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LIFE CYCLE COST-BASED PAVEMENT PRESERVATION TREATMENT DESIGN

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ABSTRACT

Classic engineering economic theory was developed to furnish the analyst a tool to compare alternatives on a basis of life cycle cost (LLC). However, tools used to apply theory to transportation focus on new construction projects with relatively long service lives. These tools do not accurately model the economic aspects of short-lived alternatives such as those that pavement managers must evaluate when seeking the most cost effective pavement preservation treatment. The field of pavement preservation seeks to “keep good roads good” and hence, pavement preservation treatments are applied to extend the functional service life of the underlying pavement. No significant research has been done to quantify the actual service lives of the pavement preservation treatments themselves nor a model been furnished to analyze their LCC. The paper addresses those two gaps in the pavement economics body of knowledge by proposing a methodology for using field test data to quantify the service lives of pavement preservation treatments for both asphalt and concrete pavements. Additionally, it concludes that a LCC model based on equivalent uniform annual cost, rather than net present value, specifically addresses the relatively short term nature of pavement preservation treatments and allows the engineer to better relate treatment LCC output to annual maintenance budgets.

INTRODUCTION

As the nation's infrastructure deteriorates, sustainability within the confines of operating and maintenance budgets becomes a contentious issue. Considering only the initial project cost may result in the selection of a maintenance alternative that is more costly over the long run (*1*), burdening an ever-shrinking transportation budget as the overall quality and safety of the network decline (*2*). A sustainable solution, *pavement preservation*, is currently being pursued and will be instrumental in addressing pavement system needs by *keeping good roads good* (*3*) instead of allowing them to deteriorate to the point of no return.

The use of economic analysis, specifically life cycle cost analysis (LCCA), to achieve the cost effectiveness and return on investment that supports pavement preservation and transportation decision-making is one way to promote sustainability in transportation (*4,5*). It can assist pavement managers in determining the *right treatment* component of the *right treatment for the right road at the right time* pavement preservation strategy (*3*,*6*,*7*).

Although LCCA is a powerful project economic evaluation tool, there is no prevalent method used by state agencies to conduct economic analysis at the pavement preservation level (*6*,*7*,*8*,*9*). In general, LCCA is not wide-spread in transportation decision making, possibly due to the complexity and challenges associated with engineering economic theory (*4*). The current issues with LCCA application methods may be resulting in its limited use, especially at the implementation-level, where it may not be used at all (*5*,*6*,*7*,*8*,*9*,*10*,*11*,*12*). Current LCCA models, such as the Federal Highway Administration's (FHWA) *RealCost,* are complex and intended for large-scale pavement design decisions (*14*) and do not adequately address pavement preservation treatment evaluation and its short-term nature (*10*,*12*).

No solid answer was garnered from the literature review on how to implement LCCA at the pavement preservation and maintenance level, possibly because the "emphasis upon economic cost analysis principles is recent, so models, methods, and tools to construct and analyze economic tradeoffs are still being developed" (*15*). The FHWA suggests, however, that the level of LCCA detail "should be consistent with the level of investment" (*13*). The level of investment of some activities at the implementation level can somewhat be inferred by the following FHWA statement: "When discounted to the present, small reactive maintenance cost differences have negligible effect on NPV [of pavement design alternatives] and can generally be ignored." (*13*) Therefore, the goal of this research became to analyze the steps and procedures of LCCA and determine if current LCCA application employed at the long-range-planning level is appropriate at the short-term-treatment-implementation level.

LCCA ISSUES

LCCA is used to compare pavement design alternatives, but there are issues regarding the real value of LCCA output (*13*,*16*,*17*). According to the FHWA, issues regarding the appropriate performance period and AP, among other things, can create obstacles in conducting LCCAs (*4*). This can create issues regarding "fairness", resulting in "controversy" (*18*) and doubt as to whether LCCA can be applied consistently and correctly to determine which alternative is truly the most cost effective. An analyst that is not thoroughly acquainted with underlying engineering economic analysis theory may inadvertently choose input values that create invalid output (*19*), especially when "asset alternatives have radically different technical aspects and dissimilar service lives" (*18*).

Analysis Period, Net Present Value Method

One important input value is the analysis period (AP). Its selection is based on either a mandated value or the analyst's judgment. The AP is often selected arbitrarily because conventional theory states that if two options are evaluated over the same period of time using the same discount rate, then the comparison is fair (*18*,*19*). While this may be true in theory, if the LCCA output effectively makes the pavement design decision (i.e. the engineer selects the one with the lowest value), then using an AP mandated by public entity for all analyses is tantamount to allowing an economist to practice pavement engineering (*18*).

