PAPER 22

What We Don't Know About Pavement Preservation

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ABSTRACT

Any economical extension of pavement service life has a significant benefit for long-term life-cycle costs. Preventive maintenance activities can substantially extend the pavement service life (or keep it from prematurely failing). The simple concept of higher costs for deferred maintenance becomes more difficult when the objective is quantifying the cost tradeoffs, and selecting among maintenance alternatives. The focus of this paper is to examine why this task is difficult, and to evaluate what we need to learn in order to improve our procedures for analyzing maintenance tradeoffs. The paper will be limited to asphalt concrete pavements (ACP), but the concepts are very similar for portland cement concrete pavements (PCCP).

Current budget constraints in Washington State necessitate the development of new strategies with regard to preventive maintenance. Even if the optimum long-term rehabilitation plan for a particular section of roadway calls for a capital construction rehabilitation project, there may not be funds available to complete the construction. This situation has resulted in the development of preventive maintenance strategies for the purpose of delaying or avoiding capital construction spending. These strategies include: (1) addressing early distress, (2) correcting short distressed sections, (3) maintaining and "holding" sections that are currently due for rehabilitation, and (4) integrating preventive maintenance with rehabilitation strategies.

INTRODUCTION AND SCOPE

Pavement Management, in its broadest sense, encompasses all the activities involved in the long-term planning, design, construction, maintenance, and rehabilitation of the pavement portion of a public works program (Hudson, Haas, Pedigo, 1979). Pavement Preservation is, therefore, a special component of Pavement Management, that emphasizes the extension of pavement service life through the use of preventive maintenance and minor rehabilitation activities.

Even though it is not possible to separate Pavement Preservation from the Pavement Management process, there is substantial benefit from optimizing the activities related to Pavement Preservation. As will be shown later in this paper, any economical extension of pavement service life is a significant benefit to the long-term life-cycle costs, and preventive maintenance activities can substantially extend the pavement service life (or keep it from prematurely failing).

Conceptually, the idea of performing maintenance during the life of a structure is a simple and familiar one, just as people are familiar with how automobile or house maintenance will stretch the service lives of those assets. This concept is illustrated for a pavement structure in Figure 1, where early maintenance will be less costly than a rehabilitation that is performed after the structure has deteriorated (O'brien, 1989).

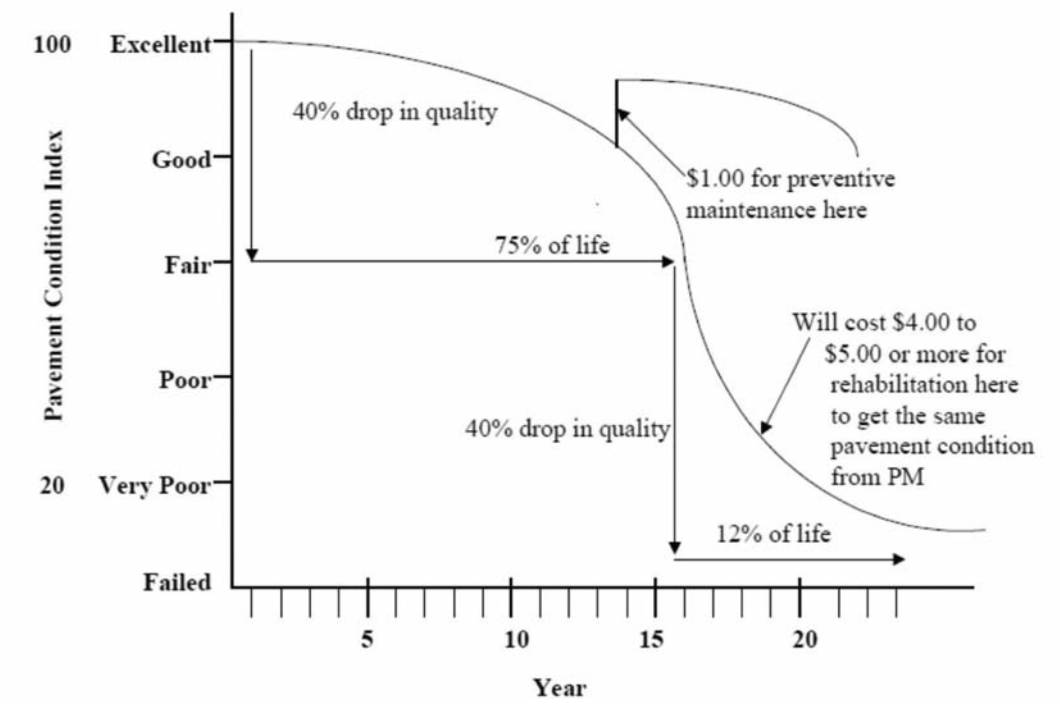


Figure 1. Influence of Maintenance Timing on Service Life (after O'brien, 1989)

This simple concept of higher costs for deferred maintenance becomes more difficult when the objective is quantifying the cost tradeoffs, and selecting among maintenance alternatives. The focus of this paper will be to examine why this task is difficult, and to evaluate what we need to learn in order to improve our procedures for analyzing maintenance tradeoffs. The paper will be limited to asphalt concrete pavements (ACP), but the concepts are very similar for portland cement concrete pavements (PCCP).

DEFINING THE OPTIMIZATION PROBLEM

The relatively simple example illustrated in Figure 1 can be framed as an optimization problem: How do we obtain the best pavement performance for the lowest long-term cost?

Objective Function

Examining the details of quantifying pavement performance is outside the scope of this paper. Suffice it to say that the use of a pavement condition index is a reasonable way to quantify how a pavement performs. The Washington State Department of Transportation (WSDOT) uses three condition indexes to evaluate ACP performance: PSC (for pavement structure, primarily cracking), PPC (for pavement profile, or roughness), and PRC (for pavement rutting). These are all quantified on a scale of 0 to 100, and the Washington State Pavement Management System (WSPMS) estimates that a rehabilitation is needed when any one of the three indexes reaches a value of 50. The value of 50 was originally justified through a life-cycle cost evaluation of different rehabilitation "trigger" values, but this procedure has also been in use for a number of years at WSDOT and historically has been shown to be an effective policy for pavement rehabilitation.

