CH	20.64	60.52	39.88	Snow & Ice	4	Normal M	-	4	$119.35	$0	$67.80	$0	$187.15	$
296770	C280	2/8/1994	US 050	CH	20.64	60.52	39.88	Snow & Ice	8	Normal M	-	16	$316.16	$300	$308.12	$0	$924.28	$
297399	C280	2/10/1994	US 050	CH	20.64	60.52	39.88	Maintain M	18	Normal M	-	10	$197.60	$91.26	$0	$0	$288.86	$
297400	C280	2/10/1994	US 050	CH	20.64	60.52	39.88	Snow & Ice	3	Normal M	-	3	$89.51	$200	$60.08	$0	$349.59	$
297721	C280	2/11/1994	US 050	CH	20.64	60.52	39.88	Snow & Ice	12	Normal M	-	12	$237.12	$350	$240.32	$0	$827.44	$
298842	C280	2/17/1994	US 050	CH	20.64	60.52	39.88	Patrolling,	70	Normal M	-	4	$79.04	$0	$36.08	$0	$115.12	$
298843	C280	2/17/1994	US 050	CH	20.64	60.52	39.88	Snow & Ice	4	Normal M	-	4	$79.04	$0	$67.80	$0	$146.84	$
299155	C280	2/18/1994	US 050	CH	20.64	60.52	39.88	Remove D	78	Normal M	-	4	$79.04	$0	$36.08	$0	$115.12	$
299156	C280	2/18/1994	US 050	CH	20.64	60.52	39.88	Snow & Ice	8	Normal M	-	8	$158.08	$0	$135.60	$0	$293.68	$
299159	C280	2/18/1994	US 050	CH	47	47	0	Repair / R	9	Normal M	-	8	$158.08	$90.94	$36.08	$0	$285.10	$
299931	C280	2/22/1994	US 050	CH	20.64	60.52	39.88	Maintain M	40	Normal M	-	16	$316.16	$101.40	$0	$0	$417.56	$
302059	C280	3/7/1994	US 050	CH	20.64	60.52	39.88	Maintain M	10	Normal M	-	8	$158.08	$50.70	$36.08	$0	$244.86	$
304322	C280	3/22/1994	US 050	CH	20.64	60.52	39.88	Remove D	80	Normal M	-	4	$79.04	$0	$52	$0	$131.04	$

Figure 5.18 Related Maintenance Cost Data filtered in the NDOT MMS Database.

For those activities whose ranges do not completely fall in the range of the road segment, the proportion of the maintenance activities that occurred on the road segment was considered, and is shown in Figure 5.19.



	NET COSTS	PRODUCTIVITY	UNIT COSTS		Protion	LABOR HR	LABOR CO	MATERIAL	EQUIPMEI	STOCKPILE	TOTAL CO	Year
2	$	3.44	$5.79		0.633149	10.13039	200.1765	1.392929	0	0	201.5695	1994
3	$	13.33	$1.48		0.633149	3.798897	75.0662	0	0	0	75.0662	1994
4	$	0.83	$41.86		1	6	118.56	63.69	27.06	0	209.31	1994
5	$	1.25	$15.81		1	8	158.08	0	0	0	158.08	1994
6	$	10	$3.54		1	6	118.56	0	93.84	0	212.4	1994
7	$	10	$2.43		0.633149	5.065196	100.0883	0	22.84403	0	122.9323	1994
8	$	2.5	$11.51		0.633149	5.065196	100.0883	0	45.68806	0	145.7763	1994
9	$	1	$61.71		0.633149	2.532598	50.04413	63.31494	42.92753	0	156.2866	1994
10	$	1	$46.79		0.633149	2.532598	75.56664	0	42.92753	0	118.4939	1994
11	$	1	$115.54		0.633149	10.13039	200.1765	189.9448	195.086	0	585.2074	1994
12	$	1.8	$16.05		0.633149	6.331494	125.1103	57.78122	0	0	182.8915	1994
13	$	1	$116.53		0.633149	1.899448	56.67498	126.6299	38.03962	0	221.3427	1994
14	$	1	$68.95		0.633149	7.597793	150.1324	221.6023	152.1585	0	523.8932	1994
15	$	17.5	$1.64		0.633149	2.532598	50.04413	0	22.84403	0	72.88816	1994
16	$	1	$36.71		0.633149	2.532598	50.04413	0	42.92753	0	92.97166	1994
17	$	19.5	$1.48		0.633149	2.532598	50.04413	0	22.84403	0	72.88816	1994
18	$	1	$36.71		0.633149	5.065196	100.0883	0	85.85507	0	185.9433	1994
19	$	1.13	$31.68		1	8	158.08	90.94	36.08	0	285.1	1994
20	$	2.5	$10.44		0.633149	10.13039	200.1765	64.20135	0	0	264.3779	1994
21	$	1.25	$24.49		0.633149	5.065196	100.0883	32.10068	22.84403	0	155.033	1994
22	$	20	$1.64		0.633149	2.532598	50.04413	0	32.92377	0	82.9679	1994

Figure 5.19 Maintenance Cost Data Converted for a Specific Road Segment.

Figure 5.20 presents the data converted after considering the portion of work that happened within the road segment concerned. These data are in a separate spreadsheet, named ‘Data’ in the program written for this study. The data in the spreadsheet ‘Data’ is filtered to different cost categories: manpower, materials, equipment, and stockpile; each is contained in a separate spreadsheet as labeled correspondingly. These costs of different categories are further broken down into different maintenance activities, which are shown at the left lower corner in Figure 5.20. The total costs of these categories are presented in this spreadsheet and then copied and pasted to the cost master file.

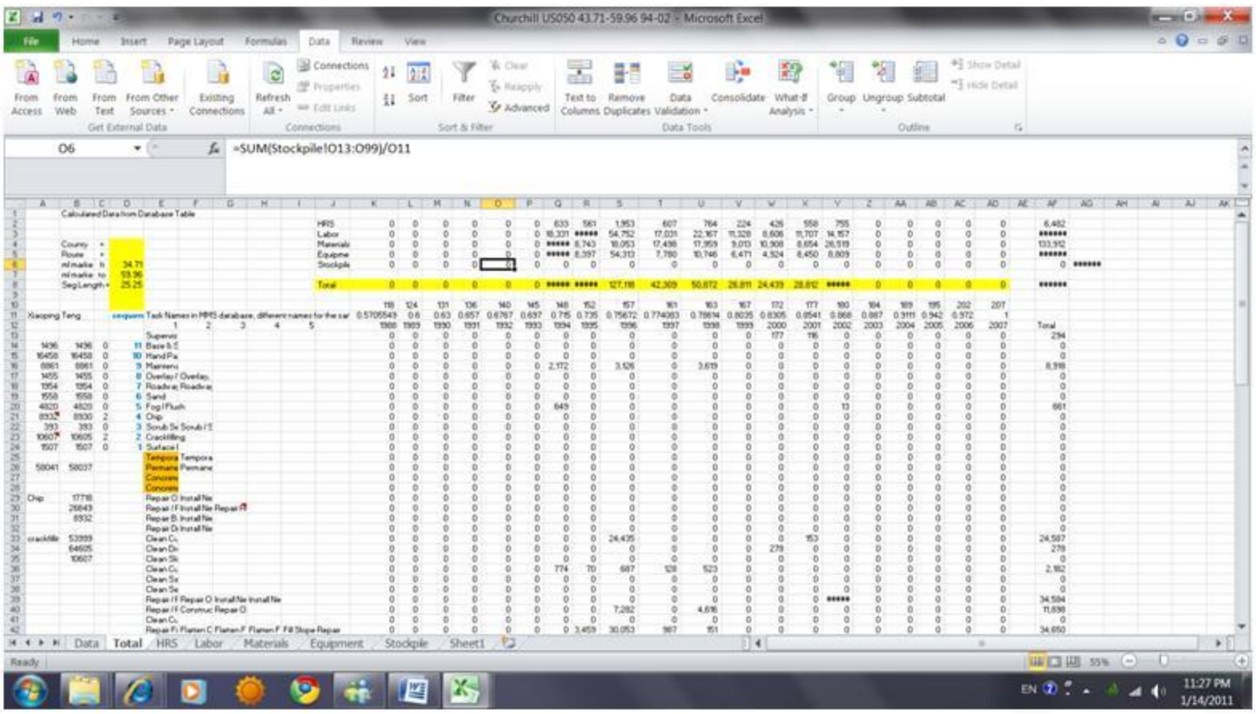


Figure 5.20 Maintenance Cost Data of Different Types of Cost Categories.

Because of the four cases of maintenance work relevant to a given road segment, when filtering the MMS maintenance cost data, the criterion ‘From MP’ should be entered as “less than or equal to”, and the value should be the ending mile post of the given road segment. The criterion ‘TO MP’ should be entered as “greater than or equal to,” and the value should be the starting mile post of the given road segment. This filtering is different from the one in extracting the road characteristics data from the NDOT PMS database, which was given special care when the cost data were collected in this study.

The maintenance costs collected using the MS Excel program are saved in individual files that are labeled in the following format: prioritization category, county, route, from MP, to MP, life cycle stage. The life cycle stages are listed as follows:

1) Cat 1 After Reconstruction
2) Cat 2 After Reconstruction
3) Cat 3 After Reconstruction
4) Cat 3 After Flush Seal
5) Cat 3 After Chip Seal
6) Cat 4 After Construction
7) Cat 4 After Flush Seal
8) Cat 4 After 1st Chip Seal
9) Cat 4 After 2nd Chip Seal
10) Cat 5 After Reconstruction
11) Cat 5 Middle After Flush, Cat Middle After Chip
12) Cat 5 Last After Chip, Cat 5 Last After Flush

Figure 5.21 shows the data derived from these steps, which are used in the analysis.

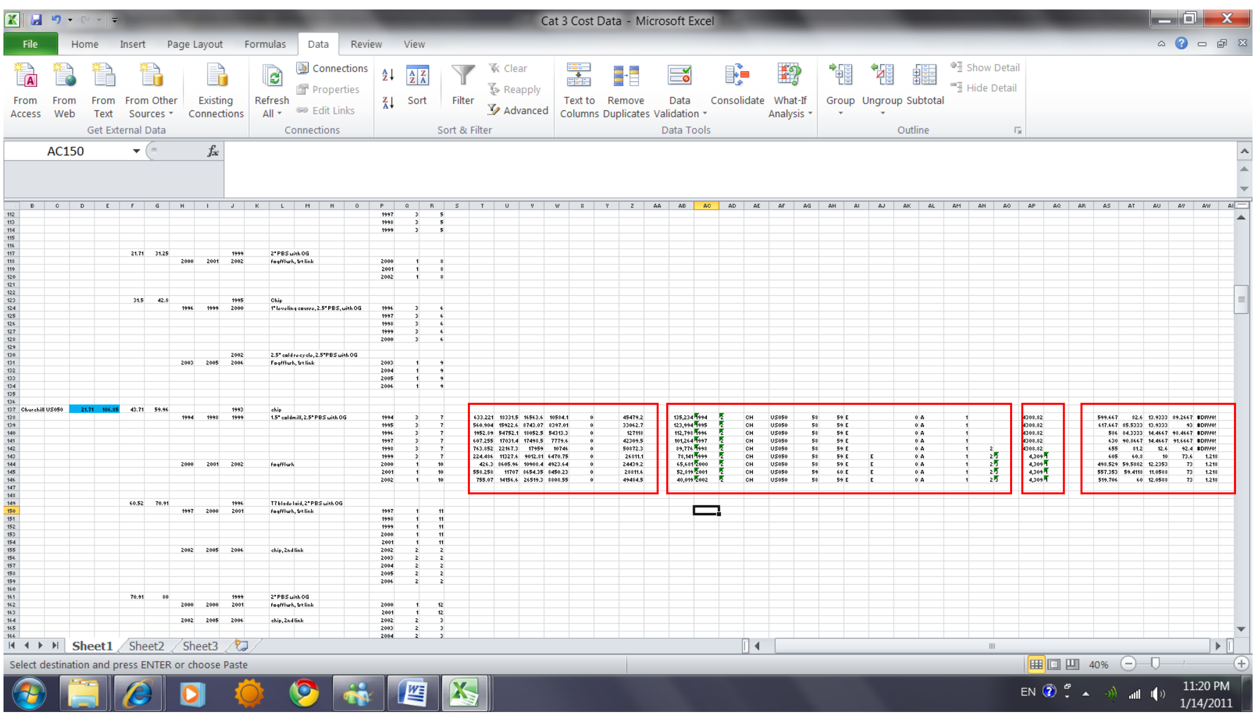


Figure 5.21 Maintenance Costs and Road Characteristics Data in the Cost Data Master File.

CHAPTER 6

MAINTENANCE COST MODEL DEVELOPMENT

6.1 Regression Models for Roads in Priority Category 1

Figure 6.1.1 shows the overall life cycle for road maintenance in Priority Category 1. Linear regression models were developed for the following total maintenance cost and the component costs: labor, equipment, materials, and stockpiles. The results of the models are listed in Table 6.1, shown at the end of this section.

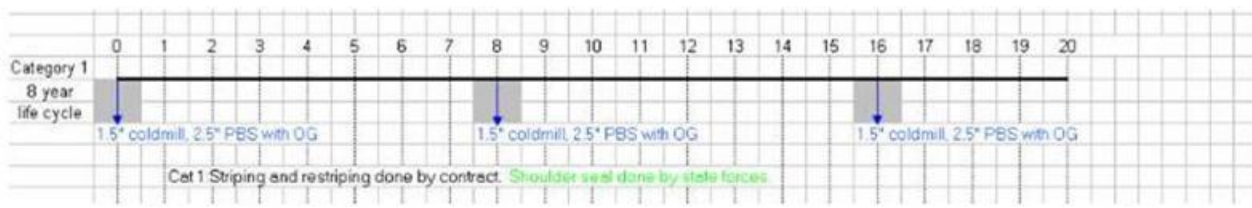


Figure 6.1.1 Life Cycle for Priority Category 1 Roads.

From Table 6.1 it can be seen that the coefficient for the variable age is positive; this implies that the total maintenance cost increases by year. In the last year before a reconstruction, certain maintenance work may not be performed; thus, the coefficient for the last year indicator is negative. The coefficient for the factor 'Asphalt Concrete' is positive, which indicates that the roads with asphalt concrete surfaces incur greater maintenance costs than rigid concrete pavement roads. The elevation of the road segment also is important to determine the amount of maintenance costs. The coefficient for the factor 'Elevation' is negative. This 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 high elevation and therefore less maintained.

The maintenance activities vary with the conditions of roads that are influenced by the amount of traffic rolling over them. The greater number of vehicles that travel on the roads results in greater deterioration, which triggers more maintenance activities. The coefficient of AADT is positive, which is consistent with this expectation. From Table 6.1, it can be seen that these influencing factors have had similar impacts on labor, materials, and equipment costs. When the total maintenance cost is analyzed, the maintenance cost in the year when a reconstruction happened was significantly less than previous years. This observation can be validated from the model for labor costs, which implies that those maintenance activities involving expensive equipment and materials were not performed during a year when major construction was scheduled.

For an assumed asphalt roadway segment in Category 1 with an elevation of 2,400 ft and an AADT of 27,000, the total maintenance costs for an eight-year life cycle can be calculated using the function coefficients given in Table 6.1. Figure 6.1.2 indicates that the total costs increase with year. The annual maintenance cost in the eighth year is lower than the linear trend because of the reconstruction work done that year.

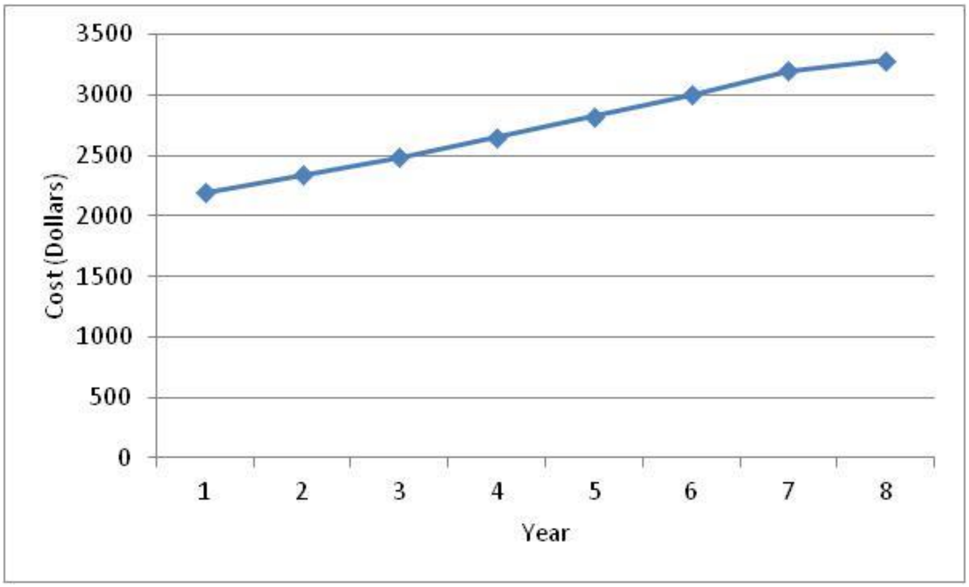


Figure 6.1.2 Total Maintenance Costs for an Eight-Year Life Cycle for Category 1 Roads.

