Research Report
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LONG-TERM MAINTENANCE NEEDS PLANNING

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Long-Term Maintenance Needs Planning

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16. Abstract

This research contributes to Kentucky's knowledge base of long-term maintenance needs in two parts. Part 1 presents an estimate of the average revenue needed to maintain four categories of highway in the first fifteen years after each is built or resurfaced. Total maintenance costs per mile for four types of facilities in five AADT volume categories were estimated. The results suggest that Kentucky is not resurfacing all its roads in a timely manner. Part II presents background information on preventive maintenance programs in the states. A review of the states found two recurring themes. The first was the widespread adoption of two types of preventive measures: thin overlays and crack sealing. The second theme was the adoption of maintenance schedules to ensure timely maintenance. The report recommends the development of a routine pavement maintenance program with three elements: (1) more timely resurfacing, (2) scheduled inspections of drainage and ditching, and (3) crack sealing. It is also recommended that the Kentucky Transportation Cabinet adopt ASSHTO's recommended performance criteria and targets for sub-drainage assets.

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Executive Summary

To be effective, maintenance programs require knowledge about the expected life spans of different facilities as well as information on the likely effects of various preventive maintenance treatments. And they require knowledge of the costs associated with maintaining a given type of facility under different traffic volumes as they age. In short, maintenance programs and expenditures can be expected to vary by the type of facility, the age of infrastructure, and the AADT.

This research report contributes to Kentucky's knowledge base of long-term maintenance needs in two parts. Part 1 presents an estimate of the average revenue needed to maintain four categories of highway in the first fifteen years after each is built or resurfaced. This entailed identifying the total cost of maintenance, which was accomplished by combining data in the PM sections spread sheet with another data set—the Annual Act Costs2--to predict the maintenance cost for each additional mile of a given type of facility, for example a new mile of state secondary and state primary or a new mile of rural secondary.

Part II presents background information on preventive maintenance. It also provides brief accounts of the programs found in several states. Presumably, Kentucky can use them as models for its own program for preventive maintenance. In doing so, Kentucky can build on a recognized strength (as stated in the 2004 report by the Dye Management Group, Inc.)—its system for collecting highway data and prioritizing maintenance needs. Dye management wrote that the current system for "identifying and prioritizing maintenance and preservation projects is well-documented and technically driven and follows standards of best practice. (Dye Report, p30).

<u>Part 1 Findings</u>

1. As expected, interstates are the most expensive category of facility to maintain and rural secondary the least expensive. Less anticipated was the finding that state primary and state secondary roads have cost profiles similar to the category of roads labelled other national highway system.

2. For each of the four categories of roadway, costs were broken down into age-related costs and non-age-related. The non-age costs are significantly greater than the age-related costs per mile.

3. Costs were presented in four age categories based on the length of time since the last resurfacing: less than five years; 5 to less than 10 years; 10 to 15; and more than 15 years. There were five volume categories based on AADT: less than 500; 500 to 1,999; 2000-4,999; 5,000- 11,999; and 12,000 and up. Costs tend to rise as roads age and volumes increase. Age and volume interact to produce rising

maintenance costs. See table below. Much of the cost increase appears to be attributable to a rise in non age costs as traffic volumes increase. However older facilities require more maintenance in each volume category.

Table A: Annual per Mile Total Costs in Age/Traffic Volume Categories

Traffic volume	Years since resurfacing	Length	Total Costs per Mile
0-499	Less than 5	2364.5	1591.56
0-499	5 to less than 10	2330.2	1724.7
0-499	10 to less than 15	1886.9	1820.67
0-499	15 and up	991.5	1827.15
500-1,999	Less than 5	2678.8	1962.58
500-1,999	5 to less than 10	3033.4	2116.93
500-1,999	10 to less than 15	2050.3	2219.54
500-1,999	15 and up	1252.6	2262.33
2,000-4,999	Less than 5	14377.1	2385.70
2,000-4,999	5 to less than 10	1475.3	2563.83
2,000-4,999	10 to less than 15	1028.1	2626.04
2,000-4,999	15 and up	525.4	2805.07
5,000-11,999	Less than 5	752.8	2366.28
5,000-11,999	5 to less than 10	971.6	2654.44
5,000-11,999	10 to less than 15	766.2	2800.88
5,000-11,999	15 and up	508.4	3412.39
12,000 and up	Less than 5	587.2	3636.82
12,000 and up	5 to less than 10	643.3	3908.58
12,000 and up	10 to less than 15	361.0	4252.34
12,000 and up	15 and up	486.4	4251.50

4. The results suggest that Kentucky is not resurfacing in a timely manner. One number in particular is far out of line with the recommended timing for resurfacing—35.8 percent of interstates have not been resurfaced in over 15 years. It is recommended that interstates be resurfaced every 11 or 12 years. Many of the other types of roads appear to receive resurfacing at appropriate intervals, especially the more lightly traveled roads with traffic volumes under 5,000 AADT. Surprisingly, however, approximately 18 percent of road miles in the 5,000 to 11,999 AADT category have not been resurfaced in over 15 years. (Table B). Taken together the results suggest that a significant percentage of the commonwealth's busiest roads are not being resurfaced in a timely manner.

Table B: Percent of Roads by Facility Type and Traffic Volume Category That Have Not Been Resurfaced in 15 Years

Traffic Volume Categories

Facility Type	<500	500-1,999	2,000-4,999	5,000-11,999	12,000 and Up
Interstate	N/A	N/A	N/A	N/A	35.8%
State Primary and State Secondary	18.1%	17.1%	12.1%	15.7%	18.0%
Rural Secondary	11.3%	11.1%	11.1%	19.1%	N/A
Other NHS	N/A	13.6%	7.4%	19.8%	12.9%

5. Total maintenance costs per mile, including resurfacing, were also estimated for each type facility for the first 15 years after a resurfacing. That is, the estimate in table 3.2 in the report includes the age and non-age related costs as well as a resurfacing in the appropriate year.

Part II Findings

1. The precise time to apply preventive maintenance depends on the condition of the pavement, the expected traffic volume, and the weather. At this time, there is no definitive guidance on when to apply the different types of treatments on specific roadways. Given the lack of research on the best time to schedule maintenance, the states must rely on their own experience as well as the research that suggests relatively broad ranges within which to apply particular preventive treatments.

2. The cost effectiveness of preventive maintenance programs varies from state to state. This is a function of differences in the programs as well as differences in climate and traffic patterns. *But all studies in all states find that preventive maintenance saves money and improves the quality of pavements.* According to FHWA-IF-02-002, a dollar spent for preventive maintenance prior to the point where the pavement condition begins its accelerated decline ultimately saves 4 to 5 dollars a few years later in reconstruction costs. That is, preventive maintenance averts the precipitous plunge in the quality of pavement condition.

3. A review of the practices of the states found two recurring themes: The first was the widespread adoption of two types of preventive measures: thin overlays and crack

sealing. The second theme was the adoption of maintenance schedules to ensure timely maintenance.

4. At this time, Kentucky appears to devote substantially fewer resources than many other states to thin overlays, crack sealing, and drain cleaning.

5. This report recommends the development of a routine pavement preventive maintenance system with three elements: (1) timely resurfacing, (2) scheduled inspections of drainage and ditching, and (3) crack sealing. This will entail the adoption of schedules for maintenance activities as well as the dedication of more resources to preventive practices. It is also recommended that the Kentucky Transportation Cabinet institute ASSHTO's recommended performance criteria and targets for subdrainage assets. Compliance with these will prolong the life of pavements.

Part 1: Maintenance Expenditures over the First Fifteen Years after Resurfacing

1.0. Introduction

After road and highway facilities are built they must be maintained. To reduce maintenance costs, state departments of transportation (DOTs) are creating systems for preventive maintenance. They are doing so because the message from research on preventive maintenance is unequivocal—a dollar spent on preventive maintenance in the present can substantially extend the life of a facility, saving $4 or more on reconstruction costs for every dollar invested in such preventive treatments as thin overlays and crack sealing.

In all regions of the nation, state highway departments are devoting increasingly more resources to both routine and preventive maintenance of their state highway systems. Kentucky is no exception. However, maintenance programs are complex and multifaceted. They require timely spending on the appropriate treatment. If, for instance, a one inch overlay is applied after structural damage has occurred it will not extend the life of the roadway and an overlay applied too early in the life of a facility does little or nothing to extend the life of the facility and is a waste of money that could have been spent on more deserving projects. The same is true for other preventive maintenance programs, for example ditching and drain cleaning.

1.1 Problem Statement

Therefore, maintenance programs require knowledge about the expected life spans of different facilities and information on the likely effects of various preventive treatments. And they require knowledge of the expected costs associated with maintaining a given type of facility under different traffic volumes. Effective maintenance programs and expenditures will vary by the type of facility and the AADT.

This research report contributes to Kentucky's knowledge base in two parts. Part 1 presents an estimate of the average revenue needed in the first fifteen years after a road is built or resurfaced in order to properly maintain it. This entailed identifying the total cost of maintenance tasks along different types of roads. This was accomplished by looking at the data in the PM sections spreadsheet and another data set—the Annual Act Costs2--to predict the maintenance cost for each additional mile of a given type of facility, for example a new mile of state secondary and state primary or a new mile of rural secondary.

Part 2 provides a review of the literature on preventive maintenance and relates it to a proposed change in Kentucky approach to maintaining its roads and highways. The change would call for more frequent overlays, ditching, and drain cleaning--to be performed according to regular maintenance schedules. Taken together the findings in these two parts of the report will contribute to more accurate predictions of the impact of changes in expenditures on the overall level of service of Kentucky's roads.

Thus, the findings will facilitate the ongoing development of a more effective maintenance program—one that will suit the particular climate and conditions of Kentucky.

The next section of the report presents a detailed explanation of the methodology and data used to construct the estimates of costs on the different types of roads under different traffic loads. This is followed by the estimates of maintenance costs in the years following a roadway's initial construction or reconstruction.

1.2 Methodology

The Kentucky Transportation Cabinet keeps two separate databases, which together provide the necessary information to generate the estimates of maintenance costs over the first 15 years following the construction or resurfacing of a facility. One data base—Annual Act Costs2—contains the data on the maintenance work done between mile markers on the state highway system. Each maintenance activity has a code as well as an associated cost. (See Appendix A for a list of the maintenance activities, their codes and costs.) Therefore it is possible to assign specific maintenance activities and costs to a given stretch of roadway. To estimate total costs, all costs that occurred along a given section of highway were totaled. Thus, every section in the state highway system could be assigned a maintenance cost. It could also be identified by its type, of which there were four: state primary and state secondary, rural secondary, interstate and other NHS.

The state has another data set that contains the traffic volumes along designated segments of the state highway system—the PM sections spreadsheet. These, too, are identified by mile marker. Sometimes the mile markers in the two data sets match (i.e., in both data sets the section begins and ends at the same milemarkers). In that case, it was possible to directly assign a traffic volume to a specific section; but sometimes the mile markers did not match.

Thus, combining the two data sets was frequently a demanding task that required a number of steps, many of which entailed a method for estimating the appropriate traffic volume to assign to a given stretch of roadway. The resulting method allows the two separate spreadsheets to communicate with each other as if they were one spread sheet. This was accomplished with the Visual Basic programming code found in Microsoft Excel.

Sometimes, even though the milemarkers did not match, it was relatively straightforward to assign a traffic volume to a segment of roadway that had maintenance activity during 2003. For example, when the beginning (b1) and ending milepoints (e1) for the activities fell within the limits of the beginning (b2) and ending (e2) milepoints for the PM traffic volumes spreadsheet, the traffic volume between that b2 and e2 could be assigned directly to the distance between milepoints b1 and e1 on the activity spreadsheet. (Table 1.1 relates the mile points to the spreadsheets.)