Selecting an AP for alternatives with differing service lives, often the case in pavement treatment alternatives is necessary in determining the *net present values* (NPV) of competing alternatives so that cost differences can be assessed and results fairly compared (*17*) and engineering economic analysis principles upheld (*19*). The methods for selecting an AP to determine the NPV of competing alternatives are as follows (*19*):

1) set AP equal to the shortest life among alternatives
2) set AP equal to the longest life among alternatives
3) set AP equal to the least common multiple of the lives of the various alternatives
4) use a standard AP, such as 10 years
5) set the AP equal to the period the best suits the organization's need for the investment
6) use an infinitely long AP

There is no consensus on which method is the "best" for selecting an AP, but the decision should be based on the investment scenario at hand (*19*). As a default, if the "best" method is not obvious, the use of a standard AP, if logical considering the investment scenario, is preferred (*19*). This default selection is evidenced in the FHWA's *Interim Technical Bulletin*, "LCCA Principles of Good Practice" section (*13*). The FHWA does suggest a standard AP chosen from the range of 35 to 40 years for pavement design decisions (*14*). But selecting an appropriate AP can be problematic due to its sensitivity, meaning that with all other inputs held constant, changing the AP can result in different alternative rankings (*19*,*20*).

It is suggested that setting the AP equal to the shortest life can easily result in the shortest-life alternative being favored over the other longer-life alternatives (*16*). It has also been suggested that setting the AP equal to the longest life alternative is preferred and that an AP be "sufficiently long to reflect significant differences in performance among the different strategy alternatives" (*13*), but not so long that it becomes unreasonable (*16*). The issues with setting the AP consistent with the methods above (1, 2 & 4) are that gaps and/or residual values must be addressed for all alternatives whose service lives are shorter or longer than the AP, respectively, and are unacceptably sensitive to the input value (*18*).

If the analyst intends to assume that costs and service life lengths will remain constant over time, then only mathematical adjustments of gaps and residual values for AP accommodation, consistent with FHWA's *Interim Technical Bulletin*, "LCCA

Principles of Good Practice" (*13*), are required. The analysis method selected, in this case, would be irrelevant because all should yield the same decision support (*19*). In other words, the same outcomes can be rendered regardless of AP chosen *so long as* gaps and residual values are proportionately spread so as to be consistent with the fully crediting the treatment in accordance with FHWA "good practices" (*13*), then the analysis can be considered "fair" (*18*) and supported by engineering economic principles (*19*). Hence, setting the AP consistent with the shortest life, longest life or using a standard AP, which require adjusting alternatives to fit the same AP can yield the same ranking of alternatives as using the least common multiple of alternatives and an infinite period, which do not require the adjust-to-fit mechanisms (*19*), rendering the "arbitrarily truncated lifetime unnecessary" (*1*). However, it is unreasonable to assume that costs and service lives will remain constant over time (*16*), especially when a specific pavement or treatment has its service life expressed as a range (*18*).

EQUIVALENT UNIFORM ANNUAL COST

Equivalent Uniform Annual Cost (EUAC) is an alternative method that avoids issues associated with NPV, such as determining the least common multiple of service lives to compare alternatives (*19*) and others previously mentioned. Furthermore, "instead of employing a rule of thumb for establishing [an AP]", one should consider the nature of the investment (*19*). EUAC has been suggested as proper to use in transportation decision making when service lives differ in length for given alternatives (*18*,*21*).

The EUAC model created for this research calculates the life cycle cost for each alternative based on the EUAC method. All incurred costs expected throughout the service life of an alternative are brought to a base year, summed, and then annualized according to the *treatment's service life* as determined by field data and pavement manager professional judgment. In other words, the AP for each treatment alternative is equal to its own *anticipated service life*:

$$[\mathbf{ASL_{alt} = analysis\ period_{alt}}]$$

In NPV models, the annualization is based on the common AP. This model is unique because it seemingly bypasses the common-AP selection process. It determines the EUAC based on each alternative's respective *anticipated service life* by using the following EUAC calculation:

$$\mathbf{EUAC\ (i\%) = [\textstyle\sum P] * [i(1+i)^n \div (1+i)^n - 1)]}$$

Where:
i = discount rate
P = present value
n = pavement treatment *anticipated service life*

The EUAC model is tailored to pavement-management decision-making. It considers the short-term, limited scenarios (*continuous and terminal*) that the pavement manager encounters. The pavement manager is able to intuitively analyze the LCCA results because they are displayed within the context of the pavement manager's expertise.