Table 6.1 Regression Models for Road Maintenance Priority Category 1

Total Cost

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

Dependent Variable: lntot

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	8.20468	0.54838	14.96167
age	6.28091e-002	1.25052e-002	5.02264
lyear	-0.34813	0.20126	-1.72979
ac	0.95257	0.21990	4.33179
elev	-9.52315e-004	1.69739e-004	-5.61045
aadt	2.81009e-005	3.89760e-006	7.20981

Number of Observations	201
R-squared	0.47872
Corrected R-squared	0.46536
Sum of Squared Residuals	1.57275e+002
Standard Error of the Regression	0.89808
Durbin-Watson Statistic	0.58584
Mean of Dependent Variable	7.88086

Total Hours

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

Dependent Variable: lnhrs

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	4.31240	0.54035	7.98083
age	5.97201e-002	1.15936e-002	5.15113
ac	0.81709	0.21217	3.85112
elev	-9.31727e-004	1.60523e-004	-5.80434
aadt	2.37703e-005	3.83671e-006	6.19549
truck	1.13264e-004	5.26564e-005	2.15100

Number of Observations	201
R-squared	0.51110
Corrected R-squared	0.49856
Sum of Squared Residuals	1.39784e+002
Standard Error of the Regression	0.84666
Durbin-Watson Statistic	0.60668
Mean of Dependent Variable	4.07294

Table 6.1 Regression Models for Road Maintenance Priority Category 1 (continued)

Labor Cost

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

Dependent Variable: lnlabor

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	7.65243	0.51194	14.94798
age	5.84997e-002	1.16742e-002	5.01104
lyear	-0.33534	0.18788	-1.78483
ac	0.91071	0.20529	4.43621
elev	-9.38479e-004	1.58459e-004	-5.92252
aadt	2.58324e-005	3.63858e-006	7.09957

Number of Observations	201
R-squared	0.47962
Corrected R-squared	0.46627
Sum of Squared Residuals	1.37066e+002
Standard Error of the Regression	0.83839
Durbin-Watson Statistic	0.48541
Mean of Dependent Variable	7.23326

Materials Cost

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

Dependent Variable: lnma

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	5.87373	0.75837	7.74515
age	7.38305e-002	1.68890e-002	4.37151
ac	1.02915	0.30212	3.40644
elev	-8.36852e-004	2.36656e-004	-3.53615
aadt	3.46083e-005	5.37191e-006	6.44246

Number of Observations	200
R-squared	0.39212
Corrected R-squared	0.37965
Sum of Squared Residuals	3.00505e+002
Standard Error of the Regression	1.24139
Durbin-Watson Statistic	1.02064
Mean of Dependent Variable	6.20744

Table 6.1 Regression Models for Road Maintenance Priority Category 1 (continued)

Equipment Cost

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

Dependent Variable: lneq

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	7.03420	0.59595	11.80334
age	6.51333e-002	1.33239e-002	4.88845
ac	0.92762	0.23842	3.89062
elev	-1.07228e-003	1.84905e-004	-5.79908
aadt	2.61492e-005	4.23932e-006	6.16825

Number of Observations	201
R-squared	0.44375
Corrected R-squared	0.43240
Sum of Squared Residuals	1.88127e+002
Standard Error of the Regression	0.97971
Durbin-Watson Statistic	0.59291
Mean of Dependent Variable	6.41503

Stockpiles Cost

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

Dependent Variable: stok

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	1.45340e+002	41.51972	3.50050
lyear	40.52599	15.08962	2.68569
ac	-51.63268	16.58173	-3.11383
elev	-3.60283e-002	1.30124e-002	-2.76877
aadt	-8.03229e-004	3.08695e-004	-2.60202
truck	7.03122e-003	4.25848e-003	1.65111

Number of Observations	201
R-squared	0.13047
Corrected R-squared	0.10817
Sum of Squared Residuals	9.22912e+005
Standard Error of the Regression	68.79593
Durbin-Watson Statistic	1.64201
Mean of Dependent Variable	19.86806

6.2 Regression Models for Roads in Priority Category 2

Figure 6.2.1 shows the overall life cycle for road maintenance in Priority Category 2. Table 6.2, shown at the end of this section, lists the results for the linear regression models for roads of maintenance priority Category 2.

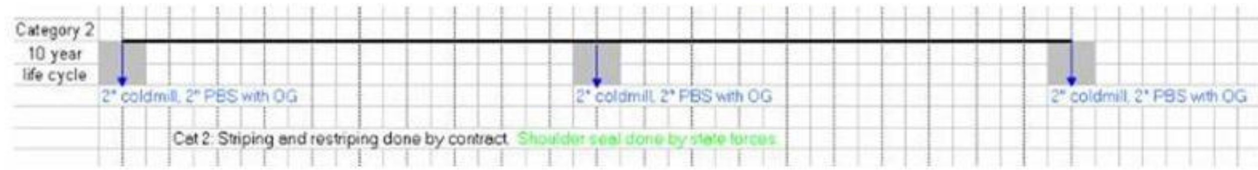


Figure 6.2.1 Life Cycle for Priority Category 2

From the scheduled maintenance, it can be seen that there is just one time segment for the roads classified under the maintenance priority Category 2. It starts right after the completion of a reconstruction, and ends at the next reconstruction. The results for the total cost in Table 6.2 shows that the total cost each year did not change with time. Total cost was significantly less than the previous year when the road was under reconstruction. This observation was similar to that for the roads in Category 1, which implies that some maintenance work may not need to be performed when a road is scheduled for reconstruction. The coefficient was positive, which indicates that the roads at high elevations tended to cost more for maintenance, probably due to the work during extreme weather, such as snow, for which additional work, such snow removal, has to be done.

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. The coefficient for AADT was positive, which is consistent with the expectation that more traffic would accelerate the deterioration of roads and, thus, produce more conditions for maintenance. A similar pattern regarding the impact of influencing factors on total maintenance cost also can be found in the models for the component maintenance costs, except for the stockpile cost.

For road segments with an average elevation of 3,987 ft and an average AADT of 11,786, the profile of annual maintenance costs were calculated using the coefficients in Table 6.2, and are presented in Figure 6.2.2. It can be seen that the maintenance costs are constant until the last year, when they drop.

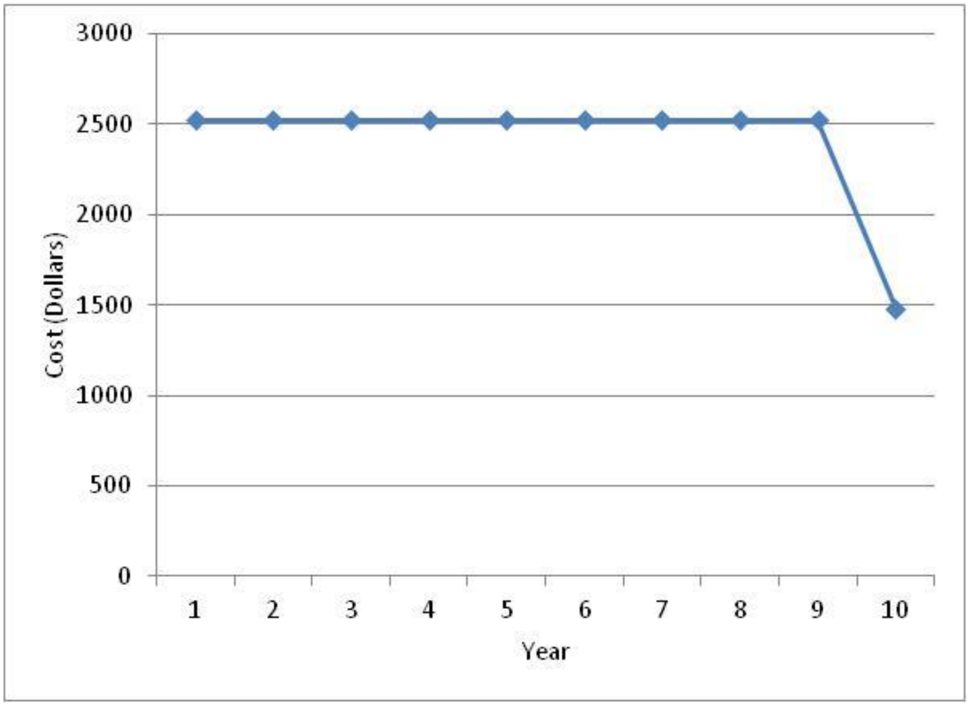


Figure 6.2.2 Total Maintenance Costs for a Ten-Year Life Cycle for Category 2 Roads.

Table 6.2 Regression Models for Road Maintenance Priority Category 2

Total Cost

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

Dependent Variable:     lntot
```

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	5.46705	0.44544	12.27327
lyear	-0.53229	0.21494	-2.47648
elev	4.81895e-004	9.19892e-005	5.23861
aadt	3.76878e-005	1.08794e-005	3.46415

Number of Observations	93
R-squared	0.26068
Corrected R-squared	0.23575
Sum of Squared Residuals	38.60876
Standard Error of the Regression	0.65864
Durbin-Watson Statistic	1.28637
Mean of Dependent Variable	7.76939

Total Hours

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

Dependent Variable:     lnhrs
```

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	1.37219	0.39046	3.51430
elev	4.48795e-004	8.03320e-005	5.58675
aadt	4.83742e-005	9.44720e-006	5.12048

Number of Observations	93
R-squared	0.30269
Corrected R-squared	0.28720
Sum of Squared Residuals	30.30499
Standard Error of the Regression	0.58028
Durbin-Watson Statistic	1.67537
Mean of Dependent Variable	3.73149

Table 6.2 Regression Models for Road Maintenance Priority Category 2 (continued)

Labor Cost

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

Dependent Variable: lnlabor

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	4.96110	0.38960	12.73369
elev	3.95786e-004	8.00296e-005	4.94550
urban	-0.32518	0.13213	-2.46100
aadt	4.40071e-005	9.81890e-006	4.48188

Number of Observations	93
R-squared	0.27885
Corrected R-squared	0.25454
Sum of Squared Residuals	29.71526
Standard Error of the Regression	0.57782
Durbin-Watson Statistic	1.44603
Mean of Dependent Variable	6.93872

Materials Cost

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

Dependent Variable: lnma

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	2.52197	0.74212	3.39834
lyear	-1.31390	0.35809	-3.66918
elev	8.60610e-004	1.53256e-004	5.61550
aadt	4.80663e-005	1.81253e-005	2.65190

Number of Observations	93
R-squared	0.31249
Corrected R-squared	0.28931
Sum of Squared Residuals	1.07164e+002
Standard Error of the Regression	1.09731
Durbin-Watson Statistic	1.58046
Mean of Dependent Variable	6.36397

Table 6.2 Regression Models for Road Maintenance Priority Category 2 (continued)

Equipment Cost

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

Dependent Variable:      lneq

Independent        Estimated             Standard              t-
 Variable         Coefficient             Error             Statistic

      one          4.25812               0.47823             8.90389
    lyear         -0.86702               0.23076            -3.75726
     elev          4.30691e-004          9.87603e-005        4.36097
     aadt          3.55617e-005          1.16802e-005        3.04463


Number of Observations                  93
R-squared                                0.25063
Corrected R-squared                      0.22537
Sum of Squared Residuals                44.50166
Standard Error of the Regression         0.70712
Durbin-Watson Statistic                  1.17276
Mean of Dependent Variable               6.29168
```

Stockpile Cost

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

Dependent Variable:      stok

Independent        Estimated             Standard              t-
 Variable         Coefficient             Error             Statistic

      one        -32.15934              11.76033            -2.73456
      age          3.33628               1.20597             2.76647
    lyear         98.90339              14.29931             6.91665
    truck          3.68374e-002          1.69156e-002        2.17772


Number of Observations                  93
R-squared                                0.51237
Corrected R-squared                      0.49593
Sum of Squared Residuals                 1.43126e+005
Standard Error of the Regression        40.10183
Durbin-Watson Statistic                  1.25756
Mean of Dependent Variable              22.45462
```

6.3 Regression Models for Roads in Priority Category 3

Three sets of linear regression models were developed, one set for each life cycle segment, as shown in Figure 6.3.1: After Construction, After Flush Seal, and After Chip Seal.

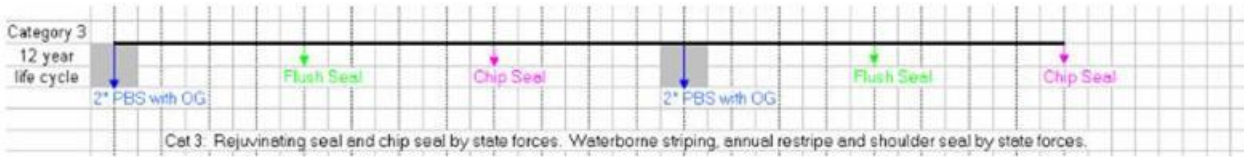


Figure 6.3.1 Life Cycle for Roads in Priority Category 3.

The results in Table 6.3, shown at the end of this section, on the regression models for the life cycle segments after reconstruction indicate that the coefficient for the last year maintenance activities is positive. This observation is consistent with practice, because the more maintenance activities are reserved for the time when a flush seal is performed. The maintenance cost between the reconstruction and flush seal can be viewed as constant over the years because the coefficient for age is not significant. The coefficient for elevation is positive, which makes sense because roads at higher elevations may have more chance of extreme weather as well as have other road features that need maintenance, such as guard rails. These observations also can be found in other maintenance cost components, including labor cost, equipment cost, and materials cost.

The results for the life cycle segment 'Flush Seal' indicates that only the variable representing the maintenance work when Chip Seal is performed is significant. This observation also is consistent with practice, leaving more maintenance work until when major preventive maintenance Chip Seal is performed. This result also can be found in other maintenance cost components.

In addition, Table 6.3 shows the results for the life cycle segment after 'Chip Seal', which ends at a reconstruction. Reflected in the results is that the coefficient for the maintenance cost at the year of reconstruction is negative because some maintenance activities may be saved for the major construction work. The coefficient for road elevation is positive, which is reasonable because more potential maintenance work could be created when a road is at a high elevation. Examples of such potential maintenance work are rail guard, slope, snow, etc. Traffic has a positive coefficient which is also consistent with intuitive. These observations can be found in the results for maintenance cost components.

Based on the results for these three life cycle segments, it can be seen that the maintenance costs in the year when construction, flush seal, and chip were performed are significantly different from those of other years. They are more or less than the regular year, depending upon the nature of the maintenance work. Elevation is an important influencing factor to the maintenance costs. Traffic is another factor that plays a significant role. Age does not show a significant impact on the maintenance cost.

Given the 12-year life cycle presented in Figure 6.3.1, for a road segment with average elevation of 4,900 ft and an AADT of 800, the annual maintenance profile can be calculated using the values in Table 6.3. As displayed in Figure 6.3.2, the profile shows that the annual maintenance costs jump when there are flush seal and chip seal, and drop when there is a reconstruction. The jump in maintenance cost caused by chip seal is more than that by flush seal. Within each life cycle, the annual maintenance costs are constant.

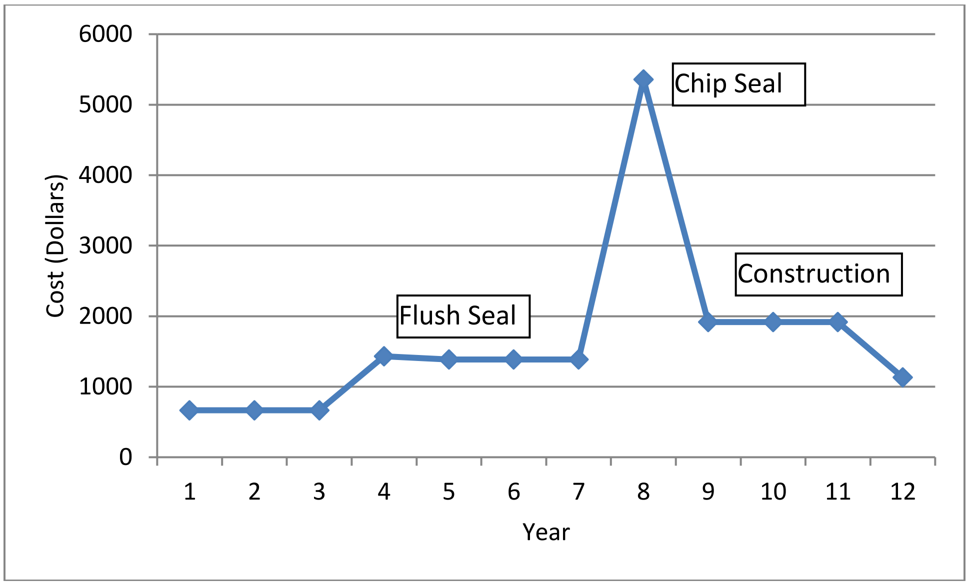


Figure 6.3.2 Total Maintenance Costs for a 12-Year Life Cycle for Category 3 Roads.