Instead of setting the level of the pavement condition index at 50 as a constraint, it would be possible to maximize the area under the pavement condition index curve as the objective function of the optimization problem (see Figure 2). This method has been developed and demonstrated through a publicly available software program called OPTime (Peshkin, Hoerner, & Zimmerman, 2004)

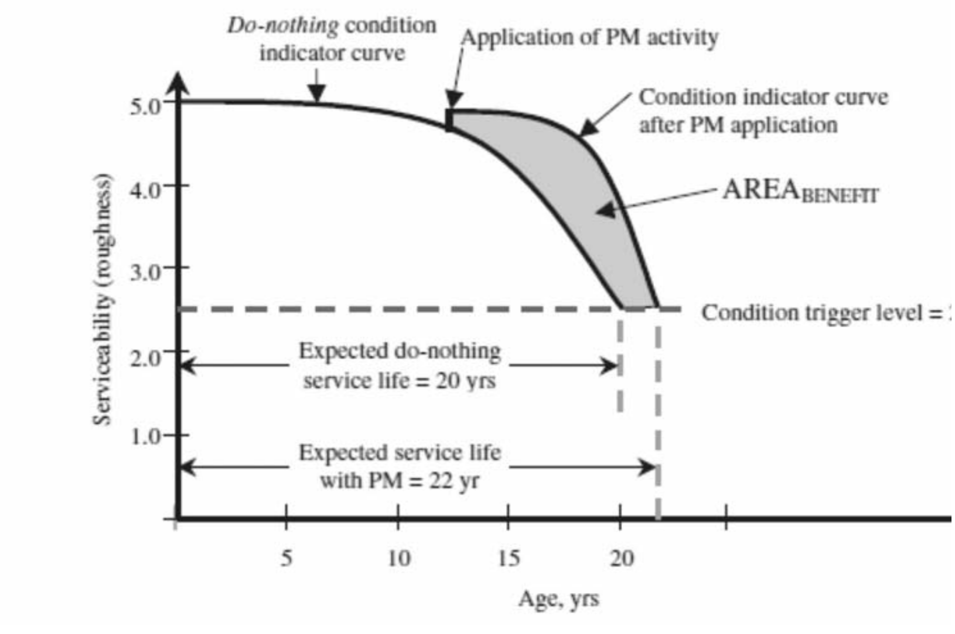


Figure 2. Maximizing the Area Under the Performance Curve (after Peshkin, et al, 2004)

The onset of severe budget constraints, particularly in the last several years when construction prices have been very erratic and have put severe limitations on the number of construction projects that can be awarded in a given year, have put downward pressure on the pavement performance objectives. Pressure exists to push the pavement condition index to lower trigger levels because funds simply are not available to implement the optimum rehabilitation strategy. So, the objective function changes from one of maximizing performance under budget constraints, to minimizing long-term costs under minimum performance constraints. In a practical sense, the minimum performance requirements are usually based on safety, and political pressure. If the roads deteriorate to such a poor condition that they are unsafe, or many citizens complain, then the performance constraint has been reached.

For pavement management purposes, an arbitrary pavement condition index trigger value could be selected for the minimum performance constraint. However, this may not be necessary. If the concept shown in Figure 1 is correct, then the higher costs of performing rehabilitations after the pavement structure has been damaged by deferred maintenance will limit the likelihood that the pavement would be in such poor condition that it would be unsafe, or in an unacceptable condition.

Decision Variables

The decision variables in the optimization problem are the maintenance and rehabilitation activities. This becomes problematic if one uses the common definition of Pavement Preservation to only include preventive maintenance, routine maintenance, and minor rehabilitations (defined as not significantly increasing the pavement structure) (Geiger, 2005). It is impossible to separate preventive maintenance from major or minor rehabilitations in evaluating the long-term strategy for a pavement. Even though preventive maintenance is typically much lower in cost, the maintenance will affect the timing of more expensive rehabilitation treatments. Both activities must be considered in the overall life-cycle cost analysis of the pavement strategy.

The decision variable becomes: what maintenance/rehabilitation activity is selected, and when is it performed? It is not difficult to generate a sample list of potential activities:

- crack sealing
- chip seal
- mill & fill (minor or major)
- crack sealing & patching
- micro-surfacing
- overlay (minor or major)
- slurry sealing
- micro-milling
- reconstruction

Each one of these activities has an agency cost, and an associated user cost (depending on traffic and construction conditions).

Effect of Decision Variables on Objective Function

At this point, the optimization problem being discussed is not overly complicated. The objective function has been simplified to one of minimizing long-term (life-cycle) costs, and it is possible to generate costs for all of the potential activities. The very difficult question to answer now, is how does one activity affect the pavement's performance/condition as it relates to the next maintenance/rehabilitation activity? How will the timing of one activity affect the timing of the next activity? As shown later in this paper, the timing of the activities will have a substantial effect on the pavement's life-cycle cost.

WHY IS MAINTENANCE EFFECTIVENESS SUCH A DIFFICULT QUESTION?

The question in the previous paragraph, on how to relate maintenance activities (decision variables) to pavement performance, can be termed the "maintenance effectiveness". The reason it is difficult to quantify, is that there are many factors affecting pavement performance. From a statistician's perspective, it is very difficult to separate out the "confounding effects" of these factors and to assign specific cause-effect relationships for different maintenance activities.

SHRP H-101 Project

Probably the most extensive study of pavement maintenance effectiveness was conducted as part of the Strategic Highway Research Project (SHRP) H-101. This was a designed experiment with the objective of evaluating the effectiveness of four preventive maintenance treatments: chip seals, crack sealing, slurry seals, and thin (1.25 in., or 3.2 cm) overlays (Smith, Freeman, & Pendleton, 1993). Within the SHRP, the Specific Pavement Study-3 (SPS-3) was designed for Project H-101 (SPS-4 was designed to evaluate maintenance effectiveness for rigid pavements). A total of 81 test sections were selected in a variety of climates and site conditions, as shown in Figure 3.