Table 1.1: Four Variables from Crosstabulation of Two Data Sets and Milepoints

	Annual Activity costs2 (Activity codes and costs)	PM Sections (Roadway Volumes)
Beginning Milepoint	b1	b2
Ending Milepoint	e1	e2

Often it was necessary to weight the volumes before assigning them to a stretch of highway between b1 and e1. This would occur because the PM sections (the b2s and e2s) would have varying volumes along the b1 to e1 stretch of highway. In this situation, it was necessary to define beginning and ending points on the PM side. Once these were defined, the different volumes involved could be weighted according to their percentage in the overall length of the mileage section in question. The weighted volumes would then be totaled and assigned to the section b1 to e1. In this way, every section on the Annual activity costs spreadsheet had a corresponding measure of traffic volume.

A more complex situation arose when a b1 and e1 (activity codes) section is longer than the corresponding b2 and e2 (roadway volumes) section. In this case, either b1 or e1 or both would fall outside the known mileage parameters of b2 and e2. These situations are depicted below in examples 1, 2, and 3.

Table 1.2: Three Mileage Matching Situations

```
Ex. 1.  b1----------------------------------e1
                B2----------------------e2

Ex. 2.  b1-----------------------------e1

        b2----------------------e2

Ex. 3   b1-----------------------------e1

                b2----------------------e2
```

In this instance, it is vital to know exactly how far in distance the activity codes fall outside the known milepoint markers for the PM (traffic volume) data. This was done by establishing an ‘out of range’ scenario, when either b1 or e1 is more than 30% greater in absolute value than its corresponding b2 or e2. When the beginning b1 or endpoint e1 was more than 30% greater it was removed from the study. If it was less than 30%, then the volume on the segment b2 to e2 was assigned to activity codes segment b1, e1.

Last, all information deemed to be inaccurate or false was purged from the database. For example, a stopping point that was less than the starting point would be deemed false and, therefore, purged from the database. In certain rare instances, a roadway with a defined activity code on the AAC spreadsheet would not appear on the PM spreadsheet and thus no traffic volume could be associated with the roadway. All the data was examined and if any inconsistencies were found, engineering judgment was use to exclude the data.

Applying the 30% range rule, 140 lines of data were found to fall outside the range specified. Also 125 lines of data were deemed false. Fortunately, these were a negligible fraction of the entire data set. In fact, only 0.6 percent of the data was excluded. In other words, the results are based on 99.4 percent of the highway sections.

After the data was collected and analyzed for suitability, it was sorted and organized into meaningful results. All roadway activity codes were categorized into three main types: roadway type; traffic volume; and years since last resurfacing. With these variables, it was then possible to estimate the maintenance costs associated with specific types of highways. That is, for instance, it was possible to predict the number of dollars that will be spent on maintenance in the first 15 years after a resurfacing for a rural secondary road with traffic volume of 500 to 1,999. The next section contains the findings for four types of facilities.

1.3 Maintenance Costs for Four Types of Facilities

To construct an estimate of the total maintenance cost it was necessary to create two sets of cost estimates with two sets of tables: (1) those for a specified set of routine maintenance up to but not including all types of resurfacing treatments (presented in Chapter II); and (2) the costs as well as the frequency of the different types of resurfacing (presented in Chapter III). The estimate of the total cost of maintaining a type of facility over its first 15 years is a combination of the two costs after taking into account differences in traffic volumes.

The commonwealth maintains four types of roads: (1) interstates; (2) state primary and state secondary, many of which are arterials. (3) Other National Highway System (parkways); and (4) rural secondary roads. With the exception of interstates, which are heavily traveled, traffic volumes on these roads can vary greatly. We therefore assessed maintenance costs within five categories of traffic volumes: (1) 0-499 AADT; (2) 500-1,999 AADT; (3) 2000-4,999 AADT; (4) 5,000-11,999 AADT; and (5) 12,000 and up.

2.0 Age and Non-age Related Maintenance Costs

Our findings are presented in a set of tables for each of the four types of facilities: interstates, rural secondary, other NHS, and state primary and state secondary. There is also a composite table for all the roads. We divided the maintenance costs into two categories—age related costs associated with wear and tear over time on the facility (e.g., pot hole patching) and non age related costs (e.g., litter clean-up, pavement markings, mowing, etc.). (See Appendix A for the particular maintenance tasks in each category.)

The age related costs tend to grow as time passes, however, there are exceptions. Age-related costs are presented in four age categories: (1) 0 to 5 years; (2) 5-10 years; (3) 10-15 years; and (4) more than 15 years. The non-age related costs stay the same from year to year. These are then added together to obtain the total costs per mile. Each table also gives the total costs and the number of miles in each volume and age category. For example, in table 1, there are 265 miles of interstate in the first age category. Their total age related cost is $130,140.21 or $489.94 for age related costs per mile each year during the first five years.

2.1 Interstates

All the interstates report AADT over 12,000. So all the pertinent information is in Table 2.1. This data was based on data for the year 2003.

The total cost per mile for maintenance in each age category shows that costs increase from $4,436.67 per mile for roads in the age 0 to less than 5 category to $5052.01 per mile in the age 5-10 category. Costs then decline to $4,721.68 in the 10-15 category, before rising to $5376.06 in the over 15 category. This pattern of rising costs followed by declining costs is an exception to the general finding that costs increase with age and may be due to the low number of miles in the 10-15 age category—only 60.6

Table 2.1: Annual Age and Non-age Related Maintenance Expenditures on Interstates (Volume > 12,000AADT)

Years since resurfacing	Age related Costs	Length In Miles	Age related costs per mile	Non-age costs	Length in miles total	Non-age costs per mile	Total costs per mile
Less than 5	130,140	265.6	489.94	3,113,973	789	3946.74	4436.67
5-10	199,618	180.6	1105.27	3,113,973	789	3946.74	5052.01
10-15	46,989	60.6	774.94	3,113,973	789	3946.74	4721.68
15+	403,338	282.2	1429.33	3,113,973	789	3946.74	5376.06

2.2 State Primary and State Secondary

There are five traffic volume categories for the state primary and state secondary roads. The results, therefore, will be presented in five tables, beginning with the lowest AADT category, less than 500 vehicles per day. From table 2.2, we can see that the total maintenance costs are the lowest of the five AADT categories. But, as facilities age, there is an increase in age-related maintenance cost per mile from $342.84 to $516.42.

Table 2.2: Annual Age and Non-age Related Maintenance Expenditures on State Primary and State Secondary (Volume < 500)

Years since resurfacing	Age related Costs	Length In Miles	Age related costs per mile	Non-age costs	Length in miles total	Non-age costs per mile	Total costs per mile
Less than 5	178,718	521.3	342.84	3,526,623	1,996	1,766.85	2,109.68
5-10	229,371	497.4	461.14	3,526,623	1,996	1,766.85	2,227.98
10-15	248,958	615.6	404.43	3,526,623	1,996	1,766.85	2,171.27
15+	186,614	361.4	516.42	3,526,623	1,996	1,766.85	2,283,27

In the next volume category (500 to 1,999 AADT) there is a much more rapid growth in age-related maintenance cost from $375.97 to 1,354.45. This produces a higher overall maintenance cost per mile. From table 2.3 it is apparent that most of the increase in cost is due to rise in age-related costs. Since these costs arise from pavement repair, the added cost is probably a function of the greater traffic volume.

Table 2.3: Annual Age and Non-age Related Maintenance Expenditures on State Primary and State Secondary (Volume 500-1,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	487,888	1297.7	375.97	7,579,114	4223	1794.72	2170.69
5-10	660,003	1260.1	523.77	7,579,114	4223	1794.72	2318.49
10-15	681,749	945.3	721.19	7,579,114	4223	1794.72	2515.91
15+	975,677	720.4	1354.45	7,579,114	4223	1794.72	3149.17

Table 2.4 continues the trend of rising average maintenance costs. However, much of the rise is due to an increase in the non-age related costs per mile. In fact the age related

maintenance cost in the two highest age categories is lower than the comparable ones in the previous traffic volume category.

Table 2.4: Annual Age and Non-age Related Maintenance Expenditures on State Primary and State Secondary (Volume 2,000-4,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	468,293	1156.6	404.88	7,371,529	3,487	2114.00	2518.89
5-10	663,868	1114.5	595.69	7,371,529	3,487	2114.00	2709.69
10-15	509,635	795.2	640.91	7,371,529	3,487	2114.00	2754.91
15+	341,930	420.6	812.95	7,371,529	3,487	2114.00	2926.95

In the 5000 to 11,999 volume category, the non age related costs go down compared to the previous traffic volume category. However the age-related go up, which is to be expected with the rise in traffic volume. Overall, the total maintenance costs in the 5000 to 11,999 AADT category are similar to those in the 2,000 to 4,999 AADT category.

Table 2.5: Annual Age and Non-age Related Maintenance Expenditures on State Primary and State Secondary (Volume 5,000-11,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	212,363	506.4	571.57	3,699,371	2025	1826.85	2398.42
5-10	316,489	669.9	674.54	3,699,371	2025	1826.85	2501.39
10-15	164,805	531.8	898.98	3,699,371	2025	1826.85	2725.83
15+	210,189	317.0	1,663.02	3,699,371	2025	1826.85	3489.87

The trend of rising total cost per mile for maintenance continues in the last category—roads with traffic volumes over 12,000. But the cost increase is rather small. The total cost rises from $3,317.72 for the newest age category to $3,868.60 per mile for the oldest. It is noteworthy, however, that, as is the case with interstates, which have a rise in age related cost followed by a decline in the 10 to 15 year category, age-related costs rise and then fall in the 10 to 15 year age category.

Table 2.6: Annual Age and Non-age Related Maintenance Expenditures on State Primary and State Secondary (Volume 12,000 and up)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	212,362	216.8	979.44	1,781,769	762	2,338.28	3,317.72
5-10	316,488	258.5	1,224.29	1,781,769	762	2,338.28	3,562.57
10-15	164,805	149.4	1102.91	1,781,769	762	2,338.28	3,441.19
15+	210,188	137.4	1530.31	1,781,769	762	2,338.28	3,868.60

2.3 Other National Highway System

The roads classified as other national highway system have very few miles with less than 500 AADT. Therefore, we present the findings in four traffic volume categories beginning with volumes in the 500 to 1,999 range. There are only 46 miles in this category and the results do not follow the customary trend of maintenance costs rising with age. In all likelihood, the fluctuation in maintenance cost between age categories reflects unusual factors on the few miles in each age category and not the impact of age in the usual sense.

Table 2.7: Annual Age and Non-age Related Maintenance Expenditures on Other National Highway System (Volume 500-1,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	810	3.5	231.70	50750	46	1103.25	1334.95
5-10	110	5.7	19.19	50750	46	1103.25	1122.45
10-15	51,922	30.7	1690.28	50750	46	1103.25	2793.53
15+	3,946	6.3	623.46	50750	46	1103.25	1726.71

Table 2.8 and table 2.9 show the expected progression in costs over time. Indeed in table 8 the age related costs rise by a factor greater than ten from the first age category to the last. The majority of other national highway miles are in this and the next category.

Table 2.8: Annual Age and Non-age Related Maintenance Expenditures on Other National Highway System (Volume 2,000-4,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	13,649	60.1	227.25	341,241	227	1503.26	1730.51
5-10	26,955	53.0	508.58	341,241	227	1503.26	2011.85
10-15	78,209	97.0	806.01	341,241	227	1503.26	2309.27
15+	46,642	16.7	2,792.77	341,241	227	1503.26	4296.03

Table 2.8 and table 2.9 also illustrate another general trend in that costs go up as traffic volume goes up. The average total cost per mile in the AADT 2,000-4,999 is $2,231, while the average for AADT 5,000-11,999 is $2,911. Yet, the overall trend notwithstanding, there are occasional exceptions. For instance the average total cost per mile for maintenance for AADT 500-1,999 is slightly higher than the AADT 2,000-4,999, $2342 to $2,231. .