Table 6.3.1 Regression Models for the Roads in Priority Category 3

Reconstruction

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

Dependent Variable:     lntot

Independent        Estimated              Standard              t-
 Variable         Coefficient              Error             Statistic

      one           5.22175               0.60923              8.57101
    lyear           0.76511               0.24410              3.13439
     elev           2.61157e-004          1.27936e-004         2.04131


Number of Observations                   88
R-squared                                 0.14154
Corrected R-squared                       0.12134
Sum of Squared Residuals                 80.97900
Standard Error of the Regression          0.97606
Durbin-Watson Statistic                   0.73424
Mean of Dependent Variable                6.62413


reg dep[lnhrs] ind[one age lyear]


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

Dependent Variable:     lnhrs

Independent        Estimated              Standard              t-
 Variable         Coefficient              Error             Statistic

      one           1.97154               0.21995              8.96344
      age           0.14556               7.58616e-002         1.91875
    lyear           0.43480               0.28253              1.53893


Number of Observations                   88
R-squared                                 0.11877
Corrected R-squared                       9.80306e-002
Sum of Squared Residuals                 83.91110
Standard Error of the Regression          0.99357
Durbin-Watson Statistic                   0.78997
Mean of Dependent Variable                2.48882

reg dep[lnlabor] ind[one]
```

Table 6.3.1 Regression Models for the Roads in Priority Category 3 (continued)

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

Dependent Variable:   lnlabor

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error              Statistic

      one          6.22976                 9.86522e-002         63.14873


Number of Observations                  198
R-squared                                 0.00000e+000
Corrected R-squared                       0.00000e+000
Sum of Squared Residuals                  3.79616e+002
Standard Error of the Regression          1.38816
Durbin-Watson Statistic                   0.85384
Mean of Dependent Variable                6.22976

reg dep[lnma] ind[one lyear elev]


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

Dependent Variable:      lnma

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error              Statistic

      one          2.76351                 0.80326               3.44035
    lyear          1.36009                 0.32184               4.22592
     elev          4.61092e-004            1.68682e-004          2.73351


Number of Observations                   88
R-squared                                 0.22988
Corrected R-squared                       0.21176
Sum of Squared Residuals                  1.40773e+002
Standard Error of the Regression          1.28692
Durbin-Watson Statistic                   1.17834
Mean of Dependent Variable                5.24172

reg dep[lneq] ind[one elev]
```

Table 6.3.1 Regression Models for the Roads in Priority Category 3 (continued)

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

Dependent Variable:      lneq

Independent        Estimated             Standard              t-
 Variable         Coefficient             Error             Statistic

      one          3.23098               0.68499              4.71685
     elev          3.99350e-004          1.44481e-004         2.76404


Number of Observations                  88
R-squared                                8.15880e-002
Corrected R-squared                      7.09088e-002
Sum of Squared Residuals                 1.04493e+002
Standard Error of the Regression         1.10228
Durbin-Watson Statistic                  0.68411
Mean of Dependent Variable               5.09624

reg dep[stok] ind[one age elev aadt]


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

Dependent Variable:      stok

Independent        Estimated             Standard              t-
 Variable         Coefficient             Error             Statistic

      one         89.06447              76.83410              1.15918
      age         43.75804               6.52950              6.70159
     elev         -2.86068e-002          1.47717e-002        -1.93659
     aadt         -3.90969e-002          1.18979e-002        -3.28604


Number of Observations                  88
R-squared                                0.37090
Corrected R-squared                      0.34843
Sum of Squared Residuals                 7.68497e+005
Standard Error of the Regression        95.64921
Durbin-Watson Statistic                  1.24008
Mean of Dependent Variable              37.28352
```

Table 6.3.1 Regression Models for the Roads in Priority Category 3 (continued)

Flush Seal

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

Dependent Variable:     lntot

Independent        Estimated            Standard              t-
 Variable         Coefficient            Error             Statistic

      one          7.23358              8.94882e-002        80.83270
    lyear          1.35252              0.17832              7.58490


Number of Observations                 135
R-squared                                0.30195
Corrected R-squared                      0.29670
Sum of Squared Residuals                 1.07573e+002
Standard Error of the Regression         0.89935
Durbin-Watson Statistic                  1.41182
Mean of Dependent Variable               7.57421


reg dep[lnhrs] ind[one lyear]


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

Dependent Variable:     lnhrs

Independent        Estimated            Standard              t-
 Variable         Coefficient            Error             Statistic

      one          3.15771              7.28452e-002        43.34822
    lyear          0.96649              0.14515              6.65841


Number of Observations                 135
R-squared                                0.25000
Corrected R-squared                      0.24437
Sum of Squared Residuals                71.28110
Standard Error of the Regression         0.73208
Durbin-Watson Statistic                  1.60848
Mean of Dependent Variable               3.40112

reg dep[lnlabor] ind[one lyear]
```

Table 6.3.1 Regression Models for the Roads in Priority Category 3 (continued)

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

Dependent Variable:   lnlabor

Independent        Estimated              Standard               t-
 Variable         Coefficient              Error              Statistic

      one          6.36667               7.74854e-002          82.16616
    lyear          0.97188               0.15440                6.29458


Number of Observations                  135
R-squared                                 0.22953
Corrected R-squared                       0.22374
Sum of Squared Residuals                 80.65149
Standard Error of the Regression          0.77872
Durbin-Watson Statistic                   1.40677
Mean of Dependent Variable                6.61145

reg dep[lnma] ind[one lyear]


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

Dependent Variable:      lnma

Independent        Estimated              Standard               t-
 Variable         Coefficient              Error              Statistic

      one          5.46978               0.17230               31.74660
    lyear          1.81760               0.34332                5.29418


Number of Observations                  135
R-squared                                 0.17406
Corrected R-squared                       0.16785
Sum of Squared Residuals                  3.98766e+002
Standard Error of the Regression          1.73154
Durbin-Watson Statistic                   1.32977
Mean of Dependent Variable                5.92755

reg dep[lneq] ind[one age lyear]
```

Table 6.3.1 Regression Models for the Roads in Priority Category 3 (continued)

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

Dependent Variable:      lneq

Independent        Estimated              Standard               t-
 Variable         Coefficient              Error              Statistic

     one            6.13286                0.19015             32.25351
     age           -0.13997                7.10209e-002        -1.97088
   lyear            1.07427                0.23502              4.57098


Number of Observations                   135
R-squared                                  0.13777
Corrected R-squared                        0.12471
Sum of Squared Residuals                   1.36325e+002
Standard Error of the Regression           1.01625
Durbin-Watson Statistic                    1.04165
Mean of Dependent Variable                 6.02601

reg dep[stok] ind[one age lyear]


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

Dependent Variable:      stok

Independent        Estimated              Standard               t-
 Variable         Coefficient              Error              Statistic

     one          -55.04097               44.36715             -1.24058
     age           53.67174               16.57150              3.23880
   lyear            1.30811e+002          54.83762              2.38542


Number of Observations                   135
R-squared                                  0.19918
Corrected R-squared                        0.18705
Sum of Squared Residuals                   7.42211e+006
Standard Error of the Regression           2.37125e+002
Durbin-Watson Statistic                    1.33741
Mean of Dependent Variable                 1.22619e+002
```

Table 6.3.1 Regression Models for the Roads in Priority Category 3 (continued)

Chip Seal

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

Dependent Variable:     lntot

Independent       Estimated           Standard             t-
 Variable        Coefficient           Error           Statistic

     one          5.95503             0.46492           12.80873
    lyear        -0.52712             0.18476           -2.85306
     elev         2.29486e-004        8.29841e-005       2.76542
     aadt         5.97617e-004        1.41487e-004       4.22384


Number of Observations               87
R-squared                             0.21895
Corrected R-squared                   0.19072
Sum of Squared Residuals             43.65673
Standard Error of the Regression      0.72525
Durbin-Watson Statistic               1.17554
Mean of Dependent Variable            7.40151


reg dep[lnhrs] ind[one lyear aadt]


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

Dependent Variable:     lnhrs

Independent       Estimated           Standard             t-
 Variable        Coefficient           Error           Statistic

     one          2.84278             0.13493           21.06839
    lyear        -0.37616             0.19367           -1.94228
     aadt         5.25182e-004        1.33687e-004       3.92846


Number of Observations               87
R-squared                             0.17414
Corrected R-squared                   0.15448
Sum of Squared Residuals             49.55862
Standard Error of the Regression      0.76810
Durbin-Watson Statistic               1.09025
Mean of Dependent Variable            3.15083

reg dep[lnlabor] ind[one lyear elev aadt]
```

Table 6.3.1 Regression Models for the Roads in Priority Category 3 (continued)

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

Dependent Variable:   lnlabor

Independent       Estimated              Standard               t-
 Variable        Coefficient              Error              Statistic

      one          5.37183                0.44704             12.01641
    lyear         -0.48416                0.17765             -2.72532
     elev          1.51135e-004           7.97929e-005         1.89409
     aadt          6.34517e-004           1.36046e-004         4.66399


Number of Observations                  87
R-squared                                0.23756
Corrected R-squared                      0.21000
Sum of Squared Residuals                40.36365
Standard Error of the Regression         0.69736
Durbin-Watson Statistic                  1.10702
Mean of Dependent Variable               6.47436

reg dep[lnma] ind[one age lyear elev aadt]


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

Dependent Variable:      lnma

Independent       Estimated              Standard               t-
 Variable        Coefficient              Error              Statistic

      one          4.13053                0.70597              5.85082
      age          0.11679                6.19514e-002         1.88524
    lyear         -0.87590                0.27677             -3.16474
     elev          2.70935e-004           1.18212e-004         2.29195
     aadt          6.77556e-004           1.99749e-004         3.39203


Number of Observations                  87
R-squared                                0.18955
Corrected R-squared                      0.15002
Sum of Squared Residuals                85.54387
Standard Error of the Regression         1.02138
Durbin-Watson Statistic                  1.30449
Mean of Dependent Variable               6.11288

reg dep[lneq] ind[one lyear elev aadt]
```

Table 6.3.1 Regression Models for the Roads in Priority Category 3 (continued)

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

Dependent Variable:      lneq

Independent        Estimated              Standard                  t-
 Variable         Coefficient              Error                Statistic

      one          4.00296                0.52272                 7.65788
    lyear         -0.63538                0.20773                -3.05871
     elev          3.50827e-004           9.33017e-005            3.76014
     aadt          5.96674e-004           1.59078e-004            3.75083


Number of Observations                   87
R-squared                                 0.22961
Corrected R-squared                       0.20177
Sum of Squared Residuals                 55.18755
Standard Error of the Regression          0.81542
Durbin-Watson Statistic                   1.14769
Mean of Dependent Variable                6.01471

reg dep[stok] ind[one lyear]


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

Dependent Variable:      stok

Independent        Estimated              Standard                  t-
 Variable         Coefficient              Error                Statistic

      one          0.38273                6.87423                 5.56757e-
002
    lyear         35.19203               13.99181                 2.51519


Number of Observations                   87
R-squared                                 6.92701e-002
Corrected R-squared                       5.83204e-002
Sum of Squared Residuals                  2.65100e+005
Standard Error of the Regression         55.84648
Durbin-Watson Statistic                   1.96267
Mean of Dependent Variable                8.87736
```

6.4 Regression Models for Roads in Priority Category 4

Four linear regression models were developed, one for each life cycle segment, as shown in Figure 6.4.1: After Reconstruction, After Flush Seal, After First Chip Seal, and After The Second Chip Seal. Each life cycle segment starts at the next year, after the major maintenance activities, and ends when these major maintenance activities are performed. The results of the model are presented in Table 6.4, shown at the end of this section. The development of these linear regression models is presented in the following sections.

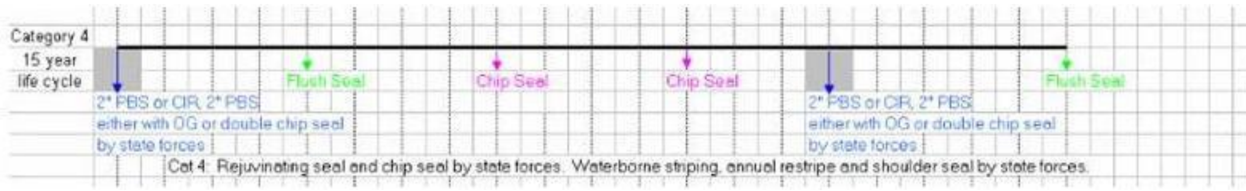


Figure 6.4.1 Life Cycles for Roads in Priority Category 4.

The results for the models estimating total maintenance cost for the first life cycle segment indicates that the coefficient for the maintenance activities performed in the last year is positive. This implies that more expenditure was incurred in the last year, during flush seal, due to a major preventive maintenance that also was performed. Another significant variable is traffic flow, which is consistent with expectations. These findings can be found in the models for the four cost components: labor, equipment, materials, and stockpile.

Relatively more variables are identified significant to the maintenance cost for the second life cycle segment starting after flush seal is performed. It can be seen that the variable representing the last year is significant, which is reasonable. Traffic flow is also significant. Age is significant, but with a negative coefficient. If this life cycle span is short – and frequently many maintenance activities are reserved for the last year – it is possible that the maintenance cost appears to decline with year; this has been confirmed in some responses to the survey conducted in this study from several state DOT maintenance divisions. In addition, where that maintenance was performed is important. The results indicate that the maintenances in Districts 1 and 2, highly likely chip seal, are more expensive than those in District 3, and those in District 2 are more expensive than in District 1. This is probably due to the fact that maintenance in District 2 was more complicated, involving more sophisticated technologies than in other districts. Another significant variable is elevation: the higher a road is located, the more expensive to maintain it, which is intuitively consistent. These findings can be found based on the results for the four maintenance cost components.

The results for the third segment, starting from after a chip seal and ending at another chip seal, indicate that there are fewer variables that are significant. Whether or not a chip seal was performed in a year is important. The coefficient for the variable representing the last year, the year with a chip seal was performed, was positive, which is reasonable. Compared to the results for the second life cycle segment, during which District 2 performed their most expensive maintenance work, District 1 did their costly maintenance for the third life cycle segment. The results for the four cost components indicate that the material costs between Districts 1 and 2 are the same statistically. Therefore, this discrepancy may be due to the type of equipment used for the second chip seal, which may vary in different districts.

The results for the last life cycle segment were very different from those for the first three segments. For example, age is significant. Also, the total maintenance cost increased with year, which is understandable. The coefficient for the maintenance cost incurred in the last year was negative, which implies that maintenance in the last year maintenance was cheaper because more maintenance were done during the year reconstruction was performed. Among the three districts, District 1 was the least expensive. This observation also is relevant to maintenance practices, probably because different materials are used in different districts. This observation can be found from the results for the four cost components: labor, materials, equipment, and stockpiles. Traffic flow AADT is significant, which is consistent with expectations.

The profile of annual maintenance cost is calculated using the values of the coefficients in Table 6.4, and is presented in Figure 6.4.2. The road segment is assumed to be located in District 1. Its elevation is 4,700 ft, and it carries traffic with an AADT of 280. It can be seen that the annual maintenance costs increase when there are flush seal and chip seals. They decrease when there is a construction. The increase with flush seal is noticeably less than that with chip seal. The first chip seal incurs less cost than the second one.

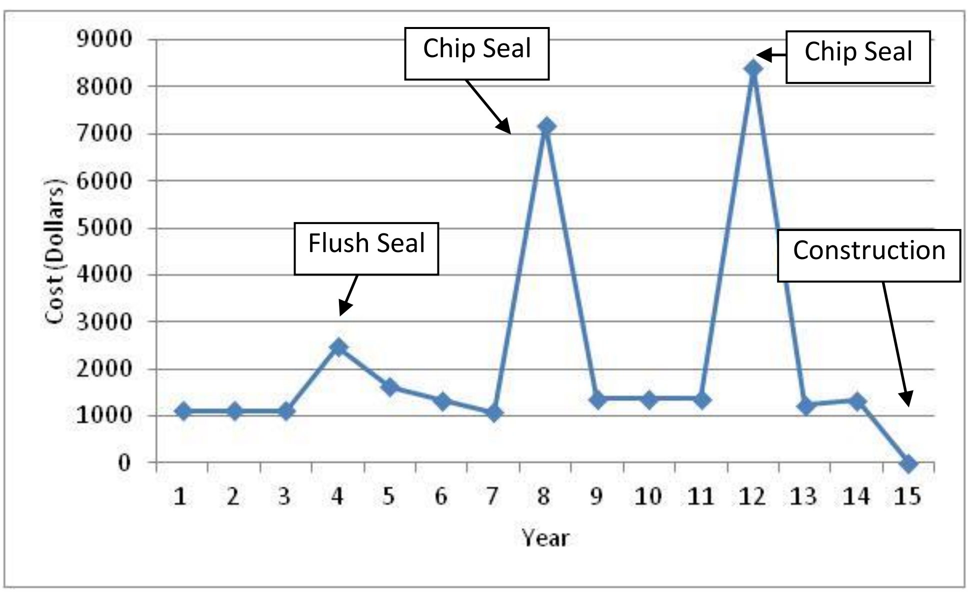


Figure 6.4.2 Total Maintenance Costs for a 15 Year Life Cycle for Category 4 Roads.

Table 6.4 Linear Regression Models for the Roads in Category 4

Reconstruction

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

Dependent Variable:     lntot

Independent        Estimated             Standard                t-
 Variable         Coefficient             Error              Statistic

      one          6.84434              0.13647             50.15368
    lyear          0.79590              0.16331              4.87348
     aadt          6.28703e-004         2.73911e-004         2.29528


Number of Observations                  97
R-squared                                0.25707
Corrected R-squared                      0.24126
Sum of Squared Residuals                41.90758
Standard Error of the Regression         0.66770
Durbin-Watson Statistic                  1.13801
Mean of Dependent Variable               7.29449


reg dep[lnhrs] ind[one lyear dist2 elev]


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

Dependent Variable:     lnhrs

Independent        Estimated             Standard                t-
 Variable         Coefficient             Error              Statistic

      one          1.79418              0.34573              5.18949
    lyear          0.79060              0.16024              4.93391
    dist2          0.32212              0.13683              2.35415
     elev          1.98493e-004         6.72233e-005         2.95274


Number of Observations                  97
R-squared                                0.28019
Corrected R-squared                      0.25697
Sum of Squared Residuals                40.44829
Standard Error of the Regression         0.65949
Durbin-Watson Statistic                  1.08792
Mean of Dependent Variable               3.08793

reg dep[lnlabor] ind[one lyear elev aadt]
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

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

Dependent Variable:   lnlabor

Independent        Estimated             Standard               t-
 Variable         Coefficient             Error              Statistic

      one          5.13562               0.33914              15.14314
    lyear          0.60321               0.16132               3.73924
     elev          1.84367e-004          6.63267e-005          2.77967
     aadt          5.36600e-004          2.70457e-004          1.98405


Number of Observations                  97
R-squared                                0.23547
Corrected R-squared                      0.21081
Sum of Squared Residuals                40.42256
Standard Error of the Regression         0.65928
Durbin-Watson Statistic                  1.33174
Mean of Dependent Variable               6.37113

reg dep[lnma] ind[one lyear dist1 aadt]


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

Dependent Variable:      lnma

Independent        Estimated             Standard               t-
 Variable         Coefficient             Error              Statistic

      one          5.59434               0.14065              39.77414
    lyear          1.20364               0.15429               7.80099
    dist1         -0.49562               0.16484              -3.00669
     aadt          7.02351e-004          2.64015e-004          2.66027


Number of Observations                  96
R-squared                                0.49153
Corrected R-squared                      0.47495
Sum of Squared Residuals                36.51409
Standard Error of the Regression         0.62999
Durbin-Watson Statistic                  1.69645
Mean of Dependent Variable               6.07392

reg dep[lneq] ind[one lyear]
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

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

Dependent Variable:      lneq

Independent        Estimated             Standard              t-
 Variable         Coefficient             Error             Statistic

      one          5.76825              0.10346             55.75149
    lyear          0.51890              0.21725              2.38850


Number of Observations                 97
R-squared                               5.66498e-002
Corrected R-squared                     4.67198e-002
Sum of Squared Residuals               76.27112
Standard Error of the Regression        0.89602
Durbin-Watson Statistic                 1.00718
Mean of Dependent Variable              5.88594

reg dep[stok] ind[one lyear dist1]


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

Dependent Variable:      stok

Independent        Estimated             Standard              t-
 Variable         Coefficient             Error             Statistic

      one         -1.57636              6.50269             -0.24242
    lyear         34.72719             12.39283              2.80220
    dist1         45.63792             12.82780              3.55774


Number of Observations                 97
R-squared                               0.17457
Corrected R-squared                     0.15701
Sum of Squared Residuals                2.45312e+005
Standard Error of the Regression       51.08523
Durbin-Watson Statistic                 1.18501
Mean of Dependent Variable             15.70979
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

Flush Seal

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

Dependent Variable:     lntot

Independent        Estimated            Standard              t-
 Variable         Coefficient            Error             Statistic

      one          5.19255              0.79175              6.55835
      age         -0.20196              6.26297e-002        -3.22469
    lyear          2.09167              0.20415             10.24556
    dist1          0.37462              0.21830              1.71610
    dist2          0.84941              0.19924              4.26331
     elev          3.97635e-004         1.30377e-004         3.04989
     aadt          5.71083e-004         3.41515e-004         1.67221
    truck         -6.07142e-003         3.59775e-003        -1.68756


Number of Observations                  78
R-squared                                0.70287
Corrected R-squared                      0.67316
Sum of Squared Residuals               27.71478
Standard Error of the Regression         0.62923
Durbin-Watson Statistic                  1.42622
Mean of Dependent Variable               7.68789

reg dep[lnhrs] ind[one lyear dist2 elev]


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

Dependent Variable:     lnhrs

Independent        Estimated            Standard              t-
 Variable         Coefficient            Error             Statistic

      one         -0.43516              0.52764             -0.82473
    lyear          1.38028              0.16348              8.44319
    dist2          1.20791              0.16166              7.47173
     elev          5.96518e-004         9.17628e-005         6.50065


Number of Observations                  78
R-squared                                0.64404
Corrected R-squared                      0.62961
Sum of Squared Residuals               28.35484
Standard Error of the Regression         0.61901
Durbin-Watson Statistic                  1.53793
Mean of Dependent Variable               3.55871

reg dep[lnlabor] ind[one lyear dist2 elev]
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

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

Dependent Variable: lnlabor

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	2.38281	0.54250	4.39225
lyear	1.25990	0.16808	7.49565
dist2	1.07410	0.16622	6.46196
elev	6.78541e-004	9.43481e-005	7.19188

Number of Observations	78
R-squared	0.61238
Corrected R-squared	0.59666
Sum of Squared Residuals	29.97511
Standard Error of the Regression	0.63645
Durbin-Watson Statistic	1.46192
Mean of Dependent Variable	6.72726