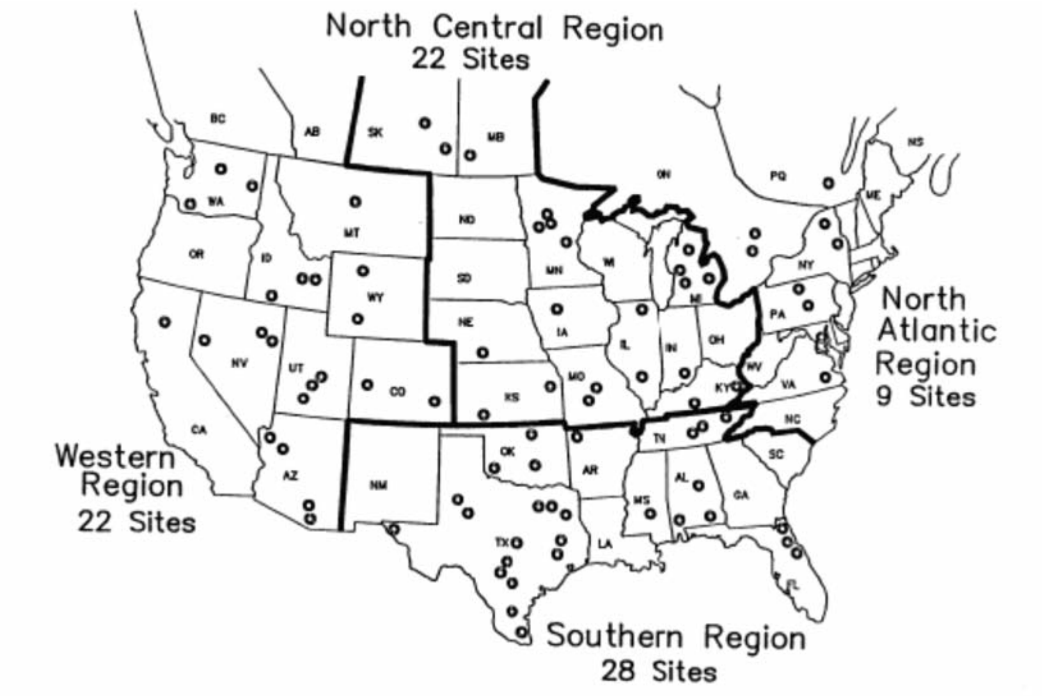


Figure 3. Location of test sites for SPS-3. (after Smith et al., 1993)

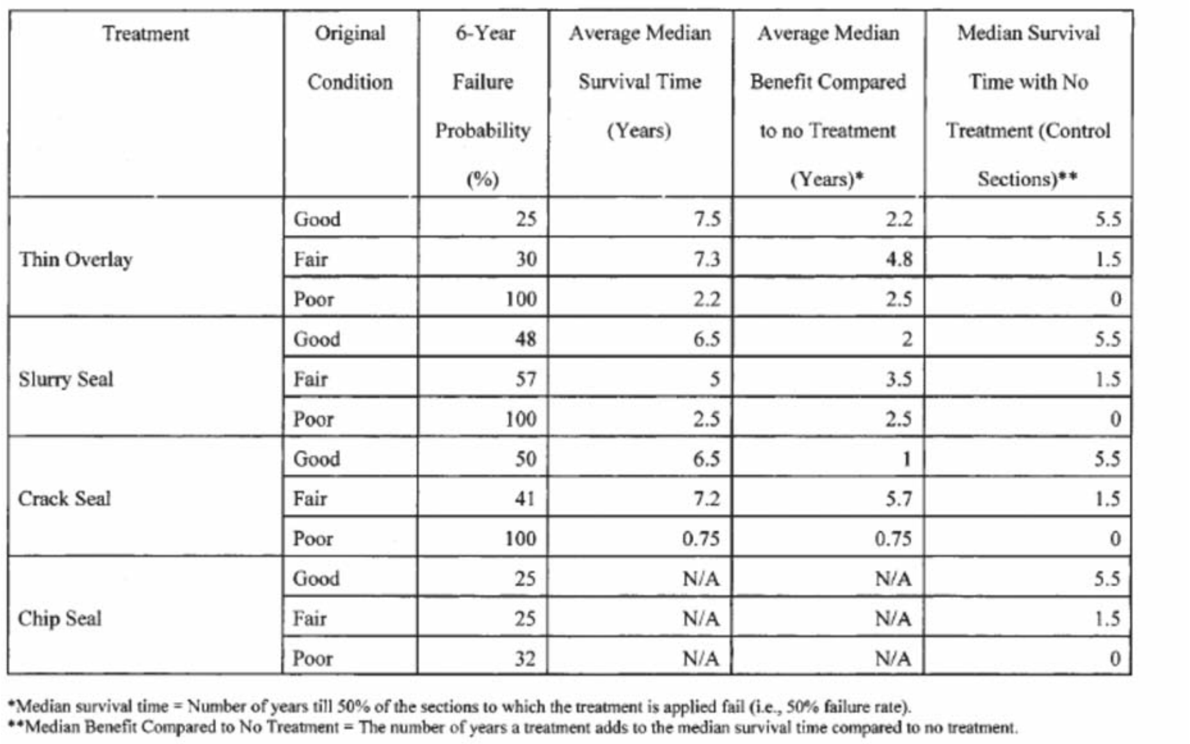
The results from the study were summarized in a report to FHWA after five years of monitoring (Morian, Gibson, & Epps, 1998). This was then followed by a separate evaluation using the Southern Region data after three additional years of monitoring (Eltahan, Daleiden, & Simpson, 1999). An overview of these studies, in addition to further analysis, was later completed as part of NCHRP Project 20-50 (Hall, Correa, & Simpson, 2002).