Table 2.9: Annual Age and Non-age Related Maintenance Expenditures on Other National Highway System (Volume 5,000-11,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	61,861	203.9	303.34	1,607,139	800	2008.92	2312.26
5-10	201,356	254.5	791.22	1,607,139	800	2008.92	2800.14
10-15	213,831	183.7	1,163.92	1,607,139	800	2008.92	3172.84
15+	243,975	158.3	1,541.07	1,607,139	800	2008.92	3550.00

In table 2.10, the progression of rising maintenance cost holds neither for the total cost nor the age related cost. This is similar to the costs associated with the other high volume roads with AADT's greater than 12,000.

Table 2.10: Annual Age and Non-age Related Maintenance Expenditures on Other National Highway System (Volume 12,000 and up)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	102,587	104.8	979.01	1,032,748	500	2065.50	3044.51
5-10	135,819	193.6	701.44	1,032,748	500	2065.50	2766.94
10-15	172,687	137.4	1257.07	1,032,748	500	2065.50	3322.57
15+	53,937	64.3	838.67	1,032,748	500	2065.50	2904.17

2.4 Rural Secondary

Many of the rural secondary roads are low volume roads. Tables 2.11 and 2.12 show that approximately 90 percent of the rural secondary miles are in the two lowest traffic volume categories—0 to 499 and 500 to1,999 AADT. On these roads there is less of a relationship between the age of the road and the dollars expended on maintenance activities for age related maintenance. However, the non-age related costs go up as traffic volume rises and therefore the total maintenance costs rise with an increase in AADT.

Table 2.11: Annual Age and Non-age Related Maintenance Expenditures on Rural Secondary Roads (Volume 0-499)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	461,581	1843.1	250.44	6,476,640	5575	1161.7	1412.17
5-10	711,202	1832.7	388.05	6,476,640	5575	1161.7	1549.78
10-15	694,383	1271.3	546.19	6,476,640	5575	1161.7	1707.92
15+	314,158	627.7	500.52	6,476,640	5575	1161.7	1662.25

Table 2.12: Annual Age and Non-age Related Maintenance Expenditures on Rural Secondary Roads (Volume 500-1,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	370,381	1377.7	268.85	7,170,140	4745	1511.09	1779.94
5-10	780,860	1767.5	441.78	7,170,140	4745	1511.09	1952.87
10-15	450,691	1074.3	419.53	7,170,140	4745	1511.09	1930.62
15+	298,585	525.9	567.73	7,170,140	4745	1511.09	2078.83

The number of rural roads with a traffic volume in the 2,000 to 4,999 range is only 792, a significant drop-off from the 4745 miles in the previous AADT category. The rise in maintenance costs is rather small, as non-age related costs go up $150 dollars and the age related remain stable.

Table 2.13: Annual Age and Non-age Related Maintenance Expenditures on Rural Secondary Roads (Volume 2,000-4,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	82,182	260.4	315.56	1,316,299	792	1661.99	1977.55
5-10	135,404	307.8	439.89	1,316,299	792	1661.99	2101.89
10-15	51,894	135.8	381.89	1,316,299	792	1661.99	2043.88
15+	32,426	88.1	368.06	1,316,299	792	1661.99	2030.06

There are only 173 miles of rural secondary roads in the traffic volume category of 5,000 to 11,999 AADT. One number in particular stands out—the age related costs per mile in the 5-10 age category is more than four times as great as the age related cost per mile in the other three age categories

Table 2.14: Annual Age and Non-age Related Maintenance Expenditures on Rural Secondary Roads (Volume 5,000-11,999)

Years since resurfacing	Age related Costs in $	Length In Miles	Age related costs per mile in $	Non-age costs in $	Length in miles total	Non-age costs per mile in $	Total costs per mile in $
Less than 5	21,886	42.5	515.42	295,083	173	1,705.68	2,221.10
5-10	108,400	47.2	2,296.70	295,083	173	1,705.68	4002.38
10-15	20,898	50.7	412.49	295,083	173	1,705.68	2118.17
15+	12,725	33.1	384.62	295,083	173	1,705.68	2090.30

The over 12,000 AADT traffic volume category is not presented because there are only 28.5 miles in the category and some of the data is incomplete.

2.5 Summary of Chapter 2

There are several patterns in the data, which become quite evident when the types of roads are combined into age and volume categories in Table 2.15. Within each traffic volume (AADT) category, age and volume interact in a smooth progression of rising maintenance costs. The non-age costs are significantly greater than the age-related costs per mile. Much of the cost increase appears to be attributable to a rise in non age costs as traffic volumes increase. However older facilities require more maintenance in each volume category.

There are some exceptions, however. In table 2.15, total costs rise as the years since the last resurfacing pass. This is true in each traffic volume category. While low volume roads tend to be less costly to maintain, there is one exception. Roads in the 5,000 to 11,999 AADT category differ little in cost from the roads in the 2,000 to 4,999 category with the additional exception of those that have not been resurfaced in more than 15 years. Clearly, the latter are more expensive to maintain.

Table 2.15: Annual per Mile Total Costs in Age/Traffic Volume Categories

Traffic volume	Years since resurfacing	Length	Total Costs per Mile
0-499	Less than 5	2364.5	1591.56
0-499	5 to less than 10	2330.2	1724.7
0-499	10 to less than 15	1886.9	1820.67
0-499	15 and up	991.5	1827.15
500-1,999	Less than 5	2678.8	1962.58
500-1,999	5 to less than 10	3033.4	2116.93
500-1,999	10 to less than 15	2050.3	2219.54
500-1,999	15 and up	1252.6	2262.33
2,000-4,999	Less than 5	14377.1	2385.70
2,000-4,999	5 to less than 10	1475.3	2563.83
2,000-4,999	10 to less than 15	1028.1	2626.04
2,000-4,999	15 and up	525.4	2805.07
5,000-11,999	Less than 5	752.8	2366.28
5,000-11,999	5 to less than 10	971.6	2654.44
5,000-11,999	10 to less than 15	766.2	2800.88
5,000-11,999	15 and up	508.4	3412.39
12,000 and up	Less than 5	587.2	3636.82
12,000 and up	5 to less than 10	643.3	3908.58
12,000 and up	10 to less than 15	361.0	4252.34
12,000 and up	15 and up	486.4	4251.50

3.0. Resurfacing Costs

After creating the cost estimates for age-related and non age-related routine maintenance, we needed to obtain the likely cost of resurfacing per lane mile. We took data from 2003. We also obtained the recommended frequency of resurfacing for the type of road and categories of traffic volume. The total cost of a type of facility over its first 15 years is a combination of the two costs after taking into account differences in traffic volumes. As a general rule, as the AADT goes up, the frequency of resurfacing also goes up.

Table 3.1 presents the costs for resurfacing (overlays) per lane mile in 2003. These costs were provided by the Transportation Cabinet officials who worked on this project—John Dade and Jon Wilcoxson. It shows that resurfacing costs vary by the roadway type and overlay type. At $67,414 a thin overlay on a rural secondary facility is the least costly. Work on the interstates is the most costly.

Table 3.1: Resurfacing Costs for Overlays per Lane Mile in 2003

Roadway Type	Overlay Type	Cost Per Mile
State Primary and State Secondary	Thin	$74,904
	Intermediate	$149,808
	Structural	Only 1% are structural
Rural Secondary	Thin	$67,414
	Intermediate	Twice the cost of thin but rarely done on rural secondary
Interstate	Thin	$400,00
	Intermediate	$550,000
	Structural	$3,500,000
	Repair and grind	$500,000
	Widening and reconstruction	$7,000,000
Other NHS	Thin	$400,000
	Intermediate	$550,000
	Structural	$2,500,000
	Repair and Grind	$500,000

John Dade provided the recommended frequency of resurfacing for each type of facility in each category of traffic volume. As table 3.2 indicates heavily traveled road ways must be repaired more often. As traffic volume increases the number of years between resurfacings goes down. The estimates of recommended intervals between resurfacings were provided by cabinet personnel. Thin overlays are applied as frequently as intermediate overlays. The decision to do an intermediate is contingent upon the condition of the road. It is noteworthy that many of the less traveled roads go more than 16 years between resurfacings.

Table 3.2: Recommended Frequency of Overlays in Years by Traffic Volume Categories

Facility type	Overlay type	0-499 AADT	500-1,999 AADT	2,000-4,999 AADT	5,000-11,999	12,000 and up
State Secondary and State Primary*	Thin	16-17 years	15-16 years	14-15 years	13-14 years	12-13 years
	Intermediate	16-17 years	16-17 years	14-15 years	13-14 years	12-13 years
Rural Secondary	Thin	16-17 years	16-17 years	14-15 years	13-14 years	12-13 years
	Intermediate					
Interstate					11-12	11-12
Other NHS					11-12	11-12

* 85 percent of overlays on state secondary and state primary are thin overlays and 15 percent are intermediate.

3.1 Is Kentucky Resurfacing in a Timely Manner?

Pavement preservation programs require resurfacings at appropriate intervals. Delays in the application of preventive maintenance can lead to larger outlays for maintenance as pavements age and distress sets in. We can use the data in this section to address the following question: *Is Kentucky performing overlays at the appropriate times given the type of facility and the traffic volume?* As the years pass since an overlay, the maintenance costs can be expected to rise. The results confirmed a pattern of rising costs. The data also showed that on a substantial percentage of the facilities there had not been a timely resurfacing (i.e., one in the time frame recommended). Table 3.3 shows the percent of roads in each facility type and volume category that have not been resurfaced in more than 15 years.

One number in particular is far out of line with the recommended timing for resurfacing—35.8 percent of interstates have not been resurfaced in over 15 years. It is recommended that interstates be resurfaced every 11 or 12 years. Therefore an even greater percentage appear to be over the recommended number of years for a resurfacing. (The data do not permit an exact estimate of the percent that have not been resurfaced in more than 12 years.) Many of the other types of roads appear to receive resurfacing at appropriate intervals, especially the more lightly traveled roads with traffic volumes under 5,000 AADT. Surprisingly, however, approximately 18 percent of road miles in the 5,000 to 11,999 AADT category have not been resurfaced in over 15 years. (See Table 3.3). Taken together the results suggest that a significant percentage of the commonwealth's busiest roads are not being resurfaced in a timely manner.

Table 3.3: Percent of Roads by Facility Type and Traffic Volume Category That Have Not Been Resurfaced in 15 Years

	Traffic Volume Categories				
Facility Type	<500	500-1,999	2,000-4,999	5,000-11,999	12,000 and Up
State Primary and State Secondary	18.1%	17.1%	12.1%	15.7%	18.0%
Rural Secondary	11.3%	11.1%	11.1%	19.1%	N/A
Interstate	N/A	N/A	N/A	N/A	35.8%
Other NHS	N/A	13.6%	7.4%	19.8%	12.9%

The absence of timely resurfacing can lead to increased maintenance costs if roads are allowed to deteriorate to the point of pavement distress--at which point a reconstruction is needed. We do not have the data to show that Kentucky is letting roads deteriorate to that extent. The evidence we have seems to be somewhat positive in that maintenance costs do not rise dramatically (with a few exceptions) as a facility type ages. There is the predictable increase over time, but it appears to be rather small—about $200 between most categories (See table 2.15.) For the most part the annual expenditure on maintenance for roads that have not been resurfaced in more than 15 years is only slightly greater than the annual expenditure for roads that have been resurfaced between 10 and 15 years ago. This implies little marked deterioration. However, there is one relatively large exception—on roads with traffic volumes of 5,000 to 11,999 there is a $611 increase in annual maintenance costs when more than 15 years have elapsed since the last resurfacing. This number in conjunction with the large number of roads in this traffic volume category that have not been resurfaced in more than 15 years suggests that structural distress may be occurring.