```
reg dep[lnma] ind[one age lyear dist2]
```

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

Dependent Variable: lnma

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	6.16959	0.28903	21.34551
age	-0.29715	0.10351	-2.87087
lyear	3.07651	0.34700	8.86597
dist2	0.60091	0.25766	2.33222

Number of Observations	78
R-squared	0.53765
Corrected R-squared	0.51891
Sum of Squared Residuals	90.86965
Standard Error of the Regression	1.10814
Durbin-Watson Statistic	1.42356
Mean of Dependent Variable	6.34646

```
reg dep[lneq] ind[one age lyear dist1 dist2 elev]
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

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

Dependent Variable:      lneq

Independent        Estimated              Standard               t-
 Variable         Coefficient              Error              Statistic

      one           2.14434               0.76851              2.79024
      age          -0.25160               7.70902e-002        -3.26374
    lyear           1.53446               0.25827              5.94137
    dist1           0.70683               0.28343              2.49387
    dist2           1.20197               0.22563              5.32727
     elev           6.91082e-004          1.40269e-004         4.92683


Number of Observations                   78
R-squared                                 0.55599
Corrected R-squared                       0.52516
Sum of Squared Residuals                 48.94189
Standard Error of the Regression          0.82447
Durbin-Watson Statistic                   1.49037
Mean of Dependent Variable                6.15327

reg dep[stok] ind[one lyear]


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

Dependent Variable:      stok

Independent        Estimated              Standard               t-
 Variable         Coefficient              Error              Statistic

      one          16.18390              25.01001              0.64710
    lyear           1.46959e+002         50.67391              2.90010


Number of Observations                   78
R-squared                                 9.96387e-002
Corrected R-squared                       8.77919e-002
Sum of Squared Residuals                  2.80475e+006
Standard Error of the Regression          1.92106e+002
Durbin-Watson Statistic                   1.75799
Mean of Dependent Variable               51.98167
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

Chip Seal - 1

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

Dependent Variable:     lntot

Independent        Estimated              Standard                 t-
 Variable         Coefficient              Error                Statistic

      one           6.91182               0.11215                61.63111
    lyear           1.81242               0.19820                 9.14448
    dist1           0.31118               0.15951                 1.95086


Number of Observations                 110
R-squared                                0.45590
Corrected R-squared                      0.44573
Sum of Squared Residuals                73.75395
Standard Error of the Regression         0.83023
Durbin-Watson Statistic                  1.50296
Mean of Dependent Variable               7.41292


reg dep[lnhrs] ind[one lyear]


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

Dependent Variable:     lnhrs

Independent        Estimated              Standard                 t-
 Variable         Coefficient              Error                Statistic

      one           2.97678               7.89735e-002           37.69336
    lyear           1.34552               0.17659                 7.61945


Number of Observations                 110
R-squared                                0.34962
Corrected R-squared                      0.34360
Sum of Squared Residuals                59.27470
Standard Error of the Regression         0.74084
Durbin-Watson Statistic                  1.38694
Mean of Dependent Variable               3.24588

reg dep[lnlabor] ind[one lyear dist1 dist2]
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

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

Dependent Variable:   lnlabor

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error               Statistic

      one           5.64555               0.21227               26.59612
    lyear           1.29042               0.17225                7.49169
    dist1           0.74466               0.23196                3.21034
    dist2           0.63657               0.23240                2.73915


Number of Observations                 110
R-squared                                0.38250
Corrected R-squared                      0.36502
Sum of Squared Residuals                54.95567
Standard Error of the Regression         0.72003
Durbin-Watson Statistic                  1.43947
Mean of Dependent Variable               6.51891

reg dep[lnma] ind[one lyear]


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

Dependent Variable:      lnma

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error               Statistic

      one           5.47692               0.13377               40.94294
    lyear           2.49629               0.29912                8.34551


Number of Observations                 110
R-squared                                0.39205
Corrected R-squared                      0.38643
Sum of Squared Residuals                 1.70068e+002
Standard Error of the Regression         1.25487
Durbin-Watson Statistic                  1.87527
Mean of Dependent Variable               5.97618

reg dep[lneq] ind[one lyear dist1]
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

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

Dependent Variable:      lneq

Independent        Estimated              Standard                  t-
 Variable         Coefficient              Error                Statistic

      one           5.48704                0.13220               41.50479
    lyear           1.33063                0.23364                5.69523
    dist1           0.32468                0.18803                1.72669


Number of Observations                  110
R-squared                                 0.25491
Corrected R-squared                       0.24098
Sum of Squared Residuals                  1.02490e+002
Standard Error of the Regression          0.97870
Durbin-Watson Statistic                   1.21138
Mean of Dependent Variable                5.89780

reg dep[stok] ind[one lyear aadt]


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

Dependent Variable:      stok

Independent        Estimated              Standard                  t-
 Variable         Coefficient              Error                Statistic

      one         -1.26382e+002          87.09322               -1.45111
    lyear          2.10994e+002          99.50933                2.12034
     aadt          0.50844                0.26590                1.91219


Number of Observations                  110
R-squared                                 7.62163e-002
Corrected R-squared                       5.89493e-002
Sum of Squared Residuals                  1.85374e+007
Standard Error of the Regression          4.16229e+002
Durbin-Watson Statistic                   1.95342
Mean of Dependent Variable               62.04891
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

Chip Seal – 2

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

Dependent Variable:     lntot

Independent        Estimated            Standard              t-
 Variable         Coefficient            Error            Statistic

      one          6.16464               0.61684             9.99388
      age          7.30700e-002          4.75945e-002        1.53526
    lyear         -0.51297               0.21971            -2.33473
    dist1         -0.35433               0.19684            -1.80010
     elev          1.73129e-004          7.67915e-005        2.25453
     aadt          1.51324e-003          7.35471e-004        2.05750
    truck         -1.29371e-002          6.05241e-003       -2.13752


Number of Observations                 89
R-squared                               0.29611
Corrected R-squared                     0.24460
Sum of Squared Residuals               53.28508
Standard Error of the Regression        0.80611
Durbin-Watson Statistic                 1.64815
Mean of Dependent Variable              7.01842


reg dep[lnhrs] ind[one dist1 elev aadt]


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

Dependent Variable:     lnhrs

Independent        Estimated            Standard              t-
 Variable         Coefficient            Error            Statistic

      one          1.39599               0.57589             2.42407
    dist1         -0.45117               0.19396            -2.32614
     elev          2.33741e-004          7.73284e-005        3.02270
     aadt          1.71945e-003          7.22166e-004        2.38096


Number of Observations                 89
R-squared                               0.22166
Corrected R-squared                     0.19419
Sum of Squared Residuals               59.66098
Standard Error of the Regression        0.83779
Durbin-Watson Statistic                 1.80314
Mean of Dependent Variable              2.86938

reg dep[lnlabor] ind[one age lyear elev aadt]
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

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

Dependent Variable:   lnlabor

Independent        Estimated              Standard                 t-
 Variable         Coefficient              Error                Statistic

      one          4.05502                0.47710                8.49922
      age          0.12064                4.42940e-002           2.72354
    lyear         -0.65300                0.20709               -3.15322
     elev          2.91755e-004           6.84721e-005           4.26093
     aadt          1.77472e-003           6.58573e-004           2.69479


Number of Observations                  89
R-squared                                0.27943
Corrected R-squared                      0.24512
Sum of Squared Residuals                52.27229
Standard Error of the Regression         0.78885
Durbin-Watson Statistic                  1.59022
Mean of Dependent Variable               6.24271

reg dep[lnma] ind[one dist1]


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

Dependent Variable:      lnma

Independent        Estimated              Standard                 t-
 Variable         Coefficient              Error                Statistic

      one          5.70053                0.15453               36.88976
    dist1         -0.79064                0.23831               -3.31764


Number of Observations                  88
R-squared                                0.11346
Corrected R-squared                      0.10315
Sum of Squared Residuals                 1.04734e+002
Standard Error of the Regression         1.10356
Durbin-Watson Statistic                  2.00749
Mean of Dependent Variable               5.36810

reg dep[lneq] ind[one age lyear elev aadt]
```

Table 6.4 Linear Regression Models for the Roads in Category 4 (continued)

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

Dependent Variable:      lneq

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error              Statistic

      one          3.50169                 0.57218               6.11988
      age          0.13717                 5.31210e-002          2.58223
    lyear         -0.76871                 0.24836              -3.09514
     elev          3.18557e-004            8.21175e-005          3.87929
     aadt          1.34731e-003            7.89815e-004          1.70586


Number of Observations                   89
R-squared                                 0.24758
Corrected R-squared                       0.21175
Sum of Squared Residuals                 75.18215
Standard Error of the Regression          0.94606
Durbin-Watson Statistic                   1.47283
Mean of Dependent Variable                5.71003

reg dep[stok] ind[one lyear]


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

Dependent Variable:      stok

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error              Statistic

      one          3.66500                 4.96974               0.73746
    lyear         16.86881                10.23103               1.64879


Number of Observations                   89
R-squared                                 3.03004e-002
Corrected R-squared                       1.91544e-002
Sum of Squared Residuals                  1.46115e+005
Standard Error of the Regression         40.98155
Durbin-Watson Statistic                   1.93233
Mean of Dependent Variable                7.64528
```

6.5 Regression Models for Roads in Priority Category 5

There is no clear definition on the life cycle for the road in Priority Category 5, as seen in Figure 6.5.1. For simplicity, three segments were proposed for the life cycle: first, second, and third. The first segment starts after the completion of reconstruction, such as 2" PBS with OG, and ends at a flush seal or a chip seal. The second segment starts after a flush seal or a chip seal and ends at the completion of another flush seal or chip seal. The third segment starts after a flush or a chip seal and ends at a construction. The second segment could be repeated for many times; this is different from the life cycle segments for Category 4, where the middle segments are each performed one time only.

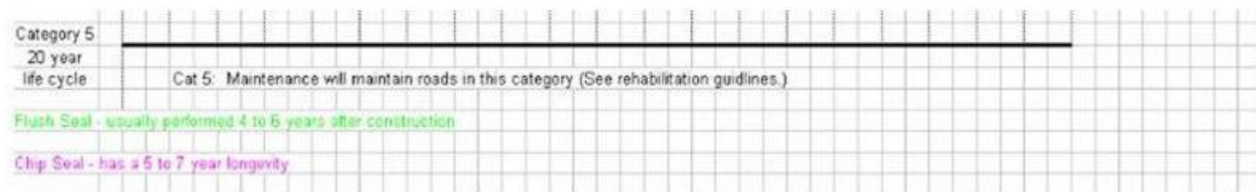


Figure 6.5.1 Life Cycles for Roads in Priority Category 5.

The results for the first life cycle segment in Table 6.5 show that age, the last maintenance, and elevation are significant factors influencing the maintenance cost each year. It is a natural expectation that total maintenance cost increases with year because declining road conditions generate more maintenance work. The last year maintenance, which is either flush seal or chip seal, involves more expensive materials or equipment. The elevation where a road is located also influences maintenance cost. The higher a road is located, the more expensive to maintain it. All these observations can be found in the models for the four maintenance cost components.

The results for the second life cycle segment indicate that the last year maintenance and elevation of roads both influence maintenance costs significantly. The impact of aging cannot be found in the result, probably due to the fact that the samples are the combination of life segments that started or ended with flush seals or chip seals, which could be performed at different stages of road deterioration conditions. Traffic flow shows a positive impact.

The results for the last life cycle segment show that age and the last year maintenance (reconstruction) are significant factors. It is understandable that more maintenance is needed as roads age. In the last year, when reconstructions were performed, some costs of these reconstructions were counted as maintenance as those for flush seals or chip seals. Thus, the last year maintenance cost becomes outstanding.

The annual maintenance profile is produced and presented in Figure 6.5.2. The values of the coefficients in Table 6.5 are used in calculating the annual maintenance costs. It is assumed that a road segment has an elevation of 5, 000 ft and has and AADT of 130. It can be seen from

Figure 6.5.2 that the annual maintenance costs increase significantly during such events as flush/chip seals and construction.

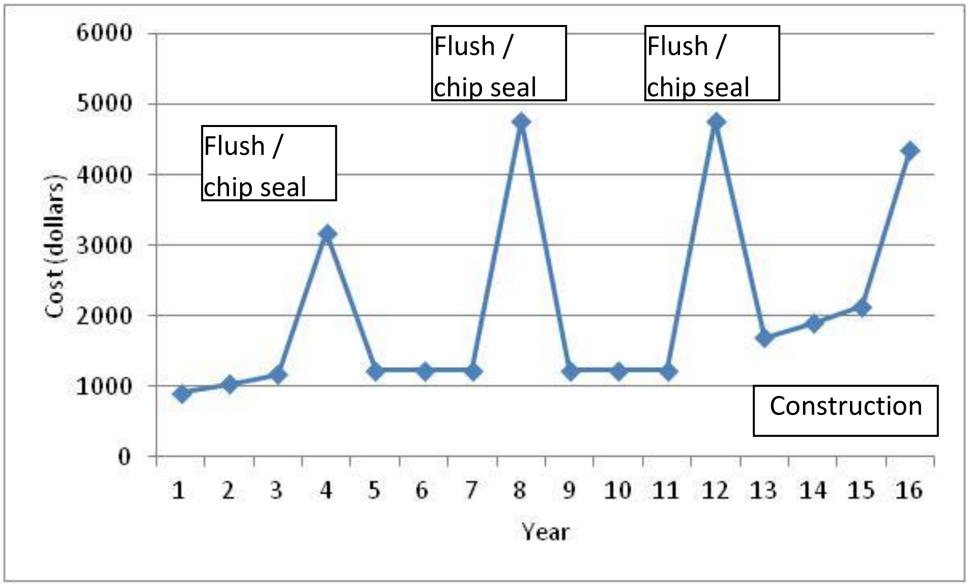


Figure 6.5.2 Total Maintenance Costs for a 16 Year Life Cycle for Category 5 Roads.