Treatment-relevant input values, such as service life, are utilized. In contrast, other (NPV) models obscure these pavement-manager relevant values in a possibly arbitrary AP selection requiring extensive engineering economic understanding garnered from *economist* experience to extricate (*4*). Thus, EUAC neutralizes the associated sensitivity and complexity issues. Because maintenance funding is authorized on an annual basis, comparing alternatives on a EUAC basis better fits the funding model than using NPV, which would assume availability of funds across the treatment's entire service life. Since pavement managers typically consider several alternatives with varying services lives based on available funding rather than technical superiority, the FHWA LCCA method based on NPV creates more problems than it solves. Furthermore, the EUAC method simplifies the LCCA process and results in the same ranking of alternatives as the NPV method, all else held constant (*19*), rendering the problematic AP irrelevant.

Continuous and Terminal Scenarios

A road segment (asset) is generally intended to remain in service indefinitely and pavement treatments are expected to be applied continuously over the life of the asset, although the service life of a treatment is finite (*1*). The pavement manager will encounter one of two scenarios in the short-term-implementation level of decision making: the year of the *next expected* rehabilitation or reconstruction will either be known (*terminal scenario*) or it will not (*continuous scenario*) (*1*). When using EUAC, the "mistake" occurs when the planning horizon, or *terminal scenario*, is not considered or acknowledged for the investment (*19*). In other words, if the *encroachment* of the next expected rehabilitation or reconstruction on the service lives of treatment alternatives is expected to have a material effect with regard to the treatment of residual value for one or more of the treatment alternatives, this encroachment must be addressed in the calculations (*19*). The intent of using EUAC as the basis of the model was to address both scenarios with its "covert" flexibility, which is recommended in economic analysis (*19*), while maintaining its efficient, "overt" inflexibility with regard to disallowing common AP selection. The continuous feature in the model disallows the "unnecessary truncating of [service] lives" (*1*) while the "automatic truncate" terminal feature is built in to ensure adherence to engineering economic principles. This *fixed flexibility* reduces the negative impact associated with standard new pavement LCCA complexities and the possibility of faulty output.

EUAC Model, Continuous Feature

EUAC accommodates the continuous, short-term nature of pavement preservation treatment application because the next expected rehabilitation/reconstruction of the pavement is commonly unknown, i.e. is not on the current work plan. The pavement manager must plan to continuously maintain, preserve or "do nothing" to the pavement in the undefined interim. Because encroachment is not expected in the continuous mode, material or mathematical adjustments to costs or service life lengths are not required and the pavement manager avoids the "unnecessary truncating of lives" (*1*). Therefore, each treatment's service life input value will be equivalent to its *anticipated service life* (n), which is the value used in EUAC calculations in this model to determine life cycle cost.

EUAC Model, Terminal Feature

In the terminal scenario, the pavement manager generally chooses the "do nothing" option. In other words, the pavement manager usually defers maintenance because the pavement is scheduled to be rehabilitated or reconstructed according to the work plan. Therefore, the decision essentially *is* to ignore pavement preservation on a given pavement knowing that it will be "fixed" in the near future. This permits the reprogramming of those funds to preserving other pavements in the network.

To avoid the common "mistake" associated with employing the EUAC method, the pavement manager must consider the encroachment upon (i.e. materially alter) treatment service lives to adhere to LCCA principles (*19*). For example, if the next rehabilitation is scheduled in two years and the pavement manager cannot defer maintenance due to safety concerns, any treatment service life that is expected to extend past two years must be truncated for the purpose of analysis, consistent with the "organization's need for the investment" (*19*). If one of the alternatives is expected to have a four-year service life, it may not be able to realize the last two years of service life because its cash flow profile would have to be materially altered to accommodate the rehabilitation in two years. In other words, the residual value would equal zero at time two for the four-year alternative because it can no longer be considered continuous. It ceases having value (or remaining service life) as a pavement treatment because it will be removed when the road is rehabilitated (*1,17)*. In a terminal scenario, it has been argued that a pavement treatment's material salvaged from removal can have salvage value, but then the analyst must quantify the cost of removal and value what has been salvaged (*1*).