3.2 Estimated Total Maintenance Costs Including Resurfacing

We are now in a position to estimate the total maintenance cost per mile for the first fifteen years after a resurfacing for the four types of facilities and five levels of traffic volume. Table 3.4 provides an estimate of the *total maintenance cost per mile* for the first 15 years after a facility has been resurfaced. This total includes the combined age-related and non age-related maintenance costs, and the costs for resurfacing. The likely year for a resurfacing is included. We took the first year as indicated in table 3.2.

In addition, we allocated a proportional cost to the years in which a resurfacing did not occur. Thus, if a type of facility and associated traffic volume was recommended to be resurfaced in the 12th year we allocated 15/12 of the cost of the resurfacing to the total 15 year cost. Conversely, if the resurfacing was to occur in the 16th year, we allocated 15/16 of the cost of the resurfacing for the road in question to the total cost for 15 years.

The table provides estimates by type of facility and traffic volume. It illustrates that costs rise significantly as the size of the facility and the volume increase. The resurfacings are thin or intermediate overlays. The estimate for interstates is based on the cost of an intermediate overlay. However, an interstate may require a restructuring, which is far more expensive than a thin or intermediate overlay.

The costs of overlays as well as age and non age-related maintenance costs rise as traffic volumes increase. For instance, on state primary and state secondary roads the cost of resurfacing is $80,756 for a road with an AADT between 0 and 499, while the resurfacing cost rises to $107,675 for a state primary and state secondary with AADT over 12,000 vehicles. Similarly, the age and non age-related costs rise from $80,756 to $107,675 from the first to the last AADT category. A similar pattern of rising costs holds for rural secondary roads and other NHS, but not for interstates. All the interstates have traffic volumes above 12,000 AADT.

Table 3.4: Total Maintenance and Overlay Cost per Mile over First 15 Years after Resurfacing for Type of Facility and Traffic Volume

Traffic Volume Categories

Facility Type		0-499	500-1,999	2,000-4,999	5,000-11,999	12,000 and Up
State Secondary and State Primary*	Overlay in Year	16	15	14	13	12
	Age and Non-age Costs	$32,545	$35,025	$39,920	$38,125	$51,610
	Resurfacing **	$80,756	$86,140	$92,293	$99,392	$107,675
	Total	$113,301	$121,165	$139,312	$137,517	$159,285
Rural Secondary	Overlay in Year	16	16	14	13	Not Apply
	Age and Non-age Costs	$23,349	$28,318	$30,620	$41,709	N/A
	Resurfacing	$63,201	$63,201	$72,229	$77,785	
	Total	$86,550	$91,519	$102,849	$119,494	
Interstates	Overlay in Year	Not Apply	N/A	N/A	N/A	11
	Age and Non-age Costs	N/A	N/A	N/A	N/A	$74,623
	Resurfacing					*** $750,000
	Total					$824,623
Other NHS	Overlay in year	N/A	11	11	11	11
	Age and Non-age Costs	N/A	$26,260	$30,260	$41,425	$45,675
	Resurfacing		**** $545,455	**** $545,455	$545,455	*** $750,000
	Total		$571,715	$575,715	$795,675	$795,675

Table 3.4 Continued:

***For state secondary and state primary, the cost of resurfacing was estimated by assuming that 85 percent were thin overlays at the cost of $74,904 per mile and 15 percent were intermediate overlays at a cost of $149,808.**

****Overlay cost is adjusted based on cost spread over 15 years (e.g., for state primary and state secondary , the total 15 year cost for resurfacing the volume of 12,000 AADT is $86,140 plus the cost for three years $21,535. The latter is one-fourth the cost at year 12.)**

*****Assuming an intermediate overlay**

******Assuming a thin overlay**

3.3 Conclusion

The results confirm that maintenance costs tend to increase as pavement ages. They also increase as traffic volumes go up. For the most part the increase in cost is not great from one age category to the next.

However, the frequency at which the more heavily traveled roads are resurfaced may not be timely, especially in the 5,000 to 11,999 AADT category for all types of roads and on the interstates. From data analyzed in this report, it appears to be the case that the time interval between resurfacings on the more heavily traveled roads needs to be shortened. Clearly, the percentage of roads in these categories that have not been resurfaced in more than 15 years seems to be far too great.

Kentucky could move to a system of more frequent resurfacings if it established a schedule for resurfacing. Some states have done this and they will be discussed in part II.

Part 2: Improving Long Term Maintenance Planning with Maintenance Schedules

4.0 Background Information on Pavement Maintenance

4.1 Introduction

Pavement Preventive Maintenance (PPM) refers to work performed on a structurally sound pavement to preserve the pavement, retard future deterioration, and/or maintain or improve the functional condition of the road. The main objective of pavement preventive maintenance is to prolong the life of the pavement—a goal primarily accomplished by reducing the amount of water infiltrating the pavement structure. The various preventive maintenance treatments are designed to slow the rate of deterioration, or correct surface deficiencies such as roughness and non-load related distress. Thus, preventive maintenance can reduce the incidence of potholes and ward off the onset of pavement distress

Part II of this report will recommend the development of a routine pavement preventive maintenance system with three elements: (1) timely resurfacing, (2) scheduled inspections of drainage and ditching, and (3) crack sealing. Its primary thesis is that Kentucky can profit from developing programs to perform all three at more regular intervals. This will entail the adoption of schedules for maintenance activities as well as the dedication of more resources to preventive practices. As will be seen in the chapter on the activities of the 50 states, Kentucky appears to devote substantially fewer resources to the three types of routine pavement preventive maintenance.

Before proposing some modifications in Kentucky's current approach to long term pavement maintenance, we present some background information on preventive maintenance. We then provide brief accounts of the programs found in several states. Presumably, Kentucky can use them as models for its own program for preventive maintenance. In doing so, Kentucky can build on a recognized strength (as stated in the 2004 report by the Dye Management Group, Inc.)—its system for collecting highway data and prioritizing maintenance needs. Dye management wrote that the current system for "identifying and prioritizing maintenance and preservation projects is well-documented and technically driven and follows standards of best practice. (Dye Report, p30)

4.2 Some Basic Facts about Pavement Management over the Pavement Lifecycle

Weather, water and the freeze-thaw cycle are the most damaging elements to any pavement. When water seeps into pavement cracks, it starts a process of erosion that eventually degrades the foundation or base upon which the pavement rests. With no base to support it, the pounding traffic will cause the pavement to fail and form a pothole. This sequence of events is enhanced drastically by the freeze thaw cycle.

While the useful life of a particular stretch of pavement is not precisely predictable, there are three well-established facts concerning pavement deterioration.

1. Pavements deteriorate very slowly during the first few years and very rapidly when they are aged. This pattern occurs for all types of paving materials.
2. Poorly timed or inappropriate maintenance decisions can greatly increase overall costs.
3. Successive years of collecting pavement condition data show that it is far more economical to preserve roads than to delay repairs to the point that reconstruction of roads is necessary. As traffic levels increase the cost of delaying repair work increase greatly. The key policy recommendation is this: perform preventive maintenance before reconstruction is needed. <u>Therefore, the traditional practice of repairing the worst roads first is a very expensive way to operate a highway system</u>.

In all, there are at least five established benefits from a program for preventive maintenance related to the pavement life cycle (Zimmerman and Peshkin 2003; Peshkin et al 1999):

- Reduced overall costs for maintaining the road network.
- Improved average pavement conditions over time
- Higher customer satisfaction with the road network
- The ability to make better, more informed decisions on an objective basis about maintenance
- Increased roadway safety

There is another benefit associated with preventive maintenance. Under the General Accounting Standards Board (GASB) statement 34, government agencies can increase the value of the assets on their balance sheets by investing in preventive maintenance. Two accounting methods are allowable: a depreciation approach and a modified approach. The latter allows an agency to credit rehabilitative and maintenance activities to the value of infrastructure (Bittner and Rosen 2004).

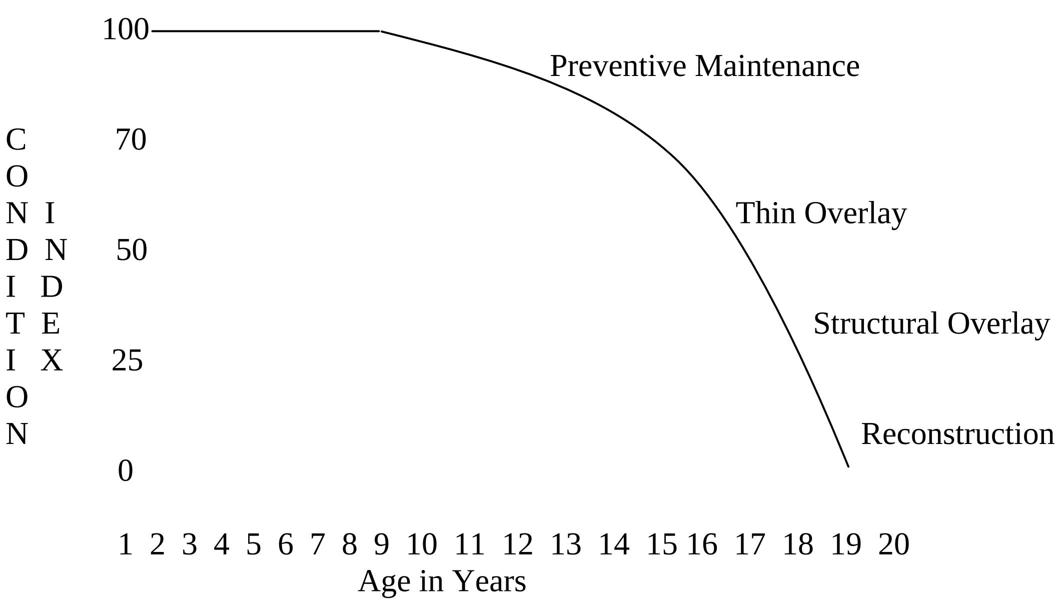
4.3 Estimates of the Appropriate Timing for Preventive Maintenance

The precise time to apply preventive maintenance depends on the condition of the pavement, the expected traffic volume, and the weather. At this time, David Peshkin and his associates are conducting a research project (NCHRP 14-14) to establish the best timing for preventive treatments under various weather and traffic volume conditions. Unfortunately, as he reported at TRB in January 2004, the project is years away from completion.

Given the lack of research on the best time to schedule maintenance, the states must rely on their own experience as well as the research that suggests relatively broad ranges within which to apply particular preventive treatments. These ranges are based on some well-established facts about the pavement lifecycle—namely, that during the first 75 percent of the design life, 40 percent of serviceability is consumed. During the next 17 percent another 40 percent is consumed. This indicates accelerating deterioration and the utility of preventive maintenance at about 75 percent of design life (Birdsall 1995). Research on the decline in the present serviceability index is in line with findings on the pavement lifecycle. The average age at which overlaid interstates and other multilane facilities reach terminal PSI (present serviceability index) or at which the pavement is again overlaid is about 14 years. But a resurfacing at year 12 will save money as renovation at year 12 is one-fourth the cost of resurfacing at year 14(Crawford 1989). The dollar difference for maintenance before and after pavement failure is known to be enormous. Waiting two or three years until failure can result in expenditures four to five times greater.

There are various ways to approach the problem of timing for treatments. We reproduce one here from a study by Zimmerman and Peshkin (2003). It is from the Metropolitan Transportation Commission in the San Francisco Bay area. It bases its approach on a standard deterioration curve, which sets treatment trigger levels for types of treatments. Thus, the trigger value between preventive maintenance and light to moderate rehabilitation occurs at a PCI of 70; the trigger value between light to moderate rehabilitation and heavy rehabilitation occurs at a PCI of 50; and the trigger value between heavy rehabilitation and reconstruction occurs at a PCI of 25.