Table 6.5 Linear Regression Models for the Roads in Category 5

1st

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

Dependent Variable:     lntot

Independent        Estimated            Standard             t-
 Variable         Coefficient            Error           Statistic

      one          4.73205              0.47258            10.01314
      age          0.12385              4.50500e-002        2.74927
    lyear          0.87737              0.17353             5.05593
     elev          3.91701e-004         9.00566e-005        4.34950


Number of Observations                 159
R-squared                                0.31564
Corrected R-squared                      0.30239
Sum of Squared Residuals                 1.17079e+002
Standard Error of the Regression         0.86911
Durbin-Watson Statistic                  1.22265
Mean of Dependent Variable               7.21153


reg dep[lnhrs] ind[one age lyear elev]


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

Dependent Variable:     lnhrs

Independent        Estimated            Standard             t-
 Variable         Coefficient            Error           Statistic

      one          0.98497              0.47155             2.08877
      age          0.10948              4.49519e-002        2.43543
    lyear          0.75458              0.17316             4.35782
     elev          3.06256e-004         8.98603e-005        3.40814


Number of Observations                 159
R-squared                                0.24844
Corrected R-squared                      0.23390
Sum of Squared Residuals                 1.16569e+002
Standard Error of the Regression         0.86721
Durbin-Watson Statistic                  1.07361
Mean of Dependent Variable               2.97677

reg dep[lnlabor] ind[one lyear elev]
```

Table 6.5 Linear Regression Models for the Roads in Category 5 (continued)

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

Dependent Variable:   lnlabor

Independent       Estimated            Standard              t-
 Variable        Coefficient            Error              Statistic

      one          4.32551              0.42914             10.07945
    lyear          0.78063              0.15558              5.01760
     elev          3.48566e-004         8.71128e-005         4.00132


Number of Observations                 159
R-squared                                0.21759
Corrected R-squared                      0.20756
Sum of Squared Residuals                 1.12736e+002
Standard Error of the Regression         0.85010
Durbin-Watson Statistic                  1.06168
Mean of Dependent Variable               6.21859

reg dep[lnma] ind[one age lyear elev]


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

Dependent Variable:      lnma

Independent       Estimated            Standard              t-
 Variable        Coefficient            Error              Statistic

      one          1.77701              0.86607              2.05181
      age          0.25317              8.25596e-002         3.06651
    lyear          1.22293              0.31802              3.84543
     elev          5.75305e-004         1.65039e-004         3.48586


Number of Observations                 159
R-squared                                0.24861
Corrected R-squared                      0.23406
Sum of Squared Residuals                 3.93208e+002
Standard Error of the Regression         1.59274
Durbin-Watson Statistic                  1.27189
Mean of Dependent Variable               5.60475

reg dep[lneq] ind[one lyear elev]
```

Table 6.5 Linear Regression Models for the Roads in Category 5 (continued)

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

Dependent Variable:      lneq

Independent        Estimated             Standard                t-
 Variable         Coefficient             Error               Statistic

      one          2.45308               0.50058               4.90043
    lyear          0.88297               0.18148               4.86544
     elev          6.22756e-004          1.01615e-004          6.12858


Number of Observations                  159
R-squared                                 0.29250
Corrected R-squared                       0.28343
Sum of Squared Residuals                  1.53397e+002
Standard Error of the Regression          0.99162
Durbin-Watson Statistic                   1.23586
Mean of Dependent Variable                5.70657

reg dep[stok] ind[one age elev aadt]


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

Dependent Variable:      stok

Independent        Estimated             Standard                t-
 Variable         Coefficient             Error               Statistic

      one         71.28619              49.00906               1.45455
      age         25.91464               4.28484               6.04798
     elev         -3.92178e-002          9.37271e-003         -4.18426
     aadt          0.72358               0.10892               6.64315


Number of Observations                  159
R-squared                                 0.39680
Corrected R-squared                       0.38513
Sum of Squared Residuals                  1.25658e+006
Standard Error of the Regression         90.03868
Durbin-Watson Statistic                   0.91552
Mean of Dependent Variable                41.95333
```

Table 6.5 Linear Regression Models for the Roads in Category 5 (continued)

2nd

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

Dependent Variable:     lntot

Independent        Estimated             Standard              t-
 Variable         Coefficient             Error            Statistic

      one           5.57972               0.24429            22.84037
    lyear           1.35616               0.10931            12.40674
     elev           2.27820e-004          4.75289e-005        4.79329
     aadt           3.03482e-003          7.75647e-004        3.91263


Number of Observations                  448
R-squared                                 0.31913
Corrected R-squared                       0.31453
Sum of Squared Residuals                  4.37368e+002
Standard Error of the Regression          0.99250
Durbin-Watson Statistic                   1.86332
Mean of Dependent Variable                7.38172


reg dep[lnhrs] ind[one lyear elev aadt]


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

Dependent Variable:     lnhrs

Independent        Estimated             Standard              t-
 Variable         Coefficient             Error            Statistic

      one           1.32745               0.21011             6.31786
    lyear           0.88479               9.40139e-002        9.41127
     elev           2.79761e-004          4.08786e-005        6.84369
     aadt           2.12973e-003          6.67118e-004        3.19243


Number of Observations                  448
R-squared                                 0.26379
Corrected R-squared                       0.25882
Sum of Squared Residuals                  3.23537e+002
Standard Error of the Regression          0.85363
Durbin-Watson Statistic                   1.91825
Mean of Dependent Variable                3.15321

reg dep[lnlabor] ind[one lyear elev aadt]
```

Table 6.5 Linear Regression Models for the Roads in Category 5 (continued)

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

Dependent Variable:   lnlabor

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error              Statistic

      one           4.64925                0.20747             22.40961
    lyear           0.91641                9.28310e-002         9.87185
     elev           2.46666e-004           4.03643e-005         6.11100
     aadt           2.35182e-003           6.58724e-004         3.57026


Number of Observations                   448
R-squared                                  0.26692
Corrected R-squared                        0.26197
Sum of Squared Residuals                   3.15447e+002
Standard Error of the Regression           0.84289
Durbin-Watson Statistic                    1.77882
Mean of Dependent Variable                 6.35050

reg dep[lnma] ind[one lyear aadt]


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

Dependent Variable:      lnma

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error              Statistic

      one           4.52583                0.18490             24.47656
    lyear           2.38705                0.18875             12.64682
     aadt           5.12930e-003           1.33309e-003         3.84767


Number of Observations                   446
R-squared                                  0.29295
Corrected R-squared                        0.28976
Sum of Squared Residuals                   1.29975e+003
Standard Error of the Regression           1.71289
Durbin-Watson Statistic                    1.55113
Mean of Dependent Variable                 5.74258

reg dep[lneq] ind[one age lyear elev aadt]
```

Table 6.5 Linear Regression Models for the Roads in Category 5 (continued)

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

Dependent Variable:      lneq

Independent        Estimated            Standard                t-
 Variable         Coefficient            Error               Statistic

      one           4.29400              0.29732              14.44254
      age          -0.10612              3.07889e-002         -3.44663
    lyear           1.04501              0.13215               7.90795
     elev           2.52489e-004         5.38903e-005          4.68523
     aadt           2.04244e-003         8.90404e-004          2.29384


Number of Observations                  448
R-squared                                 0.18904
Corrected R-squared                       0.18172
Sum of Squared Residuals                  5.59999e+002
Standard Error of the Regression          1.12432
Durbin-Watson Statistic                   1.51583
Mean of Dependent Variable                5.70223

reg dep[stok] ind[one age elev]


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

Dependent Variable:      stok

Independent        Estimated            Standard                t-
 Variable         Coefficient            Error               Statistic

      one          -2.45565e+002        47.48767              -5.17113
      age          43.44821              4.84057               8.97584
     elev           4.70426e-002         9.07278e-003          5.18503


Number of Observations                  448
R-squared                                 0.18857
Corrected R-squared                       0.18492
Sum of Squared Residuals                  1.60915e+007
Standard Error of the Regression          1.90159e+002
Durbin-Watson Statistic                   0.81661
Mean of Dependent Variable                1.09979e+002
```

Table 6.5 Linear Regression Models for the Roads in Category 5 (continued)

3rd

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

Dependent Variable:     lntot

Independent        Estimated             Standard                t-
 Variable         Coefficient             Error               Statistic

      one           7.31532               0.25695              28.47024
      age           0.11737               8.69821e-002          1.34939
    lyear           0.59437               0.32084               1.85257


Number of Observations                   94
R-squared                                 8.76198e-002
Corrected R-squared                       6.75674e-002
Sum of Squared Residuals                  1.39640e+002
Standard Error of the Regression          1.23875
Durbin-Watson Statistic                   1.30803
Mean of Dependent Variable                7.79547


reg dep[lnhrs] ind[one age]


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

Dependent Variable:     lnhrs

Independent        Estimated             Standard                t-
 Variable         Coefficient             Error               Statistic

      one           2.98440               0.26085              11.44111
      age           0.19261               8.08280e-002          2.38296


Number of Observations                   94
R-squared                                 5.81346e-002
Corrected R-squared                       4.78969e-002
Sum of Squared Residuals                  1.46151e+002
Standard Error of the Regression          1.26040
Durbin-Watson Statistic                   1.20442
Mean of Dependent Variable                3.52330

reg dep[lnlabor] ind[one age]
```

Table 6.5 Linear Regression Models for the Roads in Category 5 (continued)

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

Dependent Variable:   lnlabor

Independent        Estimated             Standard                t-
 Variable         Coefficient             Error               Statistic

      one          6.31538                0.25468              24.79744
      age          0.19669                7.89160e-002          2.49238


Number of Observations                   94
R-squared                                 6.32504e-002
Corrected R-squared                       5.30684e-002
Sum of Squared Residuals                  1.39319e+002
Standard Error of the Regression          1.23058
Durbin-Watson Statistic                   1.25373
Mean of Dependent Variable                6.86568

reg dep[lnma] ind[one lyear]


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

Dependent Variable:      lnma

Independent        Estimated             Standard                t-
 Variable         Coefficient             Error               Statistic

      one          6.20010                0.14017              44.23313
    lyear          0.63605                0.27740               2.29287


Number of Observations                   94
R-squared                                 5.40553e-002
Corrected R-squared                       4.37733e-002
Sum of Squared Residuals                  1.26528e+002
Standard Error of the Regression          1.17273
Durbin-Watson Statistic                   1.63659
Mean of Dependent Variable                6.36249

reg dep[lneq] ind[one lyear]
```

Table 6.5 Linear Regression Models for the Roads in Category 5 (continued)

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

Dependent Variable: lneq

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	6.31784	0.16710	37.80960
lyear	0.78032	0.33069	2.35967

Number of Observations	94
R-squared	5.70681e-002
Corrected R-squared	4.68188e-002
Sum of Squared Residuals	1.79812e+002
Standard Error of the Regression	1.39803
Durbin-Watson Statistic	1.26073
Mean of Dependent Variable	6.51707

reg dep[stok] ind[one elev]

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

Dependent Variable: stok

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
one	-1.63081e+002	79.83112	-2.04283
elev	3.70583e-002	1.55560e-002	2.38225

Number of Observations	94
R-squared	5.81018e-002
Corrected R-squared	4.78638e-002
Sum of Squared Residuals	1.35038e+006
Standard Error of the Regression	1.21153e+002
Durbin-Watson Statistic	1.18820
Mean of Dependent Variable	24.75170

6.6 Summary

The annual maintenance cost profiles for these five categories of roads are presented in Figure 6.6.1. It is clear that the annual maintenance costs for Categories 1 and 2 are higher than that for the other three categories. Whether or not there are major preventive or reconstruction activities significantly influences the maintenance cost, and has to be considered in calculating the annual maintenance costs.

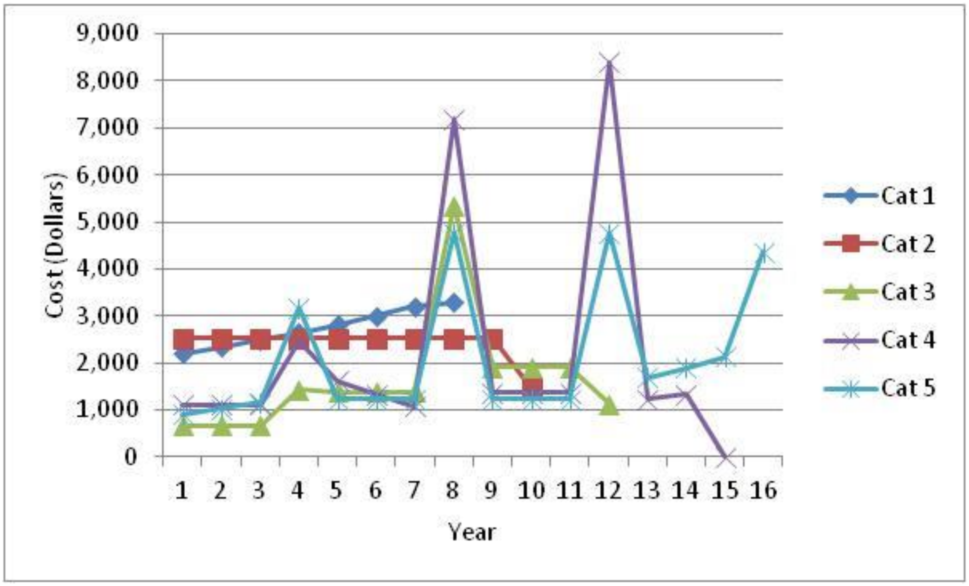


Figure 6.6.1 Comparison of Annual Maintenance Profile for Categories 1, 2, 3, 4, and 5.

CHAPTER 7

CONCLUSIONS AND FUTURE STUDY NEEDS

Conclusions

In this study, linear regression models were developed to estimate annual maintenance costs. Five priority categories of roads were considered, which is consistent with the maintenance road classification adopted by NDOT. For Categories 1 and 2, each includes only one life cycle segment spanning eight and ten years, respectively. Categories 3 and 4 include three and four life cycle segments, respectively, and each segment has three to four years' duration. There was not specific definition for the life cycle for Category 5; therefore, for the purposes of this study, three segments were defined for this category. For each segment in these five categories, linear regression models were developed. In addition to total maintenance cost, this study also developed linear regression models for four maintenance cost components: labor, equipment, materials, and stockpile.

Important influencing factors on annual maintenance costs were considered in this study:

- Age of road
- The type of maintenance activities in the last year of maintenance life cycle
- The elevation
- The district
- Traffic

The results indicate that road age is a significant factor only for some life cycle segments and some maintenance cost components. During the life cycle segment, the annual maintenance cost may be kept the same. The maintenance activities may be scheduled depending on whether they are close to the time when a preventive maintenance or reconstruction is scheduled. Reflected in the maintenance cost profile, the annual maintenance cost may decline with time and then jump up to a high level, with the costs for prevention maintenance or construction included.

Flush seal and chip seal are two preventive maintenances performed by NDOT. The costs incurred in these preventive maintenance activities are significantly higher than other routine and corrective maintenance. Thus, they were singled out in the cost estimation in this study by using indicator variables. Roadways with high elevation tend to be constructed with special safety features, such as guard rails, which would produce high maintenance costs. This observation also was noted from the results of the models. Traffic flow makes road deteriorate and generates the need for maintenance. Its impact on maintenance cost was reflected in the model estimation results. Different districts may adopt different maintenance practice in terms of the materials and equipment used in their districts; this also was observed from the models developed in this study.

It can be seen that the models that were developed – different models for different life cycle segments – uniquely integrate the life cycle concept of pavement. These life cycle segments also represent the conditions for each roadway. The practices for maintenance activities adopted in NDOT were fully taken into consideration.

The variables used in the models can be easily made available, and provides the basis for the models to be incorporated with NDOT's pavement management and maintenance management systems in order to estimate future maintenance costs. It would be very convenient for NDOT to use the models to estimate the maintenance costs and to submit those cost requirements to the Nevada legislation.

Future study needs

Sampling is a major issue for developing the regression models for some categories of road, such as Categories 1 and 2. With samples covering more areas in Nevada, useful variables – for example, the district – can be used. In this way, a more accurate estimation of annual maintenance cost can be produced.

The definition of life cycle influences the availability of sufficient samples. For example, the life cycle for Category 1 starts after a certain construction and ends at the same type of construction. This life cycle rarely exists in the database. Certain approximations were used to extract the samples for Category 1. This sampling may need to be revisited when the model is adopted by NDOT.

REFERENCES

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3. Hand, A.J. Development of Life-Cycle Cost Analysis Procedures for Nevada's Flexible Pavements. A Master Thesis, Department of Civil Engineering, University of Nevada, 1995.
4. Sebaaly, P.E., Venukanthen, S., Siddharthan, R., Hand, A., and Epps, J. Development of Pavement Network Optimization System. *Research Report No. 1198-1*, Report to Nevada Department of Transportation, Carson City, NV, 2000.

APPENDIX

APPENDIX 1

REVIEW OF NDOT PMS REPORT

Performance Model for 1995

$$PSI = 5 \times e^{-0.0041 \cdot IRI} - 1.38RD^2 - 0.01(C+P)^{0.5}$$

where:

IRI = international roughness index (in/mile)

RD = rut depth (in)

C = cracking area ($ft^2/1000ft^2$)

P = patching area ($ft^2/1000ft^2$)

The four repair categories are as follows:

a. Do Nothing
b. Maintenance
c. Overlay
d. Reconstruction

Distinctions among the categories are based on specific distress indicators and their severity. Points are assigned based on the severity and extent of each distress indicator and friction number. The total summation of the points dictates the general repair category for a section of road. The breakdown of the point assignment system and respective repair categories can be found in the tables below, prepared by NDOT.

Two maintenance techniques were considered: (1) sand seals for flexible pavement, and (2) chip seals for flexible pavement. Three rehabilitation techniques were included in the models:

(1) Flexible overlay,
(2) Roadbed modification, and
(3) Mill and overlay.

Four performance indicators were modeled:

(1) Surface cracking,
(2) Permanent deformation or rutting (RD),
(3) Surface roughness (IRI), and

(4) Present serviceability index (PSD).

In addition, the following four model forms were considered:

(1) Models for each individual district,

(2) Models for all districts combined,

(3) Models including materials properties, and

(4) Models excluding materials properties.

In total, 16 models *5 treatments = 80 models were developed. The shape of performance function is presented in Figure A.1.1.