The model has been built to accommodate the terminal scenario and engineering economic principles. Each treatment's service life input value that extends past the year of the next expected rehabilitation/reconstruction is automatically truncated to coincide with the year of the next rehabilitation/reconstruction. This truncated value becomes the treatment's *anticipated service life* (n), which is the value used in EUAC calculations in this model to determine life cycle cost.

Pavement preservation theory asserts that proactively applying treatment extends the life of the pavement, allowing for the deferment of the expected rehabilitation/reconstruction (*2*). In this case, a sensitivity analysis is useful to determine the relative impact of the possibility of pavement life extension and encroachment of the rehabilitation activity on truncated treatment service life.

If, on the other hand, the pavement manager considers employing a one-year treatment in this example, a one-year gap would exist between the treatment's service life and the year of the expected rehabilitation/reconstruction. The EUAC model is built to ignore the gap in terminal mode and calculate EUAC for all alternatives. This situation, although rare due to the "do nothing" preference and very short-term nature of the terminal scenario, may not explicitly adhere to the specific "common period of time" engineering economic principle, but does not warrant it because the gap will most likely be filled with another "do nothing" option. All analysis-period selection methods, when applied to this scenario, have inherent issues as previously stated, so one must decide which method would yield the best information for the pavement manager. The shortest-life method would adhere to the "common period of time" engineering economic principle while EUAC would overtly not. However, if the pavement manager were to choose the shortest-life alternative to set the AP and the other longer-life alternatives were adjusted to fit in accordance with FHWA straight-line-depreciation-like method, the LCCA should still yield the same preferred alternative as the EUAC method. Because the same preferred alternative is yielded from both methods, for the purposes of a consistent model, and with all of the previously-cited issues with the AP, EUAC was selected as the appropriate terminal scenario method. Even in this rare situation, EUAC behaves essentially like a covert short-life method and can provide the pavement manager with relevant decision-making information based on cost, service life and the real possibility of "do nothing" during this state.

Pavement Treatment Service Life Input Value

As pavement preservation emerges as a possible solution to the aging infrastructure problem, research has shown that coupling cost efficiency and treatment effectiveness, termed *economic efficiency* (*7*) may be the key to determining the optimal preservation timing (*2*). Microtexture and macrotexture data is routinely collected by the Oklahoma Department of Transportation (ODOT). Incorporating this type of *localized* performance data into LCCA may reduce the level of inherent uncertainty associated with [service life] "guesses" and can yield insight to a treatment's effectiveness and cost-effectiveness (*20*). If treatment effectiveness (performance) is not considered when determining cost effectiveness, the results may be biased (*7*).

Deterioration Models

A commonly used approach to determine a treatment's expected service life (effectiveness) is to extrapolate data based on surface condition (*7*) such as microtexture and macrotexture data. This is the approach used in this research and applied to pavement preservation treatments exhibited in field trials (*22*). Linear regression was applied to the treatments' microtexture and macrotexture data to approximate the deterioration rate and extrapolate the remaining service life of each treatment. These were then compared to failure criteria found in the literature. Service life was determined by identifying the time it took each treatment to deteriorate to each failure criterion. The failure criterion for macrotexture was 0.9mm, which is consistent with TNZ P12 performance specification. The failure point considered for microtexture was a skid number less than 25.

Demonstrating this methodology, Figure 1 shows the deterioration of microtexture over time experienced in current research field trial data for chip seal. Linear regression was applied. The equation shown in the upper right-hand corner of the figure was derived and the coefficient of determination (R^2) was calculated to be 0.9191. The regression equation was then used to calculate the deterioration rate beyond the available data. These values were added to the actual data points to extrapolate the curve out to 50 months (i.e. 4+ years) as shown in Figure 2. Based upon this procedure and a failure criterion of 25, it appears that the chip seal will fail due to a loss of skid resistance around the 46-month (3.8-year) mark.