Table 4:1 Sample Decision Rules about Timing from Peskin and Zimmerman



In sum, the goal is to find the right time to perform the preventive maintenance. Premature maintenance has high annual cost, while infrequent maintenance has low annual cost. But the longer the maintenance is delayed, the more frequent the need for the more expensive rehabilitation and rebuilding of the road. The two costs must be taken into account, such that the combined cost is minimized. One way to time maintenance is to associate a particular score range on a pavement condition index with preventive treatment. For example, if the PCI on a portion of roadway is less than 75 but greater than 60, a preventive treatment is appropriate. If less than 60 a corrective treatment is needed.

But reliance on past experience may be a better system. Kentucky can build its system on its history of highway maintenance. It is well-known that different types of facilities need resurfacing at different intervals and interstates needed a 2 and ½ inch overlay. In Kentucky, it appears that interstates due to their heavy truck traffic need resurfacing at 10-11 years, parkways at 12 years, state primary roads at 13-14 years, and rural secondary roads at 19 to 20. The differences are due to the customary volume and type of traffic. In fact, the roads frequented by coal haulers may need resurfacing at 4 years, which currently they receive at 9 years. (Timing estimates from an interview with John Daid)

4.4 Research Estimates of Savings Derived from Preventive Maintenance

The cost effectiveness of preventive maintenance programs varies from state to state. This is a function of differences in the programs as well as differences in climate and traffic patterns. *But all studies in all states find that preventive maintenance saves money and improves the quality of pavements.* According to FHWA-IF-02-002, a dollar spent for preventive maintenance prior to the point where the pavement condition begins its accelerated decline ultimately saves 4 to 5 dollars a few years later in reconstruction costs. That is, preventive maintenance averts the precipitous plunge in pavement condition. (Foundation for Pavement Preservation 2001). The following estimates of cost savings illustrate the long range returns from a program that invests dollars in preventive measures.

California estimates that the typical benefit-cost ratio of applying more preventive maintenance to reduce the need for rehabilitation and major maintenance is 6:1. They also assert that properly timed corrective treatments can produce an overall benefit-cost ratio of 10:1 (Foundation for Pavement Preservation 2001).

Michigan DOT estimates that had it not implemented its preventive maintenance strategy it would have spent $700 million more on expensive rehabilitation and reconstruction projects to bring pavements up to their current condition. They estimate that preventive maintenance is 6 times as cost-effective as reconstruction (Foundation for Pavement Preservation 2001).
Michigan also estimates that a non-structural bituminous overlay extends the life of a pavement by 5-10 years.

A Utah study found that each dollar spent on 2-in. maintenance overlays before surface failure saved $3.00 on heavy overlays after failure occurs (Peterson 1977).

Alberta Province. Falls and Tighe (2004) report that the province of Alberta Canada generated substantial savings from its preventive maintenance program. Its pavement quality increased from a pavement quality index score (PQI) of 6.3 in 1986 to 6.8 in 1990. Spending was stable at $40 million per year. A benefit cost analysis of the pavement management system produced an estimated total savings (reduced user costs added to increase in asset value) of $1.042 billion dollars. In other words, for the same investment, Alberta generated more than a billion dollars in value to the taxpayers and motorists of the province.

Arizona. In a study of the benefits of pavement management in Arizona, Hudson, Hudson, Visser and Anderson (2001) estimated an increase in the life of the pavement of 13.5 percent.

In sum, although estimates vary, the payoff from preventive maintenance is always substantial. But much work remains to be done in modeling the impact of maintenance expenditures on long term pavement performance Indeed, the connection between spending and performance is not yet understood. Thus, with data from Alberta, Falls and Tighe (2004) found they could explain only ten percent of the variation in maintenance costs with a measure of pavement condition. One implication of this and other research is that there are no hard and fast rules for the scheduling of specific maintenance treatments. A variety of local conditions determine the best time to resurface a pavement.

4.5 The Contribution of Effective Drainage Systems and Programs for Crack Sealing to Pavement Preservation

Water is the enemy of pavement integrity and durability. More often than not, lack of adequate drainage is the primary cause of distress in many pavements. Excess moisture in the base and subgrade reduces the amount of stress the subgrade can tolerate without developing strain. Then, strain in the subgrade transfers the stress into the upper pavement layers, which induces deformation and ultimately distress. In this way, trapped moisture in rigid pavement systems can lead to pumping, faulting, cracking and joint failure. Therefore resources must be devoted to prevent water from penetrating and damaging the pavement.

Drainage systems are multifaceted containing surface assets and subsurface assets. The *surface* assets are: culverts, catch basins, storm drains, inlets, ditches, storm water management ponds, and underground water storage structures. The *subsurface* assets are edge drains, underdrains, and mainline pipes, outlets, crosspipes, and laterals, headwalls; rodent screens, and outlet markets (Mallela et al 2001).

The Dye Management Group completed a report on the Kentucky Transportation Cabinet's operations in 2004 (Dye Report 2004). It concluded that the Cabinet needs to improve its drainage and ditch cleaning efforts. Several approaches are available to reduce water damage to pavements. For example, joint and crack sealing can be done to reduce the infiltration of water. Another is ditch-cleaning to prevent standing water on the road.

Since water can find its way under pavements under the best of circumstance, roads must have working systems for draining water away. That is, rapid removal of subsurface water can protect roads from failure. Longitudinal edge drains, for instance, can effectively prevent damage by removing water; but, of course, they must be open and functioning as designed.

In all, there are four means of draining the pavement subsurface—pipe underdrains, prefabricated edge drains, aggregate drains and free draining base systems. Strategic placement of underdrains and edgedrains can be used to capture the water quickly and outlet it. The use of free draining base is promoted to capture all pavement drainage.

To be effective however, these drainage systems require regular maintenance to ensure that they are kept open (i.e., so the pavement structure will drain.) *Years of research have shown that edge drains must be regularly inspected and maintained or they will fail causing the road in turn to fail prematurely*. *Free-draining bases must be maintained properly. Maintenance consists mainly of making sure the outlets are functioning properly and are not clogged with debris or blocked in some way.*

To be sure blockages will occur over time. Quite frequently, problems develop at pipe outlets: rodent nests, mowing clippings, sediment collecting on rodent screens at head walls, and vegetative growth among others. All can block the flow of water and must be attended to if the drainage system is to work as designed. In addition, silty material can make its way into longitudinal edge drains or lateral outlets, which material needs to be flushed periodically (Kuennen 2003).

Surface runoff flowing into the base and subgrade at the edge of pavement is often a problem where cross slopes and shoulder maintenance are inadequate. Improperly placed shoulder subdrains may feed water into the pavement structure rather than remove it. One of the major complaints about shoulder drains is that lateral drain pipes are frequently blocked, making the drain inoperable. At all times, pipe capacity and gradient must be adequate to prevent water backup into subdrains and road structure (Birgisson and Bryan 2003).

4.6 The Role of Regular Inspections

The only way to insure that drains are working properly is to establish a system of regular inspections. AASHTO's Highway Drainage Guidelines are clear on this point.

“One of the most important aspects of any maintenance/inspection program is a schedule…Each type or group of facilities must have a calendar-specific timetable of inspection or maintenance activities similar to that which exists for landscaping and mowing of medians and shoulders…Once the timetable for inspections is established, each type of facility should be reviewed to create a checklist of items which must be inspected and evaluated. (AASHTO’S Highway Drainage Guidelines, Vol. XII)

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Summing Up: Advantages of Timely Pavement Preventive Maintenance

All researchers agree that starting treatments for pavement preservation early can have a domino effect of benefits, which can lead to infrastructure optimization. Overall, preventive maintenance should minimize pavement life cycle costs, reduce delays and inconveniences, and maximize user comfort and safety. Among the many advantages:

1. Cost savings
2. Fewer major rehabilitation projects with attendant traffic delays
3. Smoother, improved ride (public satisfaction)
4. Fewer auto repair expenses (i.e., lower user costs)
5. Improved quality of overall road network
6. Fewer potholes and less money spent on pothole repair.
7. Extended performance cycle of individual pavements and network
8. Increased safety from better surfaces and fewer construction projects

Last, preventive maintenance can save money over the long run by reducing the backlog of roads needing corrective maintenance (Polhill 1987). In short, the pavement may survive longer without a major rehabilitation or reconstruction, thus reducing the life cycle cost. And the service life of the pavement may be extended. Moreover, since most pavement preservation techniques can be accomplished in a short time period, there may be less interruption to traffic due to the postponing of the more time-consuming rehabilitation and reconstruction.

5.0 Two Themes from a Review of Literature on Preventive Maintenance Practices in the States

This section of the report summarizes the results of our review of articles and documents describing the preventive maintenance practices currently used by the states. We found two recurring themes in the studies and reports on the practices of the states. The first theme reflects the popularity of two types of preventive measures: thin overlays and crack sealing. The second theme concerns the adoption of maintenance schedules for overlays, crack sealings, drain cleaning and other preventive measures. In the conclusion we will recommend that Kentucky devise a preventive maintenance policy that incorporates both themes. We turn now to the first of these.

5.1 Theme One: Thin Overlays and Crack Sealing

The popularity of these two preventive maintenance measures is evident in a survey of DOTs. In 1999, AASHTO reported the results of a survey of the 50 states on the nature of their pavement preventive maintenance programs and practices. Forty state agencies answered their survey, which obtained, among other information, the number of agencies using specific preventive maintenance treatments on flexible and composite pavements. The findings are in Table 5.1. The data is from AASHTO's website under national studies—Pavement Preservation Survey (http://leadstates.tamu.edu/pp/survey/survey_report.pdf). It obtained several findings of relevance to this report. The states vary widely in their commitment to pavement preservation, with some states being far more committed to preservation practices than others. But clearly, the vast majority of the states have adopted thin overlays and various types of crack sealing.

As can been seen in Table 5.1, most of the responding states use thin overlays in their preventive maintenance programs. But most also use many different treatments for pavement cracking in their preservation program. In fact, 30 DOTs reported using bituminous crack treatments. In sum, it appears that overlays and crack treatments are the foremost preservation treatments for flexible and composite pavements.

Table 5.1: Number of Agencies Using Preventive Maintenance Treatments for Flexible and Composite Pavements

Agencies	**Treatment**
38	Mill and Overlay
37	Bituninous (asphalt) overlay (40mm or 1.5 inch
34	Coldmilling and Bituminous Overlay (<40mm or 1.5 inch
33	Single Course Chip Seal
30	Bituminous Crack treatment (saw and seal or route and seal)
28	Single course micro-surfacing
25	Profile milling
24	Bituminous shoulder work (remove and replace shoulder)
21	Fog seal
21	Multiple course micro-surfacing
21	Cold in-place recycling
19	Overband crack fill
18	Multiple course chip seal
14	Ultra-thin bituminous overlay (< 20 mm and ¾ inch)
14	Hot in-place bituminous recycling (<40 mm or 1.5 inch)
14	Slurry seal
12	Fog seal
11	Paver placed surface seal (NovaChip)
7	Scrub seal
2	Cape seal
1	White topping
1	Crack sealing without sawing or routing
1	Full-depth cold recycling

Kentucky was one of the states that responded to the 1999 survey. Of the 40 states that responded, Kentucky was 39th in the number of pavement preservation activities for flexible and composite pavement that it reported using. Michigan reported the most, 16 activities, Hawaii the least, 3 activities. Kentucky reported 4 activities. The mean number of activities was 10.2.

Kentucky was not so far below the mean for concrete pavement preservation activities. Kentucky reported 6 activities. The mean was 6.65.

In short, the ASSHTO survey suggests that Kentucky in 1999 was below the national average in its use of pavement preservation methods.