Table A.1.1 Formulas and Determination of Category Status

FORMULAS AND DETERMINATION OF CATEGORY STATUS
FLEXIBLE PAVEMENT

TYPE	Interstate Only T.S.I. =2.5		Non-IR NHS, and STP w/ ADT >=750 T.S.I. =2.5		All Other Routes T.S.I. =2.0	
RIDE	IRI 0 - 40 41 - 70 71 - 90 91 - 105 106 - 115 > 115	PMS Points 0 100 200 300 400 500	IRI 0 - 80 81 - 100 101-115 116 - 130 131 - 160 > 160	PMS Points 0 100 200 300 400 500	IRI 0 - 90 91 - 130 131 - 150 151 - 170 171 - 200 > 200	PMS Points 0 100 200 300 400 500
RUT DEPTH	Average Rut Depth 0 to .25" .26 to 1.00" 1.01 to 1.50" above 1.50"	PMS Points 0 (675.7 x RD) - 168.9 (392.2 x RD) + 111.8 700	Average Rut Depth 0 to .25" .26 to 1.00" 1.01 to 1.50" above 1.50"	PMS Points 0 (675.7 x RD) - 168.9 (392.2 x RD) + 111.8 700	Average Rut Depth 0 to .45" .46 to 1.19" 1.20 to 1.70" above 1.70"	PMS Points 0 (675.7 x RD) - 304.1 (399.2 x RD) + 33.1 700
FATIGUE A & B BLOCK B & C	A = 1.50 x Extent B = 2.00 x Extent C = 1.00 x Extent D = 1.00 x Extent		A = 1.50 x Extent B = 2.00 x Extent C = 1.00 x Extent D = 1.00 x Extent		A = 1.00 x Extent B = 1.50 x Extent C = 0.50 x Extent D = 0.50 x Extent	
Non Wheelpath Linear TRANSVERSE BLOCK A	PMS Points = Extent x (LC Severity Factor) Where LC Severity Factor is determined from: Crack Width <1/4" ≥ 1/4", ≤ 3/4" >3/4"	 LC Severity Factor 0.20 0.8 x (crack width) + .80 1.00	PMS Points = Extent x (LC Severity Factor) Where LC Severity Factor is determined from: Crack Width <1/4" ≥ 1/4"; ≤ 3/4" >3/4"	 LC Severity Factor 0.20 0.8 x (crack width) + .80 1.00	PMS Points = Extent x (LC Severity Factor) Where LC Severity Factor is determined from: Crack Width <1/4" ≥ 1/4", ≤ 3/4" >3/4"	 LC Severity Factor 0.20 0.4 x (crack width) + .90 1.20
PATCHING	0.5 x Extent		0.5 x Extent		0.25 x Extent	
BLEEDING	Picture No 14 15 16	PMS Points 0 100 250	Picture No 14 15 16	PMS Points 0 100 250	Picture No 14 15 16	PMS Points 0 100 250
RAVELING	Picture No 17 18 19	PMS Points 100 250 500	Picture No 17 18 19	PMS Points 100 250 500	Picture No 17 18 19	PMS Points 100 250 500
FRICTION	Friction Number 2 to 20 21 to 30 31 to 38 above 38	PMS Points 400 250 100 0	Friction Number 2 to 20 21 to 30 31 to 38 above 38	PMS Points 400 200 100 0	Friction Number 2 to 20 21 to 30 31 to 38 above 38	PMS Points 400 200 100 0

Figure 5. NDOT's PMS Points Assignment System.

Table A.1.2 NDOT's Rehabilitation and Maintenance Assignment System

Repair Category Assigned	PMS Points Total
Minor Maintenance	<50
Maintenance	50 to 399
Overlay	400 to 699
Reconstruction	>699

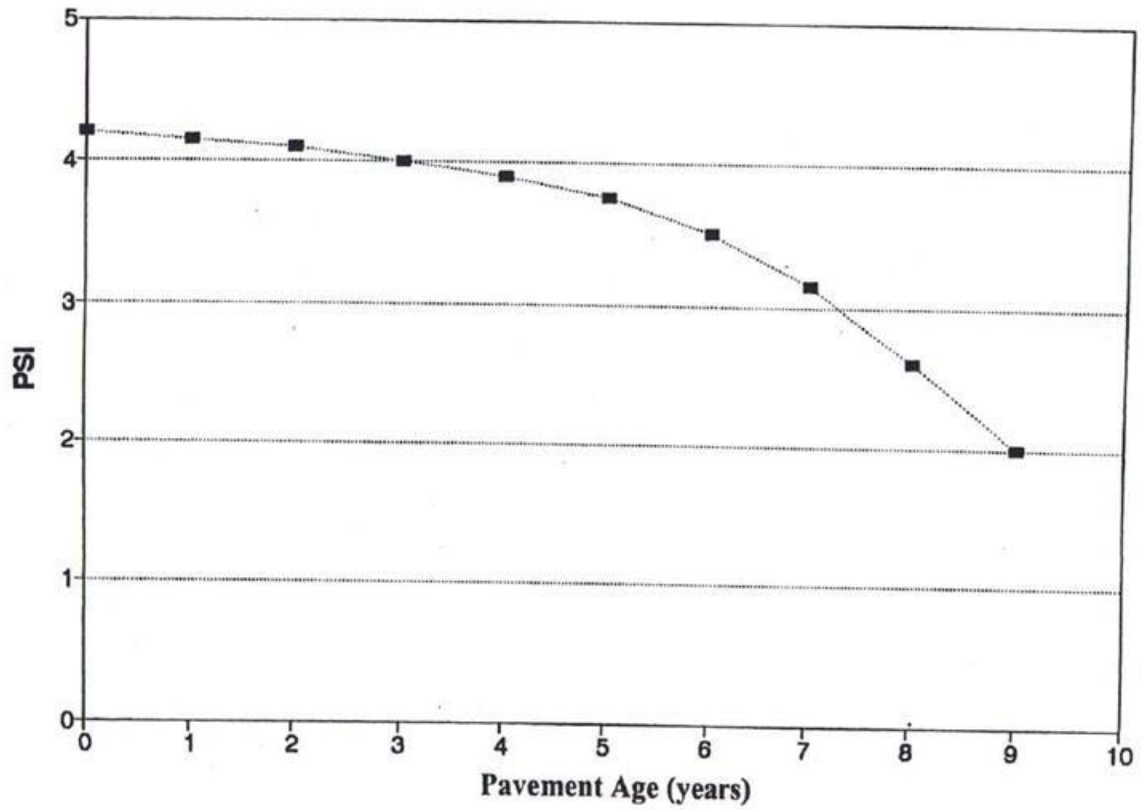

Figure A.1.1. Typical Performance Curve Generated from NDOT's Performance Models.

APPENDIX 2

SURVEY FORM

UNIVERSITY OF NEVADA, LAS VEGAS

Department of Civil and Environmental Engineering
4505 Maryland Parkway, Box 454015
Las Vegas, NV 89154-4015
Phone: 702-895-4940, Fax: 702-895-3936, E-mail: hualiang.teng@unlv.edu

Survey of the practice adopted by State DOTs on estimating the costs of highway infrastructure maintenances (routine, preventive, or corrective maintenances) that are performed by state forces.

University of Nevada, Las Vegas is conducting a research project for Nevada Department of Transportation to estimate the costs of maintenances that are performed by state force. Through this study, the impact of system expansion on maintenance can be taken into account appropriately. The information collected in the survey will help develop the models to estimate the maintenance costs. It will also be used to develop recommendation on the policies related to maintenance in NDOT. It will take approximately 15 – 20 minutes to complete this survey. By returning the survey, you agree the consent to participate in the survey. It would be appreciated if the survey can be returned before <u>November 10, 2010</u>.

SURVEY QUESTIONNARIE

(5) What are the road maintenance works performed by state force in your state DOT?

(6) What are the road maintenance works performed by contractors in your state DOT?

(7) Please list the preventive maintenances in your state DOT:

(8) Are the timings of these preventive maintenances determined based on field inspections of roadways?

□ Yes □ No

(9) Does your state DOT have separated budgets for major highway infrastructures like bridge, lighting, signing, pavement marking, sidewalk, etc.?

□ Yes □ No

If yes, please list these highway infrastructures?

(10) Which method do you use to budget for new facilities like bridge, lighting, signing, pavement marking, sidewalk lighting, etc.?

□ Historic record □ data from other agencies □ Others, specify

(11) Do you observe that maintenance costs for a roadway section increase with years after a reconstruction, a rehabilitation, or a preventive maintenance?

□ Yes □ No

(12) Are there equations in your Pavement Management System that relate the costs of roadway maintenance (excluding reconstruction and rehabilitation) to the influencing factors such as ages, traffic loads, pavement conditions, weather, etc.?

□ Yes □ No

(13) Are there equations in your Bridge Management Systems (BMS) that relate the costs of bridge maintenance (excluding reconstruction and rehabilitation) to the influencing factors such as ages, traffic loads, etc.?

□ Yes □ No

(14) In your routine, corrective and/or preventive maintenance database, is it possible to separate the works for pavements and bridges?

□ Yes □ No

(15) Do you estimate maintenance costs in terms of man power, equipment, materials, separately?

□ Yes □ No

(16) How does your state DOT deal with the annual fluctuation of maintenance costs (routine, corrective and/or maintenance) because the maintenance activities on a roadway section each year are different?

- Averaging the maintenance costs over the past three years
- Estimate the probability of occurrence of maintenance activities
- Develop advanced statistical regression models
- Others, please specify ____

Acknowledgement

We appreciate your taking part in this survey and thank you for your valuable time. Please email, mail or fax this completed form to: Dr. Hualiang (Harry) Teng, Department of Civil and Environmental Engineering, Howard R. Hughes College of Engineering, University of Nevada, Las Vegas, 4505 Maryland Parkway, Box 454015, Las Vegas, NV 89154-4015, Telephone: 702-895-4940; Fax: 702-895-3936, E-mail: Hualiang.teng@unlv.edu

APPENDIX 3

RESPONSES TO THE SURVEY

		1. What are the road maintenance works performed by state force in your state DOT?
1	AK	Maintenance and Operation responsibilities include all the activities to keep our State's highways, bridges, airports, buildings and harbors in good condition and safe for the traveling public. These include pavement repair, gravel road maintenance, ditching, snowplowing, snow-hauling, brush cutting, guardrail repair, sign maintenance, street/traffic light repair, drainage structures, fence maintenance, airport light repair, airport safety, security and facility repairs
2	AR	Asphalt patching, base repairs/replacement, joint repair and crack filling, asphalt leveling, surface patching, street sweeper operations, cold milling, seal coats, fog coats, maintaining ditches (clean/reshape), mowing, litter pickup, chemical vegetation control, bridge deck repairs, substructure repairs, painting structural steel, snow and ice removal, maintain traffic signs.
3	CO	CDOT performs all maintenance of our roadways.
4	FL	Attached is our Routine Cost Handbook. This displays all the work activities that we perform on the roads by our Maintenance Crews.
5	IA	The Iowa DOT has about 1,100 maintenance workers organized around 110 maintenance garages throughout the state. This force maintains Iowa's primary road network, which is approximately 9,500 centerline miles. These crews perform many types of maintenance, including: Surface Maintenance, Shoulder Maintenance, Roadside Maintenance, Drainage Maintenance, Traffic Services Maintenance, Snow & Ice Control, Bridge Maintenance, and Emergency Response. See attachment for a list of the major maintenance functions.
6	ID	Pot Hole Repair, Some Base Repair, minor bridge repair, bridge deck sealing, roadside mowing, brush control, vegetation spraying, road kill removal, fence repair, guardrail repair, drainage repair, pavement striping, pavement markings, sign maintenance, winter maintenance & response, brooming & sweeping.
7	IN	Snow/ice removal, chip sealing, crack sealing, mowing and brush cutting, herbicide application, patching, ditching, small culvert cleaning, bridge flushing, sign installations and modernizations, painting of centerlines/edgelines, special marking maintenance, traffic signal maintenance, some pipe replacement, underdrain inspection/cleaning, litter pickup, guard rail and cable rail repair, crash attenuator repair, minor bridge deck repair, some street sweeping
8	KS	Crack and Joint Sealing, Concrete Patching, Bituminous Overlay, Slurry Seal, Bituminous Patching, Shoulder repair, Paint Striping, Sign Maintenance
9	KY	Not an inclusive list but includes snow and ice response, cleaning ditchlines, cleaning/ repairing pipes, smaller sign replacement, emergency response due to nature or wrecks, pothole patching, shoulder repair
10	MD	Routine Maintenance, Winter Maintenance, Preventive Maintenance, Corrective Maintenance, Catastrophic Maintenance

11	MI	See attached Maintenance Activities and Accomplishment Table. Every task on this table is performed by state DOT forces
12	MT	Crack seals; chip seals; machine patching, rut filling; slope repair; blading & shaping gravel shoulders; surface patching-hand; temporary & permanent patching-PCC; crack & joint sealing-PCC; culvert cleaning, repair & replacement; base & surface repair; maintenance of unpaved surfaces; cleaning, shaping and repairing ditches; vegetation management-mechanical & chemical; guardrail repair & replacement; pavement striping & markings; maintenance of delineators, reference markers, traffic signs, traffic signals and luminaries, impact attenuators (crash barriers); repair of escape ramps; inspection of structures; maintenance & repair of structures; maintenance of buildings & sites; maintenance of rest areas; removal of debris & litter; sweeping & flushing; inspection, repair of fences and gates; cattle guard repair.
13	NJ	Mowing and vegetation control Litter pickup and deer carcass removal Stormwater management (Sweeping, inlet inspection and cleaning) – also done by contract Snow and Ice removal (also done by contract) Pothole patching, crack sealing, minor paving work Electrical Repairs (traffic signals and overhead lighting) – relamping also done by contract Fabricate and install highway signs
14	OH	All maintenance on all Interstates, and U.S. or State Routes outside of incorporated areas. This includes pothole patching, snow and ice control, drainage, guardrail, striping, mowing etc.
15	SC	SCDOT's workforce is not sufficient to perform all of the maintenance needs for our state's transportation system. Some maintenance tasks are performed solely by contract, but many tasks are performed by both state forces and contract forces. Budget fluctuations primarily dictate the amount of work performed by contract. • Preservation treatments including chip seal and crack seal • Surface and base repairs • Cement reclamation • Bridge inspection, maintenance, and replacement • Drainage maintenance • Sidewalk maintenance and repair • Vegetation management • Debris removal • Residential driveway installation and maintenance • Traffic signal repair, upgrades, and maintenance • Sign installation repair and maintenance • Pavement marking installation and maintenance • Hazardous condition responsibilities for natural disasters such as winter storms and hurricane events • Guardrail installation, repair, and maintenance • Facility and equipment maintenance and repair

16	SD	All
17	VA	See the attached copy of the Activity Code Manual that lists all the activity codes and cost center based activities.
18	WA	Generally, all routine, preventive, and corrective maintenance is carried out by state employees at the WSDOT. This ranges across the maintenance and operation of all assets that comprise the highway system. Larger-scale work such as asphalt overlays, chip seal applications, re-painting bridges, and replacing culverts and traffic signals when they've reached the end of their useful life, are performed by private sector contractors.
19	WV	MOSTLY ROUTINE WITH SOME PREVENTIVE AND CORRECTIVE: Drainage Maintenance– ditching, pipe and drainage structure cleaning and replacement Vegetation Management – mowing, brush cutting, herbicide spraying Pavement and Surface Maintenance – grading, pavement/pothole patching, crack sealing, chip seals
20	WY	WYDOT in-house forces do many activities. I have attached a list of these activities. The list does not contain the striping or electrical features maintenance activities performed by other programs within WYDOT, nor does it contain the full complement of signing activities, since some of those are completed by others as well.

		2. What are the road maintenance works performed by contractors in your state DOT?
1	AK	Contractors are used on a project by project basis. We could use a contractor for each of the tasks listed above.
2	AR	Contract mowing routes, guardrail maintenance, concrete slab jacking.
3	CO	We contract out no maintenance. Our Construction and Engineering forces do contract out some overlays and bridge deck repairs.
4	FL	The contract perform the same activities that our Maintenance Crews. The Operation centers determine if it is more beneficial to perform the work by in-house crews or contracts.
5	IA	Full depth patching, Joint & crack sealing, Joint & crack filling, Thin surface treatments, Bridge painting & maintenance, Guardrail repair.
6	ID	All seal/chip seal coats, all overlays, slurry seals, some roadside mowing, some vegetation spraying, concrete pavement repair, bridge deck repair, guard rail installation, permanent/long life pavement markings, rest area maintenance.
7	IN	Mowing, guardrail and crash attenuator repair, traffic signal maintenance, highway lighting maintenance, small amount of chip sealing, microsurface and other pavement preservation techniques, some pipe replacements and pipe liners, street sweeping
8	KS	Crack and Joint Sealing Concrete Patching Bituminous Overlay Bituminous Patching Highway Striping Sign Replacement
9	KY	Right of way mowing, some snow and ice removal, guardrail repairs, tree and brush trimming, removal, strip patching (larger than potholes), striping, rest area maintenance
10	MD	Routine Maintenance Winter Maintenance Preventive Maintenance Corrective Maintenance Catastrophic Maintenance
11	MI	See attached Maintenance Activities and Accomplishment Table. Every task on this table is contracted out to local agencies in the state. Approximately 2/3 of the lane miles that MDOT is responsible for is maintained under contract with local agencies. The other 1/3 is maintained by MDOT state forces.
12	MT	HMA overlays; crack seals; chip seals; pavement striping & markings; guardrail replacement; crack & joint sealing-PCC; rest areas; slope repair; structure repair.
13	NJ	Maintenance Resurfacing (mill and pave) Plowing and Spreading (also done in-house) Drainage video inspection, cleaning and repair (also in-house) Guiderail Repair Inspection and Cleaning of Manufactured Treatment Devices (MTD's) Sweeping (also in-house) Line Striping

		Bridge Painting Thin overlays/microsurfacing Relamping (also in-house) Bridge repairs Concrete joint repair
14	OH	Any road work over $25,000 per lane mile or any site specific maintenance work over $50,000 such as bridge repairs or traffic signals.
15	SC	State forces are supplemented by contracted work to accomplish as much work as the funding allows. Most of the items listed below are performed by contract forces and state workers. Additional notes are included as an attempt to clarify this information. • Reconstruction and rehabilitation treatments (a small amount of cement reclamation is performed by state forces) • Preservation treatments (some crack seal is performed by state forces and approximately 30 percent of the chip seal is performed with state forces) • Base repairs • Bridge inspection, maintenance, and replacement (bridges less than 210 feet in length are typically replaced with state forces) • Drainage maintenance (primarily performed with state forces) • Sidewalk maintenance and repair (primarily performed by contract forces) • Vegetation management (approximately 65% of the roadside mowing is performed by contract) • Debris removal (contract forces will likely assist during significant FEMA reimbursable events only) • Residential driveway installation (only a small percentage performed by contract forces) • Traffic signal installation, repair, and maintenance (new installations and upgrades are primarily performed by contract forces) • Sign installation repair and maintenance (interstate Q signs and logo signs are installed and maintained by contract forces) • Pavement marking installation and maintenance (all thermoplastic long line pavement markings are performed by contract) • Hazardous condition responsibilities for natural disasters such as winter storms and hurricane events (contract forces will likely assist during significant events only) • Guardrail installation, repair, and maintenance (primarily performed by contract) • Facility and equipment maintenance and repair (some repairs are contracted out) • Rest area and welcome center facility and grounds maintenance (performed by contract only)
16	SD	Large chip seal, guardrail replacement, etc. Projects beyond the manpower or equipment capabilities of dot.