There was no definitive quantification of the effectiveness of the four maintenance treatments studied in project H-101. Instead, the researchers developed guidelines that could be described as "best practices" that were learned from the results. The most important of these were:

- the most effective treatments were the thin overlay and the chip seal, followed by the slurry seal
- crack sealing had no significant long-term positive effect
- the early application of the treatments provided the best pavement performance
- traffic level and pavement structure did not have a significant effect on maintenance treatment performance
- applying maintenance to sections with a poor condition increased the risk of failure by two to four times

The fact that no quantification of maintenance effectiveness was possible from the SPS-3 data does not mean that maintenance does not affect pavement performance. It simply means that the data did not provide statistically significant clarity on the details of the effects. Some of the most promising analysis of the SPS-3 data came from using a survival analysis approach, where some of the data analysis difficulties due to variability in the data could be avoided by estimating the probability of failure instead of the explicit time to failure (Eltahan et al, 1999). An example of this is shown in Table 1.

Table 1. Results from Survivor Analysis of SPS-3 data (after Eltahan et al, 1999)



Treatment	Original Condition	6-Year Failure Probability (%)	Average Median Survival Time (Years)	Average Median Benefit Compared to no Treatment (Years)*	Median Survival Time with No Treatment (Control Sections)**
Thin Overlay	Good	25	7.5	2.2	5.5
	Fair	30	7.3	4.8	1.5
	Poor	100	2.2	2.5	0
Slurry Seal	Good	48	6.5	2	5.5
	Fair	57	5	3.5	1.5
	Poor	100	2.5	2.5	0
Crack Seal	Good	50	6.5	1	5.5
	Fair	41	7.2	5.7	1.5
	Poor	100	0.75	0.75	0
Chip Seal	Good	25	N/A	N/A	5.5
	Fair	25	N/A	N/A	1.5
	Poor	32	N/A	N/A	0

*Median survival time = Number of years till 50% of the sections to which the treatment is applied fail (i.e., 50% failure rate).
**Median Benefit Compared to No Treatment = The number of years a treatment adds to the median survival time compared to no treatment.

Obstacles Faced when Analyzing Maintenance Effectiveness

Collecting and analyzing data related to maintenance effectiveness and pavement performance is a very difficult task. Even though the SPS-3 sections were statistically designed (which is a major improvement over historical data from data bases), various other factors interfere with the clear modeling of the data.

Variability in Condition Survey Data

The modeling of pavement performance is typically based on pavement condition surveys. Methods of measuring longitudinal profile (roughness) and pavement rutting have high levels of repeatability because they are automated and performed by precise instruments. Performing condition surveys of distress types such as cracking, raveling, flushing, etc. are typically accomplished by human interpretation, and Coefficients of Variation (COV) between 9% and 35% are common (FHWA, 2000).

Natural Variability in Pavement Structures

There is a great deal of natural variability in pavement structures due to the different conditions encountered with pavement construction, materials, site conditions, traffic conditions, etc. There were 24 identical (replicate) asphalt pavement sections constructed at the AASHO Road Test (the mother of all pavement tests), and even these replicate sections (that had identical materials, thickness, and traffic loads) had a COV of 25% for the mean number of applications to failure (Luhr, 1982).

This variability in pavement structures is compounded when analyzing maintenance treatments, because you are not only dealing with construction and material variability in the original structure, but the additional variation in construction and materials for each maintenance treatment. In fact, at more than 40 percent of the SPS-3 sites, some problem or deviation occurred with the application of one or more of the maintenance treatments (Hall et al., 2002).

Difficulty in Using Pavement Management Databases

It would be appropriate to learn about maintenance effectiveness by analyzing the historical data in Pavement Management System Databases. However, this concept has a couple of difficulties: 1) most pavement management systems do not have integrated data from routine or preventive maintenance activities, and 2) in most cases the historical data has not been statistically designed.

In most state highway agencies, the management of pavement design, construction and rehabilitation activities have not been integrated with routine or preventive maintenance. This is a requirement that needs to be addressed, and WSDOT is beginning to take steps to provide better coordination and information sharing between the management of capital construction programs and roadway maintenance.

Historical databases are often difficult to analyze when developing pavement models because they are not based on a statistical design. When an agency conducts a study such as SPS-3, a lot of care is devoted in planning the levels of the various treatments so that a clear statistical analysis of the results can be developed. For example, chip seals may be applied every 3 years, 6 years, and 9 years in order to evaluate the length of time between repeat applications. A historical database typically has no such planned variations in treatments, so if chip seals are typically placed every 6 years, then an analysis of the historical data would show that the length of time between repeat applications is not a factor related to pavement performance.

EVALUATION OF MAINTENANCE EFFECTIVENSS AND LIFE-CYCLE COSTS

A life-cycle cost analysis is a key methodology for evaluating alternative pavement rehabilitation strategies. In most life-cycle cost evaluations, the cost of preventive maintenance is small in comparison to rehabilitation or user costs, so it seldom controls the long-term costs. However, if the effect of preventive maintenance on pavement service life is taken into effect, then the effect of maintenance on life-cycle costs becomes significant.

For example, if the service life of a $200,000 per lane-mile rehabilitation is expected to be 15 years, then the Equivalent Uniform Annual Cost (EUAC) for this performance period is $18,000 per year (assuming a 4% Discount Rate). If some type of preventive maintenance is applied which extends the service life by one year (to 16 years), then the EUAC becomes $17,200 per year (a 4.5% drop). So, as long as the preventive maintenance (and associated user costs) did not cost more than $800 EUAC, then the maintenance activity was cost effective (net benefit > $0). This concept of percent change in EUAC as a function of one year change in service life is illustrated in Figure 4. The example described at 16 years is also shown in the figure.