5.2 Theme Two: The Adoption of Schedules for Routine Pavement Preservation

We obtained information on the pavement preservation programs being adopted in several of the states. As a reading of the descriptions of these programs illustrates, these states are institutionalizing schedules for routine maintenance. That is, in an effort to improve the quality of their roadways they are increasing the frequency of various treatments in a systematic manner. Such scheduling of maintenance signals the end of a worst-first approach to maintenance. We offer some brief descriptions of the preventive maintenance systems being adopted in several of the states.

California

California has about 49,000 lane miles in its state highway system. It expects to have corrective needs for 5,500 per year. According to the CALTRANS 1997 State of the Pavement Report, California plans to treat each of its 43,500 candidate lane miles for preventive maintenance an average of once every 5 years. So, about 8,700 lane miles should receive preventive maintenance each year.

California reports that rehabilitation costs $150,000 to $250,000 per lane mile. Rehabilitated roads last 10 years. In comparison, preventive maintenance procedures cost from $2,500 to $30,000 per lane mile. Preventive maintenance occurs every 5 years, which brings the ten year cost to $5,000 to $60,000, far less than the cost of rehabilitation. California estimates that implementation of the preventive maintenance program will reduce the number of lane miles in need of the more expensive corrective treatments--from 14,000 lane miles to 5,500.

In sum, Caltrans concludes that low-cost surface treatments applied in a timely manner can extend the life of the pavement four or five years. Caltrans also concluded that a properly timed surface sealing at $5,000/lane mile would significantly delay the necessity of a $100,000/lane mile pavement rehabilitation project. (O'Brien 1989).

Michigan

Michigan DOT installed its preventive maintenance strategy in 1992 as a way to keep its 9,580 miles of state highways in the best shape possible despite declining financial resources. Its preventive maintenance schedule is designed to make yearly funding needs more predictable. The DOT classifies pavements in one of six categories, ranging from roads in need of almost immediate rehabilitation to roads expected to last for another 2 or 3 decades. Michigan expects to even out the number or roads in each category which will prevent huge surges in the number of roads in need of costly rehabilitation or reconstruction in any given year.

From 1992 to 1997, preventive maintenance treatments have been applied to about 2,650 miles of asphalt and Portland concrete cement pavements at a cost of $80 million. Michigan DOT says that applying maintenance treatments to pavements with light to moderate distress provides a substantial improvement in pavement life. They estimate that pavement management adds 5-10 years to the life of a road. It is estimated that had they not applied the treatments MDOT would have needed to spend $700 million in 1997 on rehabilitation and reconstruction projects to bring pavements up to their current condition—more than eight times as much money as had been spent on preventive maintenance treatments.

Their approach to scheduling preventive maintenance is reflected in this statement: “Appropriate preventive maintenance activities should employ life cycle scheduling until the repair costs exceed the benefits derived from such activities or until the pavement structure needs to be reconstructed.” “Recommended pavement condition levels are listed for each preventive maintenance treatment. These condition levels have been identified to aid the engineer in determining for what existing pavement condition a specific preventive maintenance treatment is cost effective.” Pavement condition data include measures of: RSL (remaining service life); Distress Index (DI); Ride Quality Index (RQI) and rut depth.

(From www.tfhrc.gov//focus/achives/Fcs997/97mich.htm) and Galehouse 2002)

Georgia

Georgia spends $70 to 80 million a year on preventive maintenance. Georgia DOT treats about 10 percent of its pavements each year using a variety of preventive maintenance treatments, including thin asphalt overlays. The effect of scheduling 10 percent of roads each year for such treatments has been a dramatic rise in pavement quality. Between 1972 and 1997, the smoothness of asphalt pavements in Georgia improved by more than 300 percent. This means that asphalt pavements that are about to be resurfaced today are more than four times smoother on average than similar pavements scheduled for resurfacing more than 2 decades ago. (From “Insights into pavement preservation.” USDOT 2000)

Iowa

Iowa operates on the premise that timely preventive maintenance will provide the most benefit. They use the following set of decisions rules in their approach to scheduling preventive maintenance..

- The two year old ACC pavements (the majority of which are overlays) will exhibit reflective cracking and should be routed and sealed.

- The seven year old ACC pavements have reached the point at which a thin maintenance surface should be applied.
- The seven year old PCC pavements should be resealed

Ohio

Ohio has a well-developed approach to scheduling pavement preservation and maintenance activities. It builds its pavement management system on three basic principles: (1) a major rehabilitation should be delayed as long as possible in order to get the remaining life out of an existing pavement; (2) a preventive maintenance application must be done when the pavement is in good structural condition: and (3) the scheduling of treatments should be based on data, which are used to construct ODOT's regression model of pavement deterioration.

Ohio's Maintenance Schedule. .Ohio has developed the following maintenance schedules for types of pavements. It relates type of maintenance treatment to the age of the pavement. Since many factors can impact the wear and tear on a pavement it gives age ranges.

a. Flexible Pavement (new pavement on a new alignment and complete replacement of existing pavement)

1. Year 10-15; Thin overlay, 1.25"-3", with or without milling

2. Year 18-25; Thick overlay, 3"-7", with milling, possibly pavement repairs

3. Year 28-32; Thin overlay or micro-surfacing or crack sealing.

b. Rigid Pavement

1. Year 18-25; 2%-10% full-depth rigid repairs, 1%-5% partial-depth bonded repairs, diamond grinding 3" – 6" overlay, sawing and sealing.

2. Year 28-32: 1-2% full and/or partial depth repairs, 1.25- 2" second overlay with or without milling, 3" – 4" first overlay, sawing and sealing, micro-surfacing, crack sealing, diamond grinding.

c. Composite Pavement

Composite pavement is a hybrid of rigid and flexible pavement and requires the maintenance actions of both. It is generally expected to receive full-depth rigid repairs, milling and an overlay every 8-12 years.

New York State

New York State has three major maintenance treatments in its program: crack sealing, thin overlays, and drainage system cleaning. It has developed the following schedule for these treatments to be applied.

Crack Sealing. Cracks are sealed early in the pavement's life, as early as 2 years after the pavement is placed. The new crack sealant configuration could stay in place for 5 to 6 years. "Joints and cracks in rigid pavements in appropriate condition [are] scheduled to be treated on an 8-year cycle. Asphalt concrete shoulders next to rigid pavements in good to excellent condition [are] to be chip sealed every 4 years."

Thin Overlays. "Flexible and overlaid pavements [are] to receive a single-course overlay every 12 years, with crack sealing on a 4-year cycle after the initial overlay.

Drainage Systems."Closed drainage systems [are] to be cleaned in a 10-year cycle, and open drainage systems were to be cleaned on a 12 year cycle.

Conclusion

The states employ different strategies to preserve their pavements. But two themes are evident: (1) Most states employ a combination of crack sealing and thin overlays and (2) many are establishing schedules to ensure timely maintenance.

6.0 Three Assessments of Kentucky's Maintenance Situation

There are three recent assessments of Kentucky highway maintenance that looked at pavement related issues. The first is the Maintenance Rating Program Report. The other two are reports prepared by the Transportation Cabinet. They differ in their approach in various respects, but all suggest that Kentucky can profit substantially from implementing a system of regularly scheduled preventive maintenance for pavement preservation. Thus, Kentucky's approach to pavement management can be improved by devoting more resources to pavement preventive maintenance

6.1 Maintenance Rating Program Report

In the Maintenance Rating Program (MRP), each aspect of infrastructure maintenance is given a rating from 0 to 100. The numerical scores are converted into letter grades—A, B, C, D, and F, which correspond to levels of service. For example, the rideability score is based on the rideability index. A score of 65 would indicate a level of service of D. In all, twenty-five features received numerical and letter grades. The numerical scores for each of the 25 were weighted by multiplying the numerical score by a weight factor, which was the feature's percent of the total score. (The weight factor for rideability is 10 percent.) The weighted scores are then added to produce the statewide total score. The largest weight factor was ten percent for the rideability score. The weight factors for the other features varied from 2 to 5 percent.

The statewide total score was 75.9, which is a C level of service. However, there was great variation among the 25 features, with four features rated A level of service; 6 rated B; 8 rated C; 4 rated D; and 3 rated F. Those rated A had a total weight factor percent of 14 percent; those rated B had a total of 22 percent; those rated C a total of 35 percent; those rated D a total of 17 percent; and those rated F had a total of 12 percent.

The features graded A for level of service (numerical score of 90 and above) were: segments without a reported visual obstruction; segments with right-of-way fencing reported to be fully functional; segments with barrier wall reported to be fully functional; and segments with no reported rutting of 0.375 inch or greater.

Those graded B for level of service (numerical score 80 to 89.9) were: segments with appearance rated "acceptable" or better; segments with guardrail reported to have no damage; segments with attenuator or rail end reported to have no damage; segments with average white reflectivity measurement greater than or equal to 125; segments with average yellow reflectivity measurement greater than or equal to 80; and guide sign faces meeting specifications.

Those graded C for level of service (numerical score 71 to 79.9) were: rideability score (based on rideability index); bridges with no end bumper greater than 1 inch; segments with guardrail reported to be fully within height specifications; segments with no reported high shoulder; drains reported to be at least 25 percent open; segments with curbs and/or gutters reported to be unblocked; guide sign assemblies meeting specifications; and warning and regulatory sign faces meeting specifications.

Those graded D for level of service (numerical score 60 to 69.9) were: segments without a reported vertical clearance obstruction less than 15 feet; segments with no reported pavement drop-off greater than 1.5 inches; segments with no reported shoulder drop-off greater than 3.0 inches; and warning and regulatory signs meeting specifications. The total weight factor for these four features was 17 percent.

Those graded F for level-of-service were: average number of pavement potholes per mile (6” X 6” X 1” or larger) (score of 54.3); average number of shoulder potholes per mile (6” X 6” X 1” or greater) (score of 42.7); segments with ditches reported to be unblocked (score of 52.6). The total weight factor for these three was 12 percent.

There are a variety of ways to raise the statewide total score to a B level of service (assuming that 80 points is the threshold for a B level of service). For example, it could be done by moving the scores of the three features currently providing an F level of service to a weighted average score of 85. Currently, their weighted average is 50.83. Or it could be done by raising the features scoring at the D and F level of service to an average weighted score of 75.49 from their current weighted average of 68.77.

<u>The Potential Contribution of Regularly Scheduled Pavement Preventive Maintenance to Improving LOS</u>

A schedule for pavement preventive maintenance, including more aggressive cleaning of ditches, could improve all three of the features graded F, as well as improving the rideability, which is graded C. Regular application of pavement preventive maintenance treatments(thin overlays and crack sealing) will reduce the number of potholes and improve rideability scores. It may be the case that regular pavement preventive maintenance alone would move the entire system to a B level of service.

6.2 Two State Reports on Condition of Pavements on Kentucky Highways

A. “Ride Quality and Condition of Pavements on MP System roads (State primary, state secondary, and supplemental) and on Rural Secondary Roads.”

This report looks at three types of surfaces: AC (asphalt cement); PCC (Concrete); and AC/PCC (asphalt overlay of concrete). It includes information on annual resurfacing, resurfacing needs and funding, and rideability, general condition and other pertinent information for each pavement section.

The report notes that there is a good correlation between rideability, or roughness, of pavements and their general condition.

The pavement condition index (PCI) was devised to characterize the general condition of pavements based solely on the rideability index (RI). The PCI is computed as follows:
Measured RI - Critical RI = PCI

The report evaluates the percent of roads in the following categories--poor, fair, and good--for MP and RS roads from 1988 to 2001—14 years in all. In 2001, there were 12,163 miles in the RS system. That year 50 percent were in good condition. In 2001, there were 14,026 miles in the MP system. That year 52 percent were in good condition.