17	VA	It is possible that contractors may perform any of the various maintenance activities. Actual activities performed by contractors will vary in different parts of the state dependent upon workload, vendor availability, deadline for completion, etc.
18	WA	See response to question #1.
19	WV	Primarily resurfacing
20	WY	Contractors do similar activities to those done by WYDOT’s in-house forces.

3. Please list the preventive maintenances in your state DOT:

1	AK	Pavement preservation activities include chip sealing, crack sealing, fog sealing, high-float, sand sealing, and mirco-surfacing. Other PM activities include gravel surface blading, application of dust palliatives, ditching, brush cutting, and other drainage improvements.
2	AR	Crack sealing, seal coats, fog coats. Pretreating for snow/ice events.
3	CO	Crack Filling, Chip Seals, Overlays…
4	FL	Refer to the Routine Maintenance Cost Handbook.
5	IA	Thin surface treatment, Joint & crack sealing/filling.
6	ID	Asphalt Crack Sealing,
7	IN	Chip sealing, crack sealing, ditching, small culvert inspection and cleaning, underdrain inspection and cleaning, bridge deck flushing, traffic signal preventative maintenance (conflict monitor change out, signal bulb/LED bulb change out, cabinet and hardware checklist of items, etc.), herbicide treatments
8	KS	Crack Sealing Patching
9	KY	1 ½ " Asphalt resurfacing, crack sealing, micro surfacing
10	MD	Resurfacing Safety Improvements Sign Replacement Minor Bridge Repairs Facility Maintenance Drainage Improvements
11	MI	HMA Crack Treatment, Concrete Crack Treatment, Concrete Joint Resealing With Minor Spall Repair, Overband Crack Fill- Pretreatment, Chip Seals, Micro-surfacing, Ultra-Thin HMA Overlay-Low & Medium Volume (<1″ thick), Shoulder Fog Seal, Paver Placed Surface Seal, Non-Structural HMA Overlay(1.5″)*, Surface Milling with Non-Structural, HMA Overlay (1.5″)*, HMA Shoulder Ribbons, Full Depth Concrete Pavement Repairs, Diamond Grinding, Dowel Bar Retrofit, Concrete Pavement Restoration**, Underdrain Outlet Clean Out and Repair
12	MT	Crack seals; chip seals; HMA overlays (0.15'); mill & HMA fill (0.20'), crack & joint seal-PCC; cold in-place recycling; machine patching; rut filling; culvert cleaning & repair.
13	NJ	Thin overlays Crack sealing Joint repair/replacement Bridge Painting Slab Jacking Diamond Grinding (PCC Pavement)
14	OH	Crack sealing, bridge cleaning of decks and substructures, cleaning drainage structures, and chip sealing
15	SC	Types of preventive maintenance surface treatments are listed in order of precedence: 1) Chip seal 2) Ultra-thin HMA overlays 3) Microsurfacing

		4) Full-depth patching 5) Crack seal 6) Diamond grinding (rigid pavement only)
16	SD	
17	VA	Refer to the Activity Code Manual
18	WA	There are preventive maintenance (PM) aspects of most all activities that comprise highway maintenance. Major PM programs are currently implemented by the WSDOT maintenance program for the following highway assets: Movable and Floating Bridges Keller Ferry Operation Signals Intelligent Transportation Systems Highway Lighting Urban Tunnel Maintenance and Operations Cable Guardrail We are currently developing more defined PM programs for bridges, pavements, and drainage features.
19	WV	Crack sealing, patching, chip sealing
20	WY	If you are talking about pavements or bridges, most of the repairs that are done can be classified as both preventive and reactive maintenance, and in reality, many of these treatments are used in both strategies. Due to funding challenges, most of the preventive maintenance is done using contractors, as we have been more successful in funding contracted operations over those done by in-house forces.

4. Are the timings of these preventive maintenances determined based on field inspections of roadways?

1	AK	yes	
2	AR	yes	
3	CO	no answer	To some degree, also based on Remaining Service Life.
4	FL	yes	We use our Maintenance Rating Program (MRP) to determine where work is needed on our roadways.
5	IA	yes	
6	ID	no	
7	IN	yes	
8	KS	yes	
9	KY	yes	
10	MD	yes	
11	MI	no	Not necessarily, some preventative maintenance treatments are performed on a predetermined schedule.
12	MT	yes	
13	NJ	yes	
14	OH	yes	
15	SC	yes	
16	SD	yes	
17	VA	yes	
18	WA	yes	
19	WV	yes	
20	WY	yes	Yes, field inspections carry a large amount of weight when scheduling these treatments. We have preferred time frames to accomplish these tasks, but we will do them both earlier and later based on testing and field observations

5. Does your state DOT have separated budgets for major highway infrastructures like bridge, lighting, signing, pavement marking, sidewalk, etc.?

			If yes, please list these highway infrastructures?
1	AK	no	
2	AR	yes	Heavy bridge structures, pavement markings, cold milling crew/operations.
3	CO	no	
4	FL	yes	Maintenance two major budget entities: Bridge Rehabilitation/Repair Program (BRRP) for major bridge work, and Routine Maintenance Budget Program. A summary spreadsheet summarizes routine maintenance activity needs and combines them with the fixed obligations resulting in a summary of statewide Maintenance budget needs.
5	IA	yes	Bridge yes, the rest are combined for budgeting purposes.
6	ID	yes	We have separate budget line items for these items, but we allow the District managers to move funds from each line item to others to cover the current need.
7	IN	yes	We have budgets for contracted work broken out by asset classes (expansion projects, safety projects, bridges, preservation projects and maintenance type projects. Traffic items such as lighting or signing might be lumped in an expansion project or stand alone if it is pure maintenance/modernization.
8	KS	no	
9	KY	yes	Separate budget for bridges, panel signing, guardrail at new locations, preventive maintenance
10	MD		Not strictly. We have separate budget categories for much of this work, but the funding can be moved rather fluidly from category to category to account for unforeseen needs that always occur throughout the year. Pavement Sidewalk Guardrail End-Treatments Bridge Noise Walls Park & Ride Lots Safety Hardware Facilities Intersections Drainage Improvements Crash Prevention Truck Weigh Stations
11	MI	yes	
12	MT	yes	
13	NJ	yes	Capital Maintenance projects are funded with Transportation Trust Fund dollars and include items that extend infrastructure life by 5 years or more.

			All electrical work is TTF – Electrical Program line item All Sign work is TTF funded – Sign Program line item All Maint. Resurfacing is TTF funded – Resurfacing Program line item Preventive Maint. Is TTF or Federally funded. Guiderail Repair is TTF funded – Betterments Safety program line item Line Striping is Federally funded – Long-Life Lines program line item.
14	OH	yes	Operating maintenance budget Capital improvement budget Bridges Pavements Maintenance contracting budget
15	SC	no	There are separate budgets for the pavement improvement and preservation fund, contracted bridge replacements, and separate budgets for cable rail and guard rail repair. Most other maintenance needs are prioritized and paid from the same budget.
16	SD	yes	
17	VA	yes	• Pavement, • bridges, • guardrail, • signs, • markings, • signals, • ITS assets, • tunnels, • other assets and operations
18	WA	yes	Our state legislature provides a budget for the entire highway maintenance program then we divide the program budget amongst 37 activities that comprise the program. Detailed budget plans are established for each of these 37 activities for the purpose of budget tracking and accountability. A list (in priority order) of these activities can be viewed via the enclosed web address. http://www.wsdot.wa.gov/NR/rdonlyres/5558D96F-BE37-4503-B020-0C1152CB13B0/0/0911BalancedLOSPriorities.pdf
19	WV	yes	Bridge Departments – bridge repair, maintenance, and replacement Sign Shop – lighting, signing, and pavement markings
20	WY	Not strictly	See the attached sheets for the categories. Again, this list does not contain some of the things that WYDOT maintains through other, specialized programs. work, but the funding can be moved rather fluidly from category to category to account for unforeseen needs that always occur throughout the year.

6. Which method do you use to budget for new facilities like bridge, lighting, signing, pavement marking, sidewalk lighting, etc.?

			Note

1	AK	Historic record	
2	AR	Historic record	
3	CO	historic record	
4	FL	Others	In current year budget cycle, we have a line item for additional lane miles that have not been completed by construction. This is to make sure we have the funds available to perform routine maintenance of those roadways. Once the project is complete, we inventory the items on the road and they are then captured by our regular budget cycle for future years.
5	IA	others	The Iowa DOT has a 5-year transportation plan that sets the priorities for new facilities.
6	ID	Others	New facilities are all brought into the our network through contract construction, not maintenance. Therefore, budgeting for these items is based on historical data of construction contracts.
7	IN	Others	We list all proposed projects in a class of projects and then rank the need utilizing a team of agency wide staff to prioritize with various factors such as asset rating, cost, potential benefits, etc.
8	KS	historic record	
9	KY	historic record	
10	MD	Historic record, others	previous expenditures additional quantities previous condition
11	MI	Historic record	
12	MT	data from other agencies	
13	NJ	Others	Management Systems Data (Pavement Management System, Drainage management system, Bridge Management System, etc.)
14	OH	historic record	
15	SC	others	Project funding is distributed based on need and projects are prioritized by formula. Budgets for maintenance are typically distributed to different divisions by formula. Needs are prioritized and addressed as funding permits.
16	SD	Others	Inspections
17	VA	others	Condition based or service based, targeted needs assessment
18	WA	historic record	
19	WV	others	Bridge – 6 year plan, STIP Sign Shop – historical data
20	WY	both	We use history if we already have similar facilities. We will ask other agencies who have similar. Infrastructure if we have no experience with it. Many times, this additional work must be absorbed into the existing funding levels

7. Do you observe that maintenance costs for a roadway section increase with years after a reconstruction, a rehabilitation, or a preventive maintenance?

1	AK	yes	
2	AR	yes	
3	CO	yes	
4	FL	no	
5	IA	yes	
6	ID	no	At the present time we do not have an operational Maintenance Management System (MMS) to track maintenance costs. We are in the process of implementing a new MMS that should be fully operational and on-line by June 30, 2011. Sometime after that we will be able to answer this question.
7	IN	no	A pavement preservation program can help avoid significant out year expenditures if followed soon after a reconstruction/major rehab
8	KS	yes	
9	KY	yes	
10	MD	no	
11	MI	yes	
12	MT	yes	
13	NJ	no	
14	OH	yes	
15	SC	yes	
16	SD	yes	
17	VA	yes	
18	WA	yes	We don't have specific data to support this but this is our general observation and opinion.
19	WV	yes	
20	WY	yes	We also notice that the maintenance costs go down immediately before reconstruction or rehabilitation since we don't want to spend significant amounts of our maintenance funding only to see it disappear as the reconstruction/rehabilitation takes place.

8. Are there equations in your Pavement Management System that relate the costs of roadway maintenance (excluding reconstruction and rehabilitation) to the influencing factors such as ages, traffic loads, pavement conditions, weather, etc.?

			Note
1	AK	yes	
2	AR	no	
3	CO	no answer	Do not know. Pavement management is run by the Materials and Geotechnical section
4	FL	no	
5	IA	no	
6	ID	no	
7	IN	no	This should be "sort of". We do have a level-of-service module in our maintenance management system that we have yet to use. Our pavement management system currently does not capture in-house maintenance activities.
8	KS	no	
9	KY	no answer	
10	MD	yes	
11	MI	no	
12	MT	yes	
13	NJ	no	
14	OH	no	
15	SC	no	
16	SD	yes	
17	VA	yes	
18	WA	no	Not at this time but we are working towards better integration of roadway maintenance activities, costs, and benefits into our Pavement Management System.
19	WV	yes	
20	WY	no	

9. Are there equations in your Bridge Management Systems (BMS) that relate the costs of bridge maintenance (excluding reconstruction and rehabilitation) to the influencing factors such as ages, traffic loads, etc.?

			Note
1	AK	yes	
2	AR	no	
3	CO	no answer	Do not know. Bridge Management is run by Staff Bridge.
4	FL	no	
5	IA	no	
6	ID	no	
7	IN	no	Not currently. We use Deighton's dTIMs for both pavement and bridge, which is being modified to better include these items.
8	KS	no	
9	KY	no	
10	MD	yes	
11	MI	no	
12	MT	yes	
13	NJ	no	
14	OH	no	
15	SC	yes	
16	SD	yes	
17	VA	yes	
18	WA	no	Not at this time but we are working towards better integration of roadway maintenance activities, costs, and benefits into our Bridge Management System.
19	WV	yes	
20	WY	no	

10. In your routine, corrective and/or preventive maintenance database, is it possible to separate the works for pavements and bridges?

			Note
1	AK	yes	
2	AR	yes	
3	CO	yes	
4	FL	yes	
5	IA	yes	
6	ID	no	Not at this time, but we will have this functionality when the new MMS is implemented.
7	IN	yes	
8	KS	yes	
9	KY	yes	
10	MD	yes	
11	MI	yes	
12	MT	yes	
13	NJ	yes	
14	OH	yes	
15	SC	yes	
16	SD	yes	
17	VA	yes	
18	WA	no answer	
19	WV	yes	
20	WY	yes	

11. Do you estimate maintenance costs in terms of man power, equipment, materials, separately?

			11.1
1	AK	yes	
2	AR	yes	
3	CO	no	
4	FL	yes	
5	IA	yes	
6	ID	no	Not at this time. Due to our budget process, we only estimate and budget for material or contract expenditures as man power and equipment costs are fixed within the budget. As we begin utilizing the new MMS, then we will estimate and budget for maintenance projects via all three costs that you have listed.
7	IN	yes	
8	KS	yes	
9	KY	yes	
10	MD	yes	
11	MI	no	
12	MT	no	
13	NJ	yes	
14	OH	yes	
15	SC	yes	
16	SD	yes	
17	VA	yes	
18	WA	no answer	
19	WV	yes	
20	WY	no	We currently add these together to come up with a single estimating factor. We are looking at splitting these for other systematic concerns.

12. How does your state DOT deal with the annual fluctuation of maintenance costs (routine, corrective and/or maintenance) because the maintenance activities on a roadway section each year are different?

			12.1
1	AK	Others	We target our budget where the need is. We use our annual highway condition inspection survey, Pavement Management System, Airport Pavement Management System, Bridge Management System, and other field reports to target our maintenance activities. We also prepare an annual list of deferred maintenance needs for each mode (highways, aviation, ports and harbors, facilities, and Marine Highway) and target deferred maintenance capital funds to where the need is.
2	AR	Averaging the maintenance costs over the past three years	
3	CO	no answer	We developed a Performance based budgeting system that uses surveys of roadway condition, amount spent on that area, accomplishments in that area, and determines a dollar amount required to obtain a specified level of service in that area for the following year.
4	FL	Others	The budget for future years are based on historical costs per maintenance activity.
5	IA	others	Budget-driven and priority-based
6	ID	Others	Out maintenance budgets have remained stagnant for several years. As a result, we prioritize our maintenance budget to address winter maintenance needs as priority and perform summer maintenance as funds become available. Since the Districts are responsible for their roads, it then becomes their responsibility to address maintenance needs either via regular state performed maintenance or contract maintenance, whichever they have.
7	IN	Others	Develop frequency rates so that the entire inventory of a feature gets addressed in a pre-determined timeframe/cycle
8	KS	Averaging the maintenance costs over the past three years	
9	KY	Others	We receive a baseline budget for most maintenance activities that is one large budget. We have the flexibility to spend that budget on the roads and activities necessary, as far as the money will allow. The baseline budget is based on past budgets and we

			request increases as we need. Those requests are reviewed by the Governor's Office and the General Assembly as part of the total budget bill.
10	MD	• Averaging the maintenance costs over the past three years X • Estimate the probability of occurrence of maintenance activities X	Annual Condition Assessment, Maintain core activities during budget shortfalls, seek capital funding
11	MI	Averaging the maintenance costs over the past five years	
12	MT	Estimate the probability of occurrence of maintenance activities	
13	NJ	Averaging the maintenance costs over the past three years	
14	OH	Others	Our maintenance database (Transportation Management System) tracks material, equipment, and labor costs for every maintenance job. Those standard costs are calculated and updated each year to deal with annual fluctuations.
15	SC	others	Unfortunately, SCDOT's Maintenance Division is not based on the amount of need. The funding that is dedicated to maintenance is distributed to the divisions based on need and this funding is used to address as much of the prioritized needs as possible.
16	SD	Estimate the probability of occurrence of maintenance activities	
17	VA	others	The needs assessment generates recommended units of work for each asset and each major activity type. Each asset/activity has an associated cost, which is updated each year to reflect actual costs and projected inflation over the two years. The total need for the program across each type of asset or service is then calculated by multiplying the unit cost by the number of units required of each activity type to meet performance or service targets, and then adding the results across all assets, roadway systems, and districts.
18	WA	no answer	
19	WV	others	WVDOT has developed a core maintenance program that addresses routine maintenance such as drainage maintenance, vegetation management, and pavement

			maintenance for state forces. Because maintenance costs and material prices have increased, contract resurfacing gets less and less road miles each year with the same funding. This has caused a shift to more preventive maintenance by state forces performing crack sealing, patching, chip seals, and surface treatments to extend the life of pavements to sustain our road system.
20	WY	all	· Averaging the maintenance costs over the past three years. WYDOT uses this model, but we use a five year weighted average. · Estimate the probability of occurrence of maintenance activities – WYDOT does not use this. · Develop advanced statistical regression models – We have not done this. · Others, please specify _We do have a methodology that allows us to compensate for anticipated activities that appear they will exceed our averages significantly.