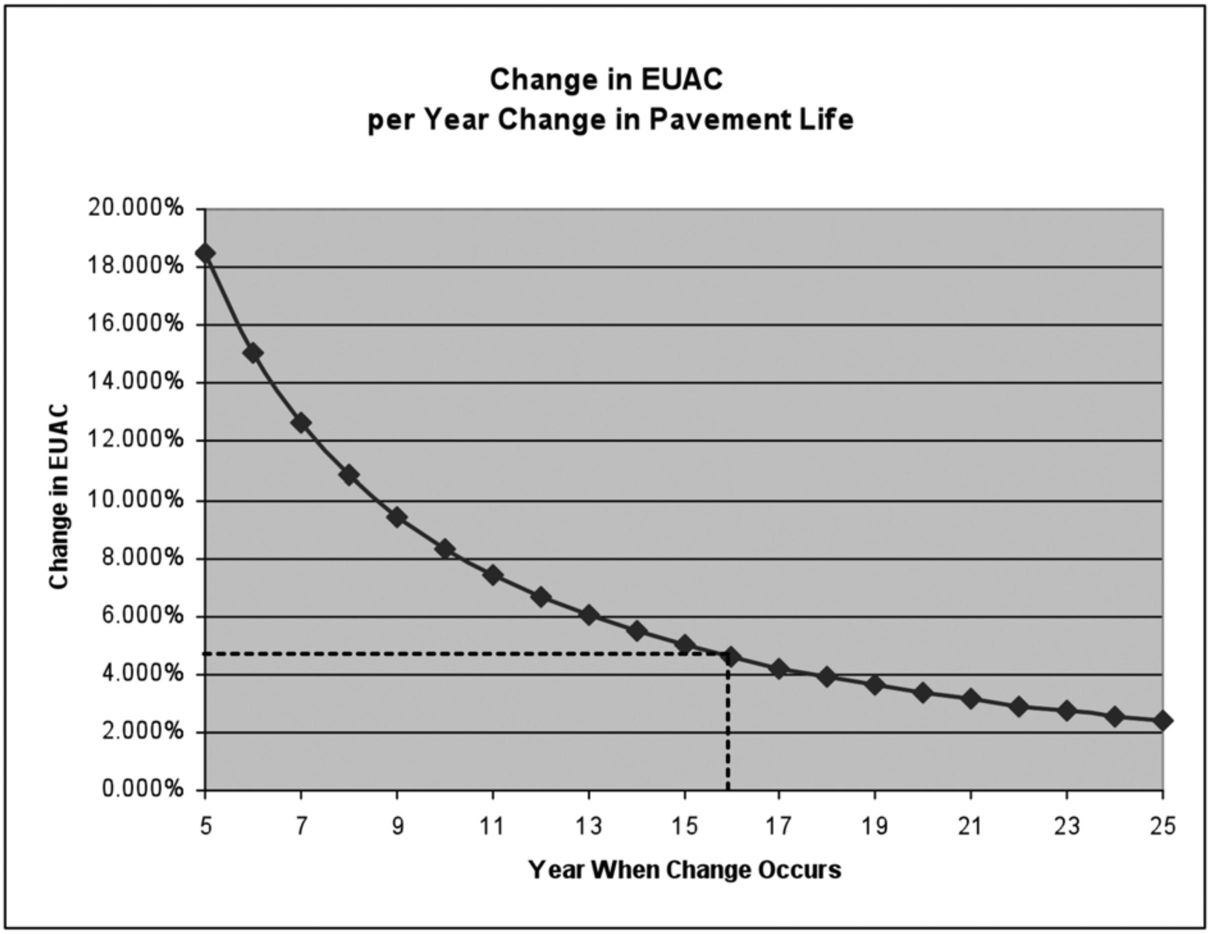


Figure 4. Percent change in EUAC as function of one-year change in service life

To evaluate the cost effectiveness of preventive maintenance activities at different times in the service life of a pavement structure, a range of activities, costs, and timeframes was analyzed by determining the life-cycle EUAC for each scenario. The modified scenario was then compared with the "do nothing" baseline of a rehabilitation cost of $200,000 per lane-mile and a 15-year service life. The various scenarios were developed by varying the following factors:

- Type of maintenance activity: (crack sealing; crack sealing & patching; chip seal)
- Year of maintenance activity: (year 5, year 10, year 15)
- Cost of maintenance activity: ($5,000 per lane-mile; $10,000 per; $35,000 per)
- Years added because of preservation: (from 0 to 10 years, depending on scenario)

Table 2 lists the various scenarios, in addition to the outcomes:

- Net difference in EUAC (expressed in $/year)
- Net percentage difference in EUAC
- Benefit/Cost factor (calculated from benefit in EUAC divided by cost of maintenance treatment)

Preservation Type Performed	Future Preservation Cost (per ln-mi)	Value of Preservation	Serviceable Life Value Added by Performing Preservation (yrs)	Total Servicable Life before next Rehabilitation (yrs)	Year Future Preservation Performed (yrs)	Net Benefit (Δ EUAC)	Net Benefit EUAC (%)	Δ Benefit / Cost Factor
Do Nothing	$0	Maximum	+0	15	15	$0	0.0%	0.0
Do Nothing	$0	Median	+0	15	15	$0	0.0%	0.0
Do Nothing	$0	No Benefit	+0	15	15	$0	0.0%	0.0
Cracksealing	$5,000	Maximum	+6	21	5	$3,510	19.5%	13.1
Cracksealing	$5,000	Maximum	+4	19	10	$2,540	14.1%	10.8
Cracksealing	$5,000	Maximum	+2	17	15	$1,370	7.6%	7.0
Cracksealing	$5,000	Median	+3	18	5	$1,880	10.4%	6.9
Cracksealing	$5,000	Median	+2	17	10	$1,320	7.3%	5.7
Cracksealing	$5,000	Median	+1	16	15	$560	3.1%	3.3
Cracksealing	$5,000	No Benefit	+0	15	5	($370)	-2.1%	0.0
Cracksealing	$5,000	No Benefit	+0	15	10	($310)	-1.7%	0.0
Cracksealing	$5,000	No Benefit	+0	15	15	($250)	-1.4%	0.0
Cracksealing and Patching	$10,000	Maximum	+6	21	5	$3,220	17.9%	6.6
Cracksealing and Patching	$10,000	Maximum	+4	19	10	$2,280	12.7%	5.4
Cracksealing and Patching	$10,000	Maximum	+4	19	15	$2,370	13.2%	6.5
Cracksealing and Patching	$10,000	Median	+3	18	5	$1,550	8.6%	3.4
Cracksealing and Patching	$10,000	Median	+2	17	10	$1,040	5.8%	2.9
Cracksealing and Patching	$10,000	Median	+2	17	15	$1,140	6.3%	3.5
Cracksealing and Patching	$10,000	No Benefit	+0	15	5	($740)	-4.1%	0.0
Cracksealing and Patching	$10,000	No Benefit	+0	15	10	($610)	-3.4%	0.0
Cracksealing and Patching	$10,000	No Benefit	+0	15	15	($500)	-2.8%	0.0
Chip Seal	$35,000	Maximum	+10	25	5	$3,360	18.7%	2.8
Chip Seal	$35,000	Maximum	+10	25	10	$3,690	20.5%	3.4
Chip Seal	$35,000	Maximum	+8	23	15	$3,300	18.3%	3.5
Chip Seal	$35,000	Median	+5	20	5	$1,070	5.9%	1.5
Chip Seal	$35,000	Median	+5	20	10	$1,450	8.1%	1.8
Chip Seal	$35,000	Median	+4	19	15	$1,330	7.4%	1.9
Chip Seal	$35,000	No Benefit	+0	15	5	($2,590)	-14.4%	0.0
Chip Seal	$35,000	No Benefit	+0	15	10	($2,120)	-11.8%	0.0
Chip Seal	$35,000	No Benefit	+0	15	15	($1,750)	-9.7%	0.0