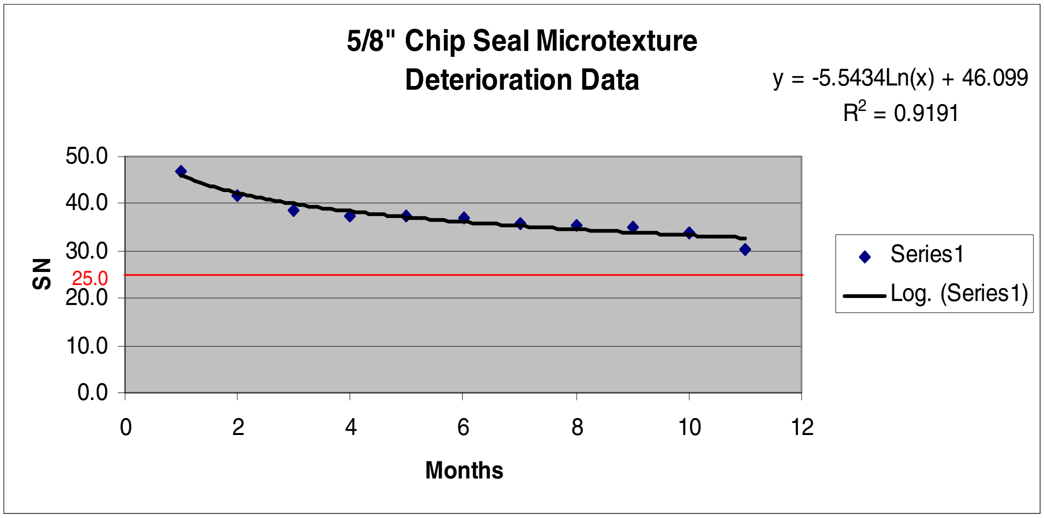

FIGURE 1 Chip seal microtexture field trial performance data.

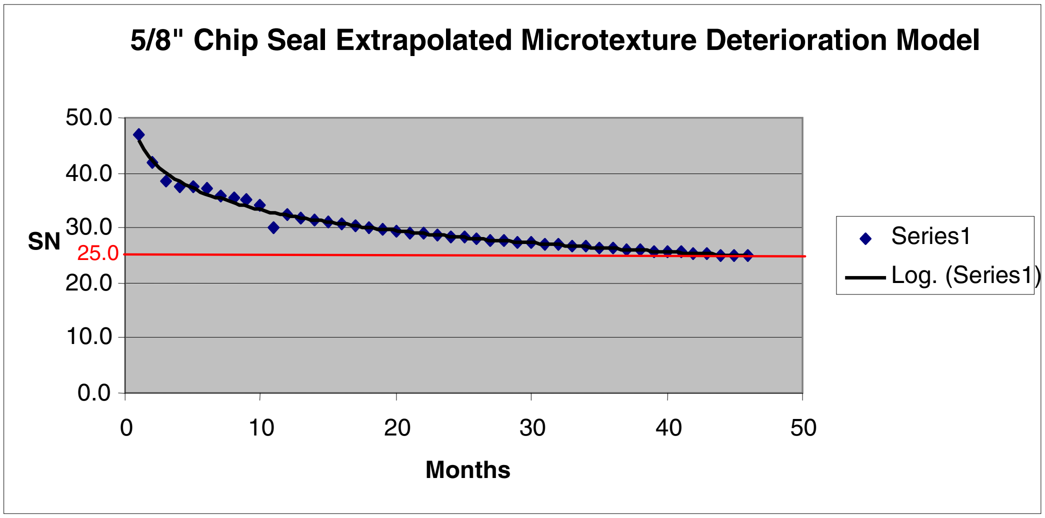

FIGURE 2 Chip seal microtexture deterioration model.

Using the same methodology outlined for microtexture data regression, chip seal macrotexture data was extrapolated (Figures 3 & 4). The chip seal is expected to fall below the failure criteria for macrotexture around 21 months (1.8 years).