The authors conclude: “Based on past experience in Kentucky, most roadways will need resurfacing in fifteen years or less due to cracking, base failure, rutting, utility cuts, pothole patching and other defects. Even roads with light traffic will need resurfacing due to the effects of weathering and oxidation of the asphalt in the pavement. If resurfacing is delayed extensive patching and sealing are required and the ultimate costs to the road users will increase.”

The authors propose a balanced funding program for resurfacing MP system roads with a funding level of $66 million. They also offer a program for rehabilitation treatments other than thin overlay (resurfacing). These are treatments mostly of PCC pavements—repairs and diamond grinding, thick overlays or pavement replacements. They estimate $12 million per year for this rehabilitation.

Overall, they estimate a need to spend $35 million per year on the RS system for rehabilitation.

B. Report on “Pavement Preservation Needs and Ride Quality Trends of Pavements on Interstate and Parkway Roads”

This report looks at three types of surfaces: AC (asphalt cement); PCC (Concrete); and AC/PCC (asphalt overlay of concrete). It includes information on annual resurfacing, resurfacing needs and funding, and rideability, general condition and other pertinent information for each pavement section.

In Kentucky there are 762 miles of interstates and 647 miles of parkways. The report says that 310 miles of interstates (41 percent) needed improvement by 2003. The report offers a balanced plan for improvement that calls for 61 million per year to be spent on interstates through 2009. The report also states that 356 miles of parkways (55 percent) needed improvement by 2003. The report offers a balanced program that calls for spending 63 million per year on parkways through 2009.

In its conclusion, the report also offered a balanced preservation program for state primary roads. The treatments mentioned are mostly for PCC pavements—repairs and diamond grinding, thick overlays, or pavement replacements. It called for $13 million per year on state primary through 2009.

6.3 Conclusion

Kentucky needs to invest substantial resources in its system of roads and highways. The above reports provided an estimate of the investment needed on an annual basis to preserve the roads at an adequate level of service. If the cabinet is to maintain the Commonwealth pavements in a minimally acceptable condition of service, then a commitment for a major increase in preventive treatments is needed. "The pavement improvement needs through 2009 will total $366 million ($61 million per year) for the Interstate system, $378 million ($63 million per year for the Parkway System), $78 million ($13 per year for State Primary rehabilitation Program), $456 million ($76 million per year) for the Annual Resurfacing Program, and $210 million ($35 million per year) for the rural Secondary System." These are considerable sums but they will reduce the total outlays by extending the working life of Kentucky roads. It is far less expensive to maintain a road than to reconstruct it. In other words, the payoff from instituting routine maintenance for ditch cleaning and pavement preservation will be substantial. With an appropriate system of scheduled maintenance, Kentucky can have a higher level of service at reduced cost.

7.0 A Proposed New System for Regularly Scheduled Maintenance to Preserve Pavements

Preventive maintenance over the expected lifecycle of a pavement can reduce the total cost to a state of maintaining its road system. The paramount goal of pavement preservation is to protect the highway from structural damage while providing the public with a smooth and safe ride. This requires routine maintenance that must be carried out in a timely manner at specified intervals according to a schedule, if serious damage to the highway is to be prevented.

The literature on pavement preservation offers two main points. (1) It is vital to appropriately time the application of treatments to extend pavement life and obtain the desired savings over the pavement lifecycle. (2) DOTs must integrate their pavement infromation system with their pavement management program. This will promote the sharing of information on condition and promote the optimal timing of treatments.

Fortunately, Kentucky is well-positioned to implement a more comprehensive preventive maintenance program, as it already possesses the needed information-gathering and analytical tools. Preventive maintenance calls for a systematic approach to pavement management. It is generally accepted that a pavement management system has three major components:

1. A system to regularly collect highway condition data;
2. A computer database to sort and store the collected data; and
3. An analysis program to evaluate proposed preservation strategies and suggest cost-effective projects to maintain highway condition.

In that Kentucky is equipped appropriately to do these, the Transportation Cabinet will be able to construct a cost-effective system for maintaining the state highway system in satisfactory condition.

The ultimate preventive maintenance system that the state puts into place will no doubt blend preventive and reactive methods for pavement maintenance. Fortunately, it appears that much of the necessary data needed to construct a better system for preventive maintenance is already being gathered (specifically, miles of types of roads and volume as well as pavement type and age and history). We can use this (and other) data to build estimates of costs of preventive programs. Based on recommendations from the research record on the recommended or ideal sequence of preventive treatments to maximize pavement life and the best preventive practices of the states, we can build estimates of the level of service and costs associated with different pavement preventive maintenance programs. Ohio has done something along these lines and may serve as a model.

7.1 A Recommended Approach

The best state programs combine several elements into a coherent program--i.e., (1) thin overlays and other resurfacings, (2) crack sealing, and (3) drainage maintenance. Aggressive and timely maintenance of drains and ditches prevents damage from water. It thus pays for itself. The same can be said for crack sealing and thin overlays. Applied in a timely fashion, these three treatments can delay the need for reconstruction. A program that combines the three wisely will save the residents of Kentucky a great deal of money in the coming decades.

We repeat our description of New York's program for preventive maintenance. Obviously, the specifics will need to be adjusted to suit the needs of Kentucky. But the stress on regular schedules for maintenance for resurfacing, crack treatments, and drainage seems ideal for Kentucky.

New York State has three major maintenance treatments in its program: crack sealing, thin overlays, and drainage system cleaning.

Crack Sealing. Cracks are sealed early in the pavement's life, as early as 2 years after the pavement is placed. The new crack sealant configuration could stay in place for 5 to 6 years. "Joints and cracks in rigid pavements in appropriate condition were scheduled to be treated on an 8-year cycle. Asphalt concrete shoulders next to rigid pavements in good to excellent condition were to be chip sealed every 4 years."

Thin Overlays. "Flexible and overlaid pavements were to receive a single-course overlay every 12 years, with crack sealing on a 4-year cycle after the initial overlay.

Drainage Systems."Closed drainage systems were to be cleaned in a 10-year cycle, and open drainage systems were to be cleaned on a 12 year cycle.

Something similar informed by Kentucky's experience and conditions, seems advisable.

7.2 Timing of Resurfacing and Highway Quality

According to Hicks, Dunn, and Moulthrop (1997), the typical highway experiences a 40 percent drop in quality, as measured by the pavement condition index during the first 16 years of operation or 75 percent of its life (They assumed the life expectancy of a road without maintenance to be about 21 years.) Another decline of 40 percent is expected over the next 12 percent of its life or 2-3 years. Thus, if rehabilitation is performed at the 12 year mark, the pavement only requires preventive maintenance such as an overlay. If rehabilitation is delayed until the 16 year mark, the pavement requires reconstruction, which is much more expensive. The rate of deterioration increases rapidly after the 75 percent use point (15 or so years).

A dollar spent on preventive maintenance can improve performance and prevent $4 or $5 dollars in repairs a few years later after rapid deterioration sets in. The manual for New Hampshire's RSMS makes the point this way. "Suppose a section of pavement that was built 12 years ago needs a preventive maintenance treatment (i.e., a slurry seal) today, estimated at $20,000. If the action is deferred for four years allowing time for the pavement to become structurally damaged, it may require a thick overlay, which could cost $60,000 to $80,000."

Kentucky Assessment of the Connection between Resurfacing Cycles and Highway Quality

As previously observed, there is no agreed upon time table for resurfacing highways. At this time, each state has to devise its own program to maximize the quality of its road system. We do, however, have some research on the Kentucky system that is suggestive. The following long quote from a report by the Operations and Pavement Management Branch suggests that the resurfacing cycle should be less than 15 years (2003:8):

"As a result of more frequent resurfacing, the percentage of pavements in good condition had increased from 48 percent in 1988 to 68 percent in 1992. But from 1993 through 1999, the resurfacing cycle was again lengthened to 15 years or more (Dade et al 2002, 8) and the number of pavements in good condition decreased to 50 percent by 2001. With more frequent resurfacings, the percentage of pavements in poor condition had decreased from 17 percent to 12 percent. But it rose to 20 percent in 2001. Likewise the average RI improved from 2.67 in 1988 to 3.00 in 1997 and decreased to 2.82 in 2001."

In regard to the appropriate frequency of resurfacing, the report noted:

"Roughness testing and condition inspections by the Pavement Management Staff indicate that highways will need resurfacing on at least a 15 year cycle (900 miles per year) just to maintain pavements in current overall condition. The department of highway's annual resurfacing program (during the six years from 1987 through 1992) resurfaced pavements on a 12 to 14 year cycle. Rideability of the State Primary, State Secondary, and Supplemental roads improved each of those years and conditions among the highway districts almost equalized. The mileage of pavements in poor condition decreased from 2,023 miles in 1988 to 1,031 miles in 1994."

These findings suggest that a 12 to 14 year cycle on average will maximize the quality of Kentucky's highways and minimize the need to reconstruct highways.

7.4 Inspection Schedules for Drain and Ditch Cleaning

Money needs to be set aside for inspecting and cleaning ditches and drains. The AASHTO Highway drainage Guidelines spell out in some detail the specific tasks that belong in a drain and ditch inspection schedule. They also relate drainage maintenance to other types of maintenance. "Routine maintenance shall include activities which should be performed regardless of the inspection reports (e.g., mowing, trash removal, sediment removal.) Each type of facility should have a list of specific activities which must be completed, including provision for certification when each item is completed, date completed and any additional observations or information which may be appropriate."

Perhaps most important of all, drains must be built with maintenance issues in mind. To that end, the AASHTO guidelines state: "Free outlets for the underdrain systems should be provided and maintained. It is desirable that outlets for longitudinal pipe underdrains be placed at intervals of not more than 300 meters. Terminal and intermediate cleanouts should be provided for periodic high pressure flushing to prevent clogging. Cleanout risers and outlets should be protected from damage by mowers and other maintenance equipment, yet provide convenient access for cleaning. A suitable guard or screen may be needed at outlets to prevent small animals from being trapped inside the pipe or clogging it with their nests." (AASHTO's Highway Drainage Guidelines, Vol. IX--P41)

7.5 AASHTO's Recommendations

It is recommended that the Kentucky Transportation Cabinet institute ASSHTO's recommended performance criteria and targets for subdrainage assets. Compliance with these will prolong the life of pavements. They are laid out in tables 7.1 and 7.2.

Table 7.1: Recommended Performance Criteria and Targets for Surface Drainage

Asset Item	Performance Goal	Performance Target, % that shall meet goal
Culverts	• <10% deteriorated barrel • >90% open • Minimal erosion at end • No settlement	90%
Catch basins	• Free of debris • Allow easy access to drain pipes	90%
Inlets	• Free of debris and functional • Grate unbroken • No flooding or settlement	90%
Storm Drain Pipes	• >90% open, no flooding • No settlement	100%
Paved roadside ditches	• At proper elevation w.r.t. pavement • Aligned to grade • Structurally sound • Clean	90%
Unpaved roadside ditches	• At proper elevation w.r.t. pavement • Aligned to grade • No obstacles to flow of water • No excessive silting	95%
Median ditches	• At proper elevation w.r.t. pavement • Functional	90%
Curb and gutter	• 90% of c&g free of structural distresses • 100% free of obstructions • 90% pavement/gutter joint is well sealed or flush	100%
Storm water management ponds	• Clean • Connections intact • Fencing present and intact	100%
Sidewalks and ramps	• Smooth, safe, sound	N/A

Table 7.2: Recommended Performance Criteria and Targets for Subdrainage Assets

Asset Item	Performance Goal	Performance target, % that shall meet the performance goals described
Edge drains/underdrains	• Functional and not clogged • No crushed or ruptured pipes • Free of debris and animal nests • Well-connected to outlets	90
Outlets/crosspipes/laterals	• Clearly visible and above the design flow line in ditch • 90 percent or greater area open • Not crushed or ruptured • Well connect to edgedrins • Laid out at 3% slopes	100
Headwalls	• Visible, intact, and provide protection to outlet • Minimal erosion of surrounding soil	80
Rodent screens	• Present and functional	75
Outlet markers	• Present and visible	100

7.6 A Commitment to Crack Sealing

The third component of the recommended maintenance program concerns sealing pavement cracks. Doing so can prolong pavement life and reduce the need to reconstruct roads damaged by infiltration of water. Crack sealing may be especially useful for low volume roads

While the precise timing for crack sealing may vary by AADT and other factors, more frequent crack sealing will extend the life of many pavements. Local officials with expertise in this area can no doubt devise an appropriate response to the problem of cracking.