Table 2. Combinations of factors in different scenarios for cost effectiveness evaluation

The results of the analysis shown in Table 2 indicate that substantial cost savings can be realized with most preservation treatment scenarios. The minimum level scenarios (no change in service life as a result of the preservation treatment) are the only cases that show a loss (negative net EUAC)—as you would expect. All other scenarios showed a positive net benefit (where the savings in EUAC were greater than the cost of the preservation treatment). Figure 5 shows a graphical comparison of the different net benefits (expressed as a percentage of the "do nothing" case). Savings ranged from 3% to 20% of the EUAC, which is a substantial effect.

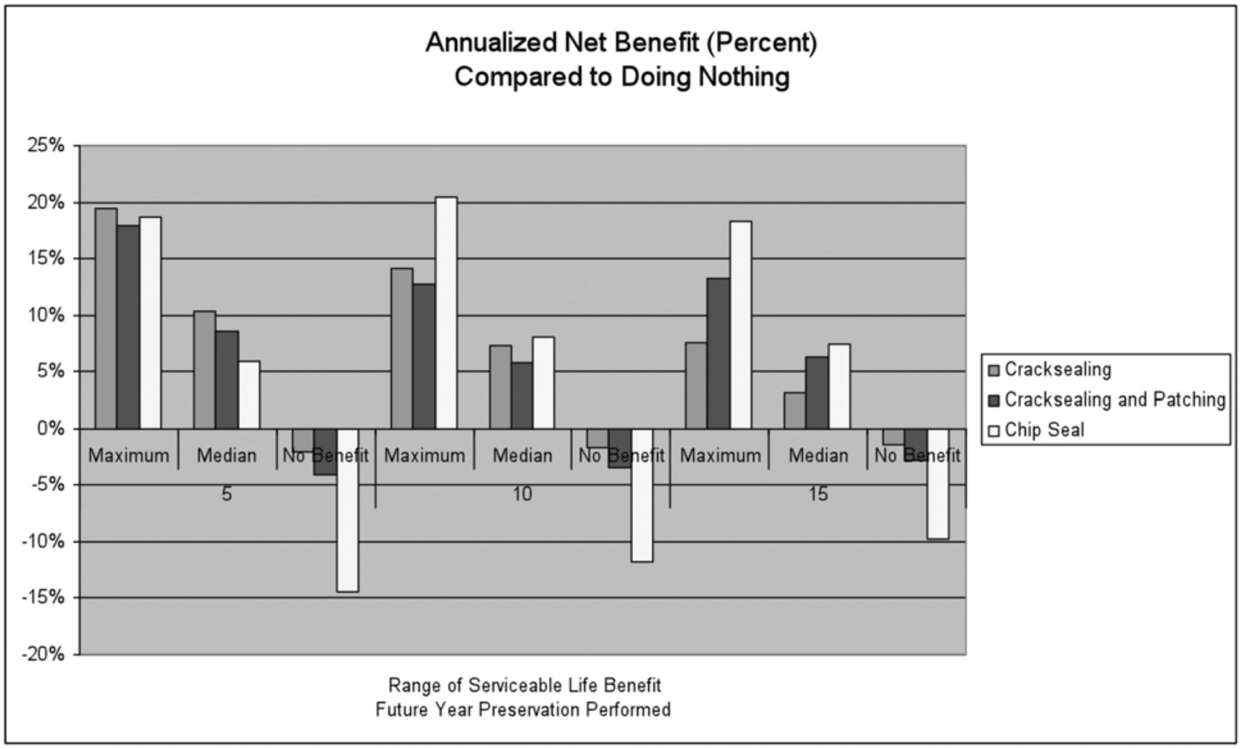


Figure 5. Net EUAC benefit (expressed in %), as function of maintenance treatment

Figure 6 illustrates the "breakeven point", which is the number of years increase in service life that will pay for the maintenance activity. The figure demonstrates that only one additional year in service life was required to pay for the less expensive crack sealing & patching activities. Only three additional years of pavement life was required to pay for the chip seal. Even though the results illustrated in the graphs are only from one specific set of example scenarios, in general they indicate that the low costs of preventive maintenance are easily paid for with only small increases in pavement life.