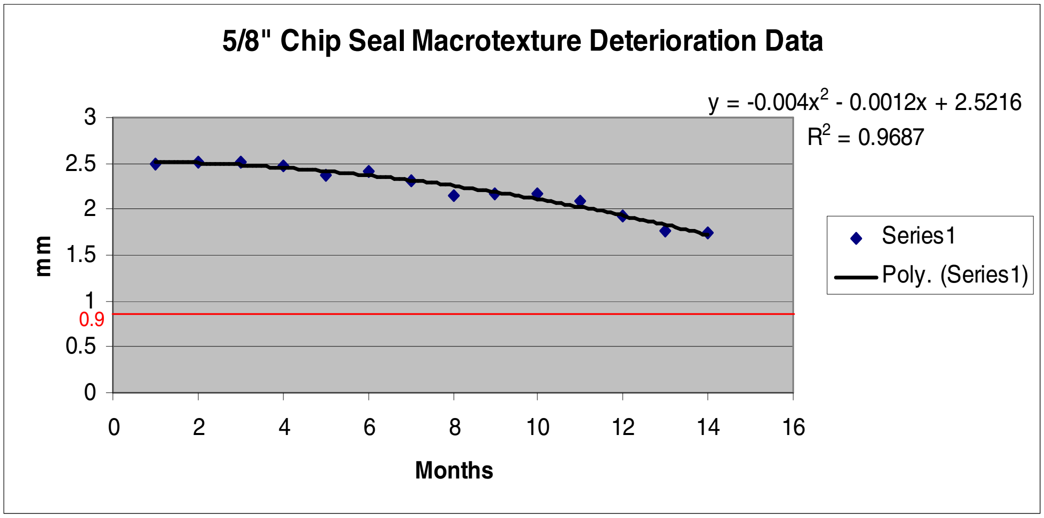

FIGURE 3 Chip seal macrotexture field trial performance data.

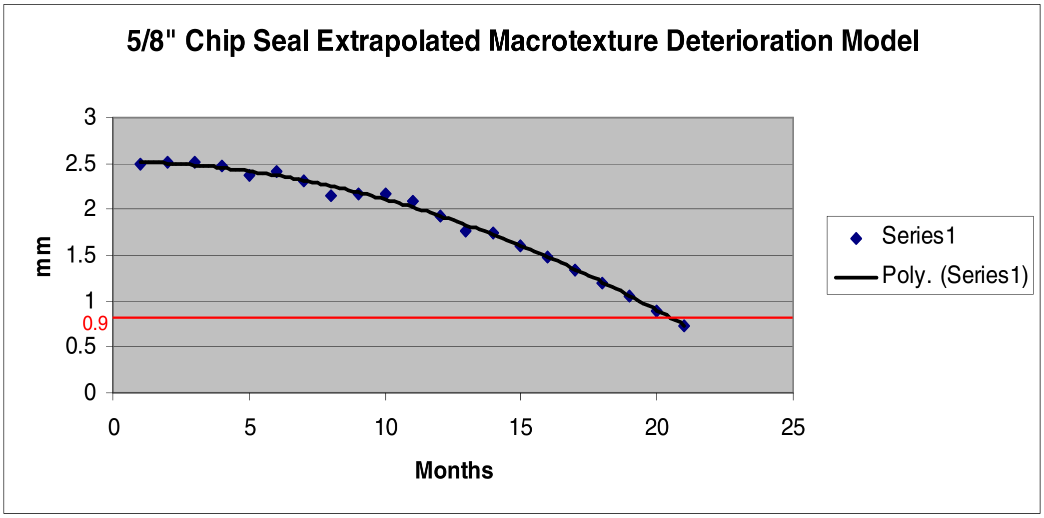

FIGURE 4 Chip seal macrotexture deterioration model.

The resulting approximate service life input values for each alternative were compared to the ODOT survey and literature review results (*11*,*23*,*24*). The average cost for treatments and maintenance came from the ODOT survey and was verified by field trial and vendor data, literature review results (*11*,*23*,*24*), and bid tabulations. These values are displayed in Table 1.

TABLE 1 Treatment Service Life and Average Cost

Pavement Preservation Treatment	Service Life (years)				Average Cost
	Microtexture	Macrotexture	ODOT & Lit. Review	Minimum	$/SY
on asphalt pavement					
1" Hot Mix Asphalt Mill & Inlay (HMA)	>10	N/A	10	10	4.00
Open Graded Friction Course (OGFC)	>10	5.3	10	5.3	3.75
5/8" Chip Seal	3.8	1.8	5	1.8	1.77

The service life input value for each treatment for EUAC LCCA would be the minimum service life value represented in Table 1 and is expressed:

$$SL_{alt} = MIN<Mi, Ma, Ex>$$

Where the service life input for a treatment alternative (SL_{alt}) equals the
MIN (minimum value) of the
Mi (microtexture deterioration model output),
Ma (macrotexture deterioration model output), and the
Ex (pavement manager's expectation of treatment service life).