7.7 Conclusion

The proposed plan would require an increase in spending over the first few years. It would reduce, however, total spending in the future, as well as produce an improved road system for Kentucky drivers. We have not offered precise schedules for performing resurfacings, drain-cleaning, ditching, and crack treatments. These schedules are best designed by practitioners in the field. Once tentative schedules are devised, we can use the results of our concurrent study of maintenance costs over the first 15 years of a highway's life to construct estimates of the proposed costs associated with a new schedule for pavement preservation. This would also facilitate an estimate of maintenance costs over the long term.

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Appendix A: Maintenance Activities

Activity	Activity Number	Effected by Pavement Age?
1430 Design Part-Con	1430	1
1650 BRIDGE INSPECT-ST FORCES	1650	1
A010 SUR-POT HOLE PATCH	A010	1
A020 MACHINE PATCH	A020	1
A030 SURF-ABNORM REP	A030	1
A040 SURF-REPAIR PCC	A040	1
A041 CONTRACT-SURF-REPAIR PCC	A041	1
A050 SURFACE-SPOT SEAL COAT	A050	1
A070 JT-CRK SEAL OF PCC	A070	1
A080 SEAL PVMT-SHDL JT	A080	1
A140 TOTAL CONTRA PATCH	A140	1
A150 VENDOR AIDED PATCH	A150	1
A440 MUDJACKING	A440	1
A710 MILLING-STATE MACH	A710	1
A720 MILLING-VENDOR	A720	1
A980 SURF & SHLDR	A980	1
B010 SHR-POT HOLE HOT	B010	1
B020 SHR-MACH PATCH HOT	B020	1
B040 SHOULDER-SEAL COAT	B040	1
B050 SHR- ABNORMAL REP	B050	1
B540 EDGE UNPAVED SHDLS	B540	1
B990 MISC SHR MAINT	B990	1
3010 PREL ENGINEERING-RAI	3010	0
3010 PREL ENGINEERING-RAI	3010	0
3020 PREL ENGINEERING-UTI	3020	0
3020 PREL ENGINEERING-UTI	3020	0
3030 INSPECTION&SUPER-RAI	3030	0
3030 INSPECTION&SUPER-RAI	3030	0
3040 INSPECTION&SUPER-UTI	3040	0
3040 INSPECTION&SUPER-UTI	3040	0
3550 RAILROAD CONTRACTS	3550	0
3550 RAILROAD CONTRACTS	3550	0
3560 UTILITY CONTRACTS	3560	0
3560 UTILITY CONTRACTS	3560	0
4010 CONSTRUCTION ENGR.	4010	0
4210 State Force Const	4210	0
4220 Traff Signs and Devices	4220	0
4230 Const General- Traffic	4230	0
4250 SIGNING PLANS - TRAF	4250	0
4260 SIGNAL PLANS - TRAF	4260	0
4270 LIGHTING PLANS - TRAF	4270	0
4290 Pavement Markings- SF	4290	0
4580 Construction Contracts	4580	0
5021 Core Drilling	5021	0
7010 INJURY	7010	0
7010 O/H EXCEPT MAINT & EQUIP	7010	0
7020 TIRE RECLAMATION	7020	0
7060 ACCOUNTS RECEIVABLE MISC.	7060	0
7110 O/H OFFICE-GAR-LABOR-PAYR	7110	0
7410 INMATE LABOR & SUPRVSN	7410	0
7510 KPDES BMP PLAN	7510	0

A100 MT RR PROT DEVICES	A100	0
A110 SURF-TB MAINT	A110	0
A120 SURF-PATCH TB MAIN	A120	0
A880 BIT COLD MIX PREPARATION	A880	0
A990 MISC SURF MAINT	A990	0
B110 WEDG PAVE SHR HOT	B110	0
B120 BIT EDGE SHDL	B120	0
B130 GRADE SHRS-GRASS	B130	0
B140 SHR TBM MAINT	B140	0
B150 CONTRA SHLD MAINT	B150	0
B210 GRADE SHOULDERS	B210	0
B220 GRADE SHR ADD MAT	B220	0
B230 GRADE SHLD UNDR GR	B230	0
C010 SLIPS-SLIDES	C010	0
C020 PERM REPR/SLIP	C020	0
C040 RA ATTN SERV	C040	0
C050 CNTRCT RA	C050	0
C090 LOADOMETER MNT	C090	0
C100 LITTER CLNUP EX	C100	0
C110 LITTER CLEANUP	C110	0
C111 CONTRACT-LITTER CLEANUP	C111	0
C130 DEAD ANIMAL	C130	0
C140 SWEEP	C140	0
C150 CONT-MECH SWEEP	C150	0
C190 CRASH CUSHIONS	C190	0
C200 REPAIR FENCES	C200	0
C300 REP ST BM GRL	C300	0
C330 REP GR END TR	C330	0
C390 CNTRCT GRAIL	C390	0
C400 CNTRCT GRAIL EN	C400	0
C980 MISC RDSIDE OH	C980	0
C990 ROADSIDE GEN	C990	0
E010 TREE&BRUSH RMVL	E010	0
E020 GRADER	E020	0
E030 CONTR TREE-BRSH	E030	0
E110 TREE&SHRUB MNT	E110	0
E120 TRAINING AND CALIBRATION	E120	0
E210 EROSION BY VEG	E210	0
E220 WILDFLOWER EST & MAINT	E220	0
E280 WEED CONTR	E280	0
E290 HERB GRAIL	E290	0
E300 SPOT SPRAY HERB	E300	0
E310 MECH SPRAY OF H	E310	0
E330 MCH GRAN FERT	E330	0
E980 MISC AGRON OH	E980	0
E990 MISC RDSDE AGRN	E990	0
F050 SLOPE MOWING	F050	0
F080 MOWER SUPPORT	F080	0
F081 CONTRACT-MOWER SUPPORT	F081	0
F090 HAND TRIM/LAWN MOW	F090	0
F091 CONTRACT-HAND TRIMMING	F091	0
F210 MOW-TP2-STATE FORCES	F210	0

F310 MOW-STATE FORCE	F310	0
F311 MOW-CONTRACT FORCES	F311	0
F320 MOW-CONTRACT	F320	0
F990 MISC MOWING MAINT	F990	0
H010 BDG CTRCT/ENGR	H010	0
H110 CLNG BDG DECKS ETC	H110	0
H130 BRDG JOINT SEALING	H130	0
H150 CONTRA BRIDGE MAINT	H150	0
H210 REPAR BDG HANDRAIL	H210	0
H320 MAINT BRIDGE CHNL	H320	0
H410 REPAIR TIMBER DECK	H410	0
H520 PATCH BRIDGE DECKS	H520	0
H610 BENT SUP/SUBS REPR	H610	0
H620 SUPER STRUCT REPAR	H620	0
H710 REP & PAINT ST BDG	H710	0
H810 FERRY OPERATION	H810	0
H880 OPR CO BDG STR YD	H880	0
H980 MISC BDG OH	H980	0
H990 MISC BDG MAINT	H990	0
J010 HAND CLN CULVRT	J010	0
J020 MACH CLN CULVRT	J020	0
J021 CONTRACT-MACH CLN CULV	J021	0
J030 RPR CULV/PIPE	J030	0
J070 PVT ENT MAINT	J070	0
J110 SLOPE PROTECT	J110	0
J150 CONTRACT DRNGE	J150	0
J151 CONTRACT-DRAINAGE	J151	0
J210 DITCH W/ GRADE	J210	0
J230 SPT DCH BOOM EQ	J230	0
J310 PAV/ ROCK DTCH	J310	0
J320 CLN DRAIN CHNL	J320	0
J980 MISC DRAIN OH	J980	0
J990 MISC DRAINAGE	J990	0
K010 PLOWING SNOW	K010	0
K020 SPREAD SALT	K020	0
K030 PLOW SPREADNG	K030	0
K120 SNOW INIT PREP	K120	0
K150 VENDR ICE/SNOW	K150	0
K160 SNOW TRUCK FEES	K160	0
K170 SNOW TRUCK USE	K170	0
K500 SALT BLDG MNT	K500	0
K880 STOCK SNOW MATL	K880	0
K990 MISC SNOW/ICE	K990	0
M130 EMR RLF WK CO RDS	M130	0
M140 EMR REPAIRS ST RDS	M140	0
M170 FLOOD WORK	M170	0
M550 EMR FED FUND	M550	0
M990 OTHER EXTRA MNT	M990	0
N010 BLDG/GR HSKEEP	N010	0
N020 MAINT BLDGS REP	N020	0
N040 EQUIP SERVICE	N040	0
N050 INCL WTHR/STDBY	N050	0

N060 STDBY/EQ BKDWN	N060	0
N080 ENGR & R/W	N080	0
N110 SAFETY	N110	0
N120 TRAINING OH	N120	0
N130 PRMTS SUPERVSN	N130	0
N140 CO GEN EXP	N140	0
N150 DO MT GEN EXP	N150	0
N170 CNTY CRW GEN EX	N170	0
N180 SPEC CRW GEN EX	N180	0
N200 EQUIPMENT OH	N200	0
N210 MIN ASSESS RENT	N210	0
N220 MINOR EQ CHARGE	N220	0
N250 OVERWGHT PERMIT	N250	0
N900 MATERIAL INV	N900	0
N990 MISC MT	N990	0
P010 DIST RA INSPCTN	P010	0
P020 MNT RATNG PROG	P020	0
P030 Environmental Compliance	P030	0
T010 CONTRACT 4" YELLOW STRIP	T010	0
T011 CONTRACT 4" WHITE STRIP	T011	0
T012 CONTRACT 6" YELLOW STRIP	T012	0
T013 CONTRACT 6" WHITE STRIP	T013	0
T020 S.F. 4" YELLOW STRIPING	T020	0
T021 S.F. 4" WHITE STRIPING	T021	0
T022 S.F. 6" YELLOW STRIPING	T022	0
T023 S.F. 6" WHITE STRIPING	T023	0
T040 HAND PVMT MARK	T040	0
T050 HAND PVMT PAINT	T050	0
T060 RAISED PVMT MRK	T060	0
T070 HZD DLN RDSD ST	T070	0
T080 HAND - THERM	T080	0
T110 PNT LNE&EDG LNE	T110	0
T180 ENGR EXP	T180	0
T190 TRF CT PVMT MRK	T190	0
T200 PLCMNT SHT SIG	T200	0
T210 RPLC SIGN & DEL	T210	0
T220 SHEETING APPL	T220	0
T230 SIGN FABRICATN	T230	0
T240 SIGN MNT	T240	0
T250 MNT PANEL SIGNS	T250	0
T260 PLACE NEW DELN	T260	0
T270 DELINEATOR MNT	T270	0
T290 TRF CT SIGN PRJ	T290	0
T400 TRF SIGN INSTL	T400	0
T410 TRAF SIGNAL MNT	T410	0
T460 HWY LIGHTNG MNT	T460	0
T480 MNT ELC OPR SGN	T480	0
T490 MNT NAV SYS	T490	0
T500 HWY SGN LGHT MT	T500	0
T590 TRAF CT ELECTRC	T590	0
T600 TRAF DATA COLL	T600	0
T610 TRAF DATA ANAL	T610	0