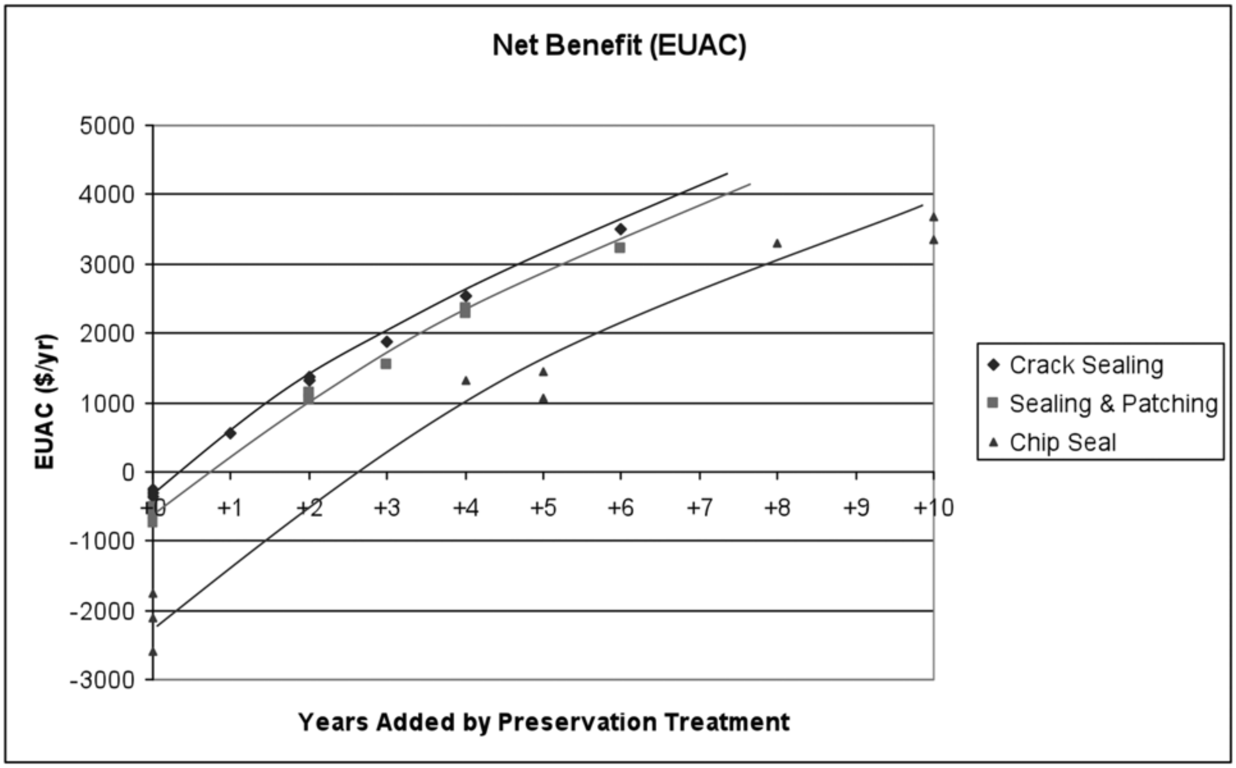


Figure 6. Net benefit EUAC (and break-even point) as function of treatment type

The evaluation of net benefits (where the EUAC of costs are determined) is the best way to compare different pavement strategies and life-cycle costs. This will provide the strategy with the lowest cost. However, if funds are not available to implement the lowest cost strategy, then sub-optimum strategies may be the best alternative. When this occurs, it is useful to evaluate which sub-optimum strategies are the most cost efficient. This type of evaluation is analyzed best using a benefit-cost ratio.

Figure 7 provides a graphical comparison of benefit-cost ratios for the scenarios in Table 2. Even though some of the crack sealing scenarios have a relatively low net benefit, some have very high benefit-cost efficiencies, so they could be selected when budget limitations may not allow the strategy with the highest net benefit.