Conducting EUAC Life Cycle Cost Analysis on Selected Treatments

Treatment cost-effectiveness evaluation based on engineering economic principles was conducted on the pavement preservation treatments listed in Table 1. The FHWA suggests the following LCCA procedures when evaluating design alternatives (*13*,*17*):

1. Establish design alternatives [and AP]
2. Determine [performance period and] activity timing
3. Estimate costs [agency and user]
4. Compute [net present value] life cycle costs
5. Analyze results
6. Reevaluate design strategies

This study has demonstrated that FHWA LCCA procedures 1, 2 & 4 in the above list do not adequately address pavement preservation treatment evaluation and need to be adapted so that it can be used as a frontline tool by the pavement manager to determine pavement treatment cost effectiveness. To recap, EUAC LCCA procedures include:

1. Establish [treatment] alternatives, where a treatment's *anticipated service life* equals its AP: **[ASL_{alt} = analysis $period_{alt}$]**
2. Determine [performance period and] activity timing, where the service life of an alternative equals the minimum value of microtexture and macrotexture deterioration model outputs and engineering judgment:
   [SLalt = MIN{Mi, Ma, Ex}]

4. Compute [EUAC] life cycle costs, where n is each treatment's *anticipated service life:* **[EUAC(i%)alt = [∑P] [$i(1+i)^n \div (1+i)^n - 1$)]]**

and the *anticipated service life* is further adjusted as necessary by the terminal feature of the EUAC model.

FHWA LCCA procedures 3, 5 and 6 are incorporated into the EUAC evaluation. Initial construction costs and associated future maintenance costs were estimated for the alternatives being analyzed. Activity timing includes maintenance, which is a crack seal and 2%-of-total-area patching with a three-year frequency for all asphalt treatments. The selected alternatives and the corresponding minimum service life values from Table 1 were entered into the model, as well as other items required for LCCA.

User costs have been shown to potentially contribute a notable difference between the life cycle costs of preservation treatment alternatives (*7*,*8*), so they were included in this analysis. The initial construction installation time is represented by days, to two significant digits, to capture the differences between alternatives for user cost calculations. Production rates came from the ODOT survey and vendor data. The discount rate selected for the demonstration of the model is 4%, in accordance with FHWA recommendation (*13*). In this calculation, the continuous state is assumed, so each treatment's service life is equal to its *anticipated service life*. Project length will be one lane-mile. The pavement treatment alternative with the lowest EUAC should be considered for selection. EUAC results for the treatments were manually verified and are listed in Table 2.

TABLE 2 EUAC LCCA Results, Continuous Mode

Pavement Preservation Treatment	Microtexture SL	Macrotexture SL	Expected SL
on asphalt pavement	EUAC, $/lane-mile	EUAC, $/lane-mile	EUAC, $/lane-mile
1" Hot Mix Asphalt Mill & Inlay (HMA)	4,696	4,696	4,696
Open Graded Friction Course (OGFC)	4,460	6,434	4,460
5/8" Chip Seal	4,696	7,529	3,651

The FHWA suggests that a sensitivity analysis be included in LCCA (procedure 5). The sensitivity of the service life input value for treatments is exhibited in Table 2. Based on this data, the service life parameter is sensitive, as one should expect, because an alternative's service life and cost are directly correlated in LCCA. By changing the service life input value of chip seal from 1.8 years (Mi) to 3.8 years (Ma) and then to 5 years (Ex), its rank changes from 3 to tied with HMA to 1, respectively.

Essentially, EUAC allows for the sensitivity to be moved from the AP parameter, which may be arbitrary and uncontrollable, to the service life parameter, which allows the pavement manager to intuitively adjust and account for service life selection and sensitivity based on professional judgment. In this case, the pavement manager can consider whether or not the chip seal is expected to remain in service for at least 3.8 years to justify the chip seal decision. Using NPV, the pavement manager would only be able to adjust an arbitrary "common period of time" to assess sensitivity, and the service life sensitivity would be obscured. Extensive economist training would be required to determine service life sensitivity and creates an LCCA-implementation obstacle.

This proves that using field data derived deterioration curves and performance-based failure criteria in an EUAC setting provides a more accurate result than the empirical values for service life in an NPV setting in use for the current FHWA-approved LCCA process. The sensitivity analysis tool, coupled with deterioration models, can yield information that would satisfy "What if" scenarios pertinent to pavement managers and gives the pavement manager the enhanced ability to truly identify, then justify, the most cost-effective pavement treatment for a given project, enhancing stewardship.

The pavement manager would need to put the LCCA results into context, then reevaluate the results in accordance with FHWA "good practices" (procedure 6). LCCA results should be coupled with other decision-support factors such as "risk, available budgets, and political and environmental concerns" (*17*). The output from an LCCA should not be considered the *answer*, but merely an indication of the cost effectiveness of alternatives (*13*).