APPENDIX 4

ROAD INVENTORY DATA IN TERMS OF MAINTENANCE PRIORITIZATION CATEGORY

Road Inventory Data for Carson City County

		Section 1		Section 2		
Prioritizati	Road	From	To	From	To	
1	US395	0.56	9.61			
2	SR520	0.00	1.23			
	SR529	0.56	6.22			
	SR530	0.00	1.46			
	SR531	0.00	1.65			
	US050	0.00	7.63	12.27	16.40	
	US395	0.00	0.56			
3	FRCC01	0.00	1.91			
	FRCC04	0.19	0.69			
	FRCC05	0.00	0.13			
	FRCC06	0.00	0.80			
	SR028	0.00	3.95			
	SR511	0.00	0.81			
	SR512	0.00	2.28			
	SR513	0.00	2.38			
	SR516	0.67	2.45			
	SR518	0.00	1.02			
	SR525	1.77	3.09			
4	SR513	2.38	4.66			
	SR516	0.00	0.67			
5A						
5B						
5C	SR705	2.94	4.02			

Road Inventory Data for Churchill County

		Section 1		Section 2	
Prioritizati	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		
	SR115	0.00	1.01		
	SR361	0.00	15.69		
5C	FRCH01	0.00	0.12		
	FRCH03	0.00	2.57		
	FRCH04	0.00	0.61		
	FRCH06	0.00	4.20		
	FRCH07	0.00	0.20		
	PCH15	0.00	0.16		
	PCH16	0.00	2.89		
	PCH16B	0.40	0.00		
	PCH17	0.00	0.65		
	PCH18	0.00	0.82		
	SR120	0.00	6.26		
	SR121	0.00	26.95		
	SR722	0.00	16.62		
	SR839	0.00	13.92		

Road Inventory Data for Clark County

		Section 1		Section 2		Section 3			
Prioritized	Road	From	To	From	To	From	To		
1	[illegible]	0.00	125.75	r					125.75
	[illegible]	0.00	15.12	r					15.12
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		36.76
			r		r		r		
2	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	SR147	26.84	34.61	r					7.77
	SR159	17.03	31.00	r					13.97
	SR160	0.00	11.07	r					11.07
	SR165	0.00	19.26	r					19.26
	SR169	13.84	24.31	r					10.47
	SR562	25.33	34.81						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]
	SR574	21.46	31.90						10.44
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	SR582	14.32	31.10						16.78
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	SR592	21.46	31.38						9.92
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	SR604	44.51	58.31						13.80
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	US93S	1.61	10.90						[illegible]
	US95	0.00	56.25	[illegible]	[illegible]	[illegible]	[illegible]		56.25
5	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	PRCL41	0.08	0.00						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	PRCL46	1.00	0.00						[illegible]
	PRCL47	0.00	1.04						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	0.00	[illegible]	r					21.16
	[illegible]	0.00	[illegible]	r					17.05
	[illegible]	[illegible]	[illegible]	r					32.50
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	6.22						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]	r					12.52
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]	all Credit	r				34.57
4	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	PRCL142	0.15	0.00						[illegible]
	SR158	0.00	6.66						[illegible]
	[illegible]	0.00	[illegible]		r				16.60
	[illegible]	[illegible]	[illegible]	all Credit	r				25.72
	SR169	5.82	15.84						[illegible]
									[illegible]
5A	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]	all Credit	r				17.59
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]		r				10.26
									[illegible]
5B	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]	r					11.00
	[illegible]	0.00	[illegible]						[illegible]
									[illegible]
5C	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	[illegible]	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]
	[illegible]	0.00	[illegible]						[illegible]

Road Inventory Data for Douglas County

		Section 1		Section 2	
Prioritizati	Road	From	To	From	To
1					
2	SR088	0.00	7.87		
	US050	0.00	14.55		
	US395	0.00	33.96		
3	SR028	0.00	1.23		
	SR207	0.00	11.09		
	SR208	0.00	8.80		
	SR756	0.00	3.97		
	SR759	0.00	1.00		
4	SR206	0.00	15.42		
	SR757	0.00	3.19		
	SR760	0.00	0.60		
5A					
5B					
5C	PDO01	0.00	0.31		
	PDO03	0.00	0.38		
	PDO03B	0.00	0.09		
	PDO03C	0.00	0.16		

Road Inventory Data for Elko County

		Section 1		Section 2		Section 3	
Prioritizati	Road	From	To	From	To	From	To
1	IR080	0.00	132.73				
2	SR225	27.34	28.79				
	SR227	0.00	7.03				
	SR535	21.71	27.24				
	US093	74.06	141.82				
3	FREL17	0.00	0.86				
	SR223	74.63	75.76				
	SR225	28.79	54.48				
	SR227	7.03	18.34				
	SR766	0.00	3.10				
	US093	0.00	74.06				
4	FREL01	0.00	0.70				
	FREL05	0.00	3.60				
	FREL08	0.00	3.85				
	FREL21	0.00	0.10				
	FREL22	0.00	0.10				
	FREL38	0.00	0.75				
	FREL40	0.00	0.25				
	FREL43	0.00	0.31				
	FREL47	0.00	0.24				
	FREL49	0.00	0.06				
	FREL54	[illegible]	35.77				
	FREL58	0.00	0.16				
	FREL59	0.00	0.44				
	FREL70	0.00	0.37				
	SR221	1.44	4.42				
	SR225	54.48	77.06	112.98	127.64		
	SR227	18.34	28.13				
	SR228	6.86	33.67				
	US093A	24.92	53.51				
3A	FREL33	0.00	0.93				
	SR223	73.77	74.63				
	SR225	77.06	112.98				
	SR233	0.00	34.23				
	SR278	0.00	4.91				
	US093A	0.00	24.92				
3B	FREL04	0.00	0.10				
	FREL05	3.60	3.85				
	FREL18	0.00	0.37				
	FREL19	0.00	0.30				
	FREL20	0.00	0.25				
	FREL23	0.00	1.30				
	SR226	0.00	20.00				
	SR229	0.00	50.36				
	SR232	2.62	17.15				
3C	FREL02	0.00	0.44				
	FREL03	0.00	2.20				
	FREL06	0.00	3.32				
	FREL07	0.00	0.20				
	FREL09	0.00	0.86				
	FREL10	0.00	0.84				
	FREL23	1.30	3.25				
	FREL24	0.00	0.52				
	FREL26	0.00	0.57				
	FREL27	0.00	1.72				
	FREL28	0.00	11.50				
	FREL30	0.00	0.85				
	FREL31	0.00	1.71				
	FREL32	0.00	1.85				
	FREL35	0.00	1.60				
	FREL36	0.00	0.10				
	FREL37	0.00	0.63				
	FREL39	0.00	0.14				
	FREL41	0.00	0.27				
	FREL42	0.00	0.22				
	FREL46	0.00	1.85				
	FREL49	0.06	3.31				
	FREL55	0.00	1.86				
	FREL57	0.00	0.11				
	FREL60	0.00	0.25				
	FREL61	0.00	0.23				
	PEL74	0.00	1.51				
	PEL74B	0.00	0.52				
	PEL76	0.00	0.50				
	SR226	20.00	39.02				
	SR230	0.00	13.06				
	SR231	0.00	11.70				
	SR232	0.00	2.62				
	SR767	37.18	39.10				

Road Inventory Data for Esmeralda County

		Section 1		Section 2	
Prioritizati	Road	From	To	From	To
1					
2	US006	18.87	57.79		
	US095	0.00	45.42	85.40	99.06
3					
4					
5A	US006	0.00	18.80		
5B	SR264	0.00	33.67		
	SR266	0.00	40.34		
	SR773	25.46	35.96		
	US006	18.80	18.87		
5C	FRES01	0.00	0.44		
	FRES02	0.00	0.64		
	SR265	0.00	20.50		
	SR267	0.00	9.36		
	SR774	0.00	7.46		

Road Inventory Data for Eureka County

		Section 1		Section 2		Section 3	
Prioritizati	Road	From	To	From	To	From	To
1	IR080	0.00	25.70				
2							
3	SR766	0.00	6.32				
	US050	0.00	47.39				
4	SR278	0.00	20.23				
	SR306	0.00	20.62				
5A	SR278	62.42	82.66				
5B	SR278	20.23	62.42				
5C	FREU01	0.00	1.69				
	FREU02	0.00	5.49				
	FREU03	0.00	0.10				
	FREU04	0.00	1.39				
	FREU05	0.00	0.38				
	FREU06	0.00	4.25				
	FREU08	0.00	0.51				
	FREU09	0.00	1.04				
	FREU10	0.00	0.15				
	SR780	0.00	2.27				

Road Inventory Data for Humboldt County

		Section 1		Section 2	
Prioritizati	Road	From	To	From	To
1	IR080	0.00	61.38		
2	SR294	4.03	8.97		
	SR787	0.00	0.50		
	US095	0.00	33.00		
3	SR289	14.28	15.92		
	SR294	0.00	4.03		
	SR794	14.62	17.06		
	US095	33.00	75.40		
4	FRHU03	0.00	1.38		
	FRHU05	0.00	0.28		
	FRHU10	1.07	1.19		
	FRHU12	2.02	2.20		
	FRHU20	0.00	3.38		
	SR789	0.00	16.25		
	SR795	0.00	1.25		
	SR796	0.00	1.36		
5A	FRHU11	0.00	2.21		
	SR140	0.00	65.58		
	SR290	0.00	18.01		
	SR293	0.00	3.40		
5B	FRHU04	0.16	0.27		
	FRHU08	0.00	0.51		
	FRHU09	0.69	0.70		
	FRHU15	3.06	9.95		
	SR140	65.58	110.11		
	SR293	3.40	23.99		
5C	FRHU01	0.00	0.19		
	FRHU04	0.00	0.16		
	FRHU07	0.00	0.87		
	FRHU08	0.51	0.94		
	FRHU09	0.00	0.69		
	FRHU10	0.00	1.07		
	FRHU12	0.00	2.02		
	FRHU13	0.00	0.41		
	FRHU14	0.00	0.37		
	FRHU17	0.00	0.32		
	SR292	65.58	68.52		

Road Inventory Data for Lander County

		Section 1		Section 2	
Prioritizati	Road	From	To	From	To
1	IR080	0.00	26.97		
2					
3	SR304	4.42	8.21		
	SR305	115.73	118.52		
	US050	0.00	57.00		
4	SR305	93.00	115.73		
	SR376	0.00	18.07		
5A	SR305	30.80	93.00		
	SR306	2.31	12.34		
5B	FRLA01	0.00	8.25		
	SR806	0.00	5.90		
5C	FH030	0.00	9.80		
	FRLA02	0.00	19.14		
	FRLA05	0.00	1.96		
	SR722	0.00	41.52		

Road Inventory Data for Lincoln County

		Section 1		Section 2	
Prioritizati	Road	From	To	From	To
1					
2					
3	SR318	0.00	49.42		
	US093	0.00	50.61	92.49	95.53
4	SR319	50.00	70.91		
	SR321	0.00	5.11		
	SR322	0.00	0.78		
	US093	50.61	92.49	95.53	172.87
5A	SR317	56.78	58.59		
5B	SR317	37.10	56.78		
	SR322	0.78	18.58		
	SR375	0.00	49.05		
	SR816	0.00	0.61		
5C	PLN12	0.00	1.72		
	PLN12B	0.00	0.84		
	PLN13	0.00	0.39		
	PLN15	0.00	1.69		
	PLN17	0.00	2.00		
	SR320	0.00	10.67		

Road Inventory Data for Lyon County

		Section 1		Section 2	
Prioritizati	Road	From	To	From	To
1	IR080	0.00	15.91		
2	SR341	0.00	4.90		
	SR822	0.00	0.15		
	US050	0.00	14.04		
	US050A	0.00	7.82		
	US095	0.00	2.82		
3	SR208	2.45	8.91	28.09	29.10
	SR339	0.00	11.52		
	SR340	0.00	1.08		
	SR342	0.00	0.84		
	US050	14.04	35.40		
	US095A	0.00	60.59		
4	FRLY01	0.00	0.04		
	FRLY04	0.00	0.35		
	SR208	0.00	2.45	8.91	28.09
	SR338	0.00	30.90		
	SR427	0.00	1.66		
	SR823	0.00	7.11		
	SR824	0.00	5.57		
	SR827	0.00	1.50		
	SR828	0.00	7.74		
5A	SR827	1.50	5.8		
	SR829	0.00	3.17		
5B	SR823	7.11	7.61		
	SR825	0.00	0.42		
5C	FRLY01	0.00	2.51		
	FRLY03	0.00	1.50		
	PLY12	0.00	0.31		
	PLY13	0.00	1.33		
	PLY16	0.00	1.02		
	PLY16B	0.00	0.38		
	PLY16C	0.00	0.35		
	PLY16D	0.00	0.18		
	PLY16E	0.00	0.04		
	PLY19	0.00	2.20		
	PLY19B	0.00	0.12		
	PLY19C	0.00	0.06		
	PLY19D	0.54	0.00		
	PLY19E	0.00	0.18		

Road Inventory Data for Mineral County

		Section 1	
Prioritizati	Road	From	To
1			
2	SR362	0.00	1.30
	US095	0.00	92.14
3	SR360	0.00	23.25
	US006	0.00	11.96
4	SR359	32.89	33.35
	US095A	0.00	10.68
5A	US006	11.96	15.20
5B	SR359	0.00	32.89
	SR361	0.00	22.20
5C	PMI33	0.00	0.58
	SR839	74.82	78.97

Road Inventory Data for Nye County

		Section 1		Section 2	
Prioritizati	Road	From	To	From	To
1	US095	0.00	6.86		
2	SR372	0.00	7.77		
	US006	0.00	1.80		
	US095	6.86	107.22		
3	SR160	0.00	9.72		
	SR318	0.00	38.79		
	US006	1.80	2.00		
4	FRNY33	0.00	0.36		
	SR160	9.72	37.03		
	SR373	0.00	16.30		
	SR374	8.20	8.84		
	SR376	0.00	81.75		
	US006	2.00	14.01		
5A	SR374	0.00	8.20		
	US006	14.01	51.21	117.96	132.03
5B	SR361	0.00	24.96		
	SR375	0.00	49.36		
	US006	51.21	117.96		
5C	FRNY01	0.00	0.71		
	SR082	0.00	27.00		
	SR267	0.00	12.07		
	SR377	0.00	6.60		
	SR379	0.00	19.53		
	SR844	0.00	12.32		

Road Inventory Data for Pershing County

		Section 1	
Prioritizati	Road	From	To
1	IR080	0.00	75.09
2			
3			
4	FRPE14	5.10	5.39
	SR856	0.00	1.40
5A	SR398	0.00	4.76
	SR401	0.00	2.35
5B	FRPE21	0.00	0.19
	SR399	0.00	18.18
	SR858	0.00	0.55
5C	FRPE01	0.00	28.17
	FRPE02	0.00	1.05
	FRPE04	0.00	0.34
	FRPE05	0.00	0.18
	FRPE06	0.00	0.67
	FRPE07	0.00	4.21
	FRPE09	0.00	1.27
	FRPE11	0.00	4.08
	FRPE12	0.00	0.11
	FRPE13	0.00	3.90
	FRPE14	0.00	5.67
	FRPE15	0.00	7.49
	FRPE16	0.00	0.14
	FRPE17	0.00	0.08
	FRPE21	0.19	1.47
	FRPE22	0.00	1.75
	FRPE23	0.00	1.62
	FRPE24	0.00	1.79
	FRPE25	0.00	0.25
	PPE32	0.74	0.00
	PPE33	0.00	0.17
	PPE34	0.00	0.13
	SR396	0.00	7.70
	SR397	0.00	11.84
	SR400	0.00	16.58
	SR854	0.00	4.12
	SR860	0.00	1.89

Road Inventory Data for Storey County

		Section 1	
Prioritizati	Road	From	To
1			
2			
3	SR341	8.02	15.74
	SR342	0.00	2.94
4	SR341	4.90	8.02
5A			
5B			
5C			

Road Inventory Data for Washoe County

		Section 1		Section 2	
[illegible]	Road	From	To	From	To
1	IR080	0.00	45.08		
	IR580	5.09	30.19		
	US395	[illegible]	[illegible]	29.57	[illegible]
2	[illegible]	[illegible]	0.16		
	[illegible]	[illegible]	0.16		
	FRWA25	0.15	0.00		
	[illegible]	21.11	21.56		
	[illegible]	5.22	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	0.37		
	[illegible]	17.01	[illegible]		
	[illegible]	[illegible]	3.55		
	[illegible]	2.34	11.37		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	5.36		
	SR650	1.94	12.41		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	21.46	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	US395	6.98	29.57		
3	[illegible]	[illegible]	0.37		
	[illegible]	[illegible]	0.34		
	[illegible]	[illegible]	1.37		
	[illegible]	[illegible]	0.15		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	0.19		
	[illegible]	[illegible]	0.17		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	5.22		
	[illegible]	15.74	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	SR431	0.00	24.41		
	[illegible]	11.37	[illegible]		
	SR447	0.00	15.80		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	0.57		
4	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	FRWA10	0.00	1.10		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	3.15	[illegible]		
	[illegible]	0.11	[illegible]		
	[illegible]	[illegible]	2.57		
	SR429	0.03	7.82		
	SR445	20.06	40.05		
	SR446	0.00	13.16		
	SR447	15.80	74.65		
	SR877	0.00	4.30		
5A	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
5B	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
5C	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	5.41	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	0.11		
	[illegible]	[illegible]	0.15		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	1.15		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	0.51		
	[illegible]	[illegible]	0.35		
	[illegible]	[illegible]	[illegible]		
	PWA96	0.00	0.38		
	[illegible]	[illegible]	1.14		
	[illegible]	[illegible]	[illegible]		

Road Inventory Data for White Pine County

		Section 1	
Prioritizati	Road	From	To
1			
2			
3	SR318	0.00	22.57
	US006	13.92	101.88
	US050	0.00	68.43
	US093	53.45	116.71
4	SR490	0.00	8.93
	US093	0.00	26.71
5A	SR487	2.04	11.03
	SR488	0.00	5.49
	US006	0.00	13.92
	US093A	0.00	5.69
5B	SR487	0.00	2.04
5C	PWP01	0.00	2.47
	PWP01B	0.00	0.67
	SR486	0.00	33.30
	SR892	0.00	35.92
	SR893	0.00	39.75
	SR894	0.00	16.62
	SR895	0.00	1.48

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