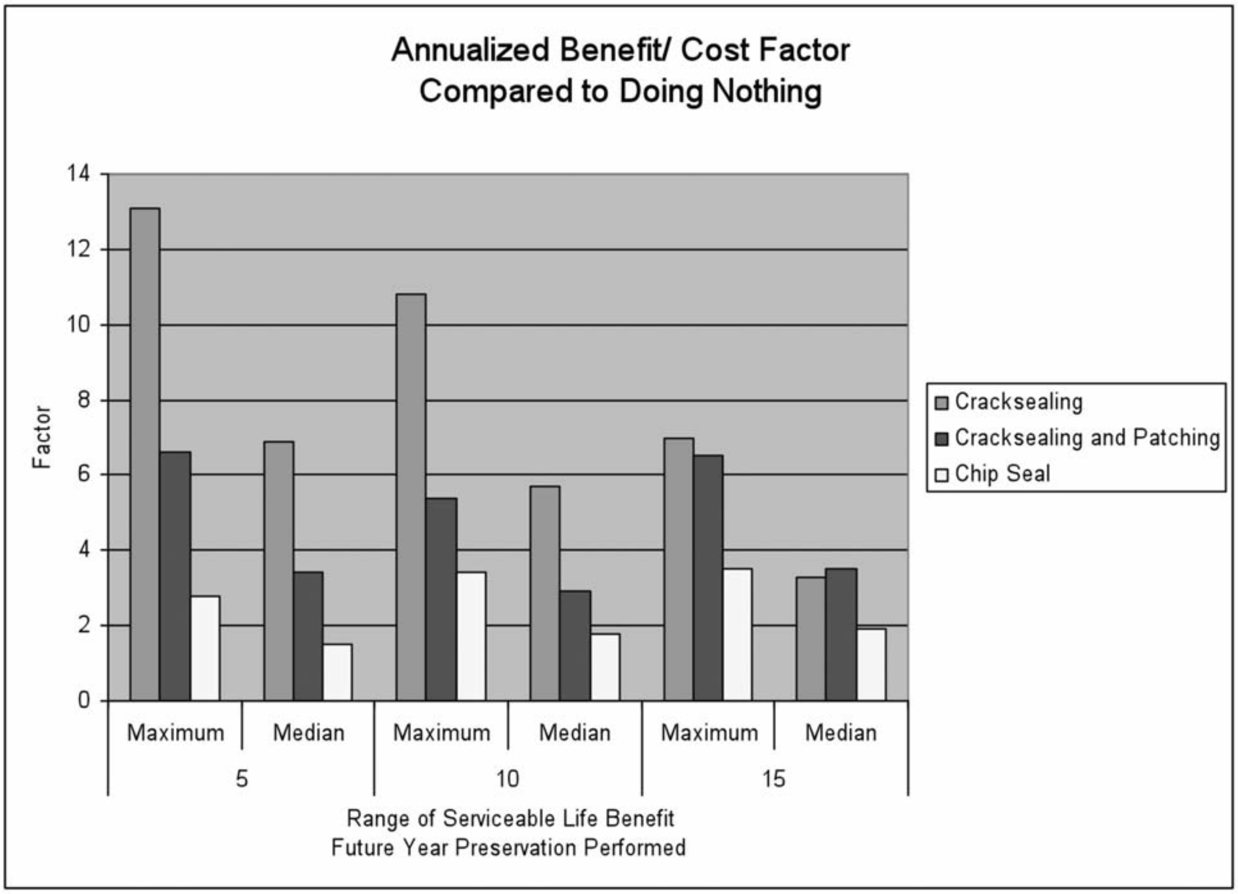


Figure 7. Benefit-cost ratios for different preservation scenarios

NEW WSDOT PREVENTIVE MAINTENANCE STRATEGIES

Current budget constraints in Washington State necessitate the development of new strategies with regard to preventive maintenance. Even if the optimum long-term rehabilitation plan for a particular section of roadway calls for a capital construction rehabilitation project, there may not be funds available to complete the construction. This situation has resulted in the development of preventive maintenance strategies for the purpose of delaying or avoiding capital construction spending. In these strategies, capital program funds are being specifically allocated for preventive maintenance activities.

Addressing Early Distress

In this situation, premature distress may be occurring relatively early in the performance period. This may be due to construction problems, reflection cracking, or some other factors, but if those premature distresses are not addressed, then an early rehabilitation may be required which will substantially increase the life-cycle costs. As discussed earlier in this paper, it has been recognized that applying preventive maintenance treatments early in a performance period is far more effective than applying it to a pavement in poor condition.

Correcting Short Distressed Sections

This strategy involves using preventive maintenance to repair distresses in short (less than 0.5 mile, or 0.8 km) sections which may be causing longer sections of roadway to be programmed for rehabilitation. In this case, the analysis is not simply project oriented (regarding one pavement section), because the evaluation is being done for a number of adjacent pavement sections. This again illustrates that pavement preservation needs to be evaluated within the overall framework of pavement management.

Maintaining Sections that are Currently Due for Rehabilitation

As discussed above, sometimes a section may be due for rehabilitation, but no funds are available. In this case maintenance is performed as an effort to hold the pavement together until the rehabilitation can be performed, and may prevent further damage that could lead to reconstruction. It is recognized that this is not an efficient or effective long-term use for funds, but it is sometimes necessary for short-term situations.

Integrating Preventive Maintenance with Rehabilitation Strategies

One strategy employed by WSDOT to delay the effect of the growing backlog of ACP pavement rehabilitation has been to use chip seals for lower-volume roadways. The chip seals cost less, but do not last as long as ACP rehabilitations. By resurfacing lower-volume ACP pavements with chip seals, WSDOT has added five to seven more years to its life for one-third the equivalent annual cost ($5,000 vs. $15,000 per lane mile per year). About 40% of WSDOT ACP roads are “lower volume” (average daily traffic of 5,000 or less). This temporary strategy stretches the funds available for pavement preservation over more road miles, but will not reduce the backlog of pavement rehabilitation needs over the long run.

WSDOT FUTURE DIRECTION

The future direction of WSDOT with regard to maintenance effectiveness and pavement management will be to develop better capabilities with regard to evaluation of maintenance/rehabilitation alternatives. As discussed in this paper, there are many unknowns with regard to predicting how preventive maintenance activities will affect future pavement performance. The understanding of these cause-and-effect relationships will not improve unless the agency begins a long-term effort to experiment with different treatments and study how they affect pavement performance. This paper discussed the difficulty of this type of study, and how important it will be to carefully monitor and analyze the results.

SUMMARY AND CONCLUSIONS

There is much that is unknown about the relationship between maintenance and pavement performance. Preventive maintenance can be proven as a cost effective activity, once the cause-and-effect relationship between maintenance and pavement performance is understood. Because preventive maintenance activities are inexpensive, it only takes small improvements in pavement performance to make the cost of the maintenance break even.

The most difficult aspect of this analysis is determining how and when different maintenance activities effect pavement performance, and by how much. Major studies have been undertaken, including the SHRP research program, without definitive conclusions on maintenance effectiveness. General guidelines on best practices were developed, but there is more quantification needed concerning the effectiveness of different types of preventive maintenance.

One of the principal reasons that it is difficult to determine the cause-and-effect relationship between maintenance and pavement performance, is that a great deal of variability exists in the pavement structure, and in the maintenance activities and pavement performance, that the data become difficult to determine specific conclusions. This point must be remembered when states try to improve their methods by studying the performance of their maintenance treatments. The measurements taken, and the methods used in the analysis, must be done carefully in order to separate out the effects of data variability.

Pavement preservation is an extremely important aspect of pavement management, and needs to be evaluated within the context of life-cycle costs and pavement rehabilitation decisions. As advances continue in the understanding of maintenance relationships, then optimization of pavement management strategies will be more easily obtained.

Current budget constraints in Washington State necessitate the development of new strategies with regard to preventive maintenance. Even if the optimum long-term rehabilitation plan for a particular section of roadway calls for a capital construction rehabilitation project, there may not be funds available to complete the construction. This situation has resulted in the development of preventive maintenance strategies for the purpose of delaying or avoiding capital construction spending. These strategies include: (1) addressing early distress, (2) correcting short distressed sections, (3) holding sections that are currently due for rehabilitation, and (4) integrating preventive maintenance with rehabilitation strategies.

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