If the next expected rehabilitation/reconstruction was expected in six years and was entered into the model, the model would automatically *switch* to terminal mode. The HMA and OGFC service lives would be automatically truncated from 10 years to 6 years. Thus, the *anticipated service life* for both would be 6 years. With a 5-year service life, the chip seal EUAC would remain $3,651 as shown in Table 2. With 6-year anticipated service lives, the HMA and the OGFC would have EUAC values of $6,124 and $5,759 respectively. In this case, chip seal would be the preferred alternative. It would also be the intuitive choice because it, with a short "do nothing" period, would efficiently fill the gap. A quick sensitivity analysis, conducted in accordance with FHWA LCCA procedure 5, reveals that even if HMA or OGFC were expected to extend the life of the underlying pavement by its full, 10-year service life, chip seal would still have the lowest EUAC, as shown in Table 2. If, on the other hand, the pavement-life extension parameter was sensitive, the pavement manager may ascertain the effect by intuitively adjusting the year when the next rehabilitation is expected, which will automatically adjust a treatment's *anticipated service life* value until the preferred alternative changes, within the expected limits of service life for alternatives. As in the continuous scenario, the pavement manager is able to intuitively analyze model results in terminal mode because input and output are both in the realm of the pavement manager's expertise.

Comparable NPV Calculations, Continuous Mode

To verify the model, EUAC and NPV were calculated to demonstrate that all should yield the same preferred alternative when gaps and residual values are addressed as discussed and cited as appropriate in the previous sections (*19*). The standard AP was set to twenty years, consistent with an FHWA case study on project-level planning (*11*). User costs were omitted for simplification. All methods returned the same ranking, as illustrated in Table 3, in support of validating the EUAC model as an appropriate pavement preservation LCCA method. This illustrates the point that using different APs corresponding with the differing service lives of alternatives in a life cycle cost analysis does not remove the "fairness" nor does it result in differing benefits; it does, however, bypass the commonly problematic AP selection, associated adjust-to-fit requirements and well-cited sensitivity issues for that parameter.

TABLE 3 Comparable EUAC (Continuous Mode) & NPV Rankings

PAVEMENT TREATMENTS	Agency	Analysis	
	Costs	Period	Rank
EUAC			
ODOT Standard 5/8" chip seal (5-yr)	3,408	5	1
Open Graded Friction Course (10-yr)	4,150	10	2
1" Hot Mix Asphalt mill/inlay (10-yr)	4,367	10	3
Present Value - Shortest Life			
ODOT Standard 5/8" chip seal (5-yr)	15,172	5	1
Open Graded Friction Course (10-yr)	20,463	5	2
1" Hot Mix Asphalt mill/inlay (10-yr)	21,343	5	3
Present Value - Longest Life & LCM			
ODOT Standard 5/8" chip seal (5-yr)	30,344	10	1
Open Graded Friction Course (10-yr)	33,663	10	2
1" Hot Mix Asphalt mill/inlay (10-yr)	35,423	10	3
Present Value - Standard Period			
ODOT Standard 5/8" chip seal (5-yr)	60,688	20	1
Open Graded Friction Course (10-yr)	67,326	20	2
1" Hot Mix Asphalt mill/inlay (10-yr)	70,846	20	3

Comparable NPV Calculations, Terminal Mode

The model should rarely be operated in terminal mode due to a pavement manager's propensity to "do nothing" when the next rehabilitation/reconstruction is known. However, if "do nothing" is not an option, the model can be used to determine the preferred alternative in this short-term period. Although it can yield the same preferred alternative as NPV regardless of AP selected as exhibited in Table 4, it can be sensitive to the AP selection depending on the input data. In an AP-sensitive situation, the EUAC will function like NPV when setting the AP consistent with the shortest-life alternative.

TABLE 4 EUAC (Terminal Mode-Year 6) & NPV Results

PAVEMENT TREATMENTS	Agency Costs	Analysis Period	Rank
EUAC			
ODOT Standard 5/8" chip seal (5-yr)	3,408	5	1
OGFC (10-yr)	5,553	6	2
1" Hot Mix Asphalt mill/inlay (10-yr)	5,889	6	3
Present Value - Shortest Life			
ODOT Standard 5/8" chip seal (5-yr)	15,172	5	1
OGFC (10-yr)	29,111	5	2
1" Hot Mix Asphalt mill/inlay (10-yr)	30,871	5	3
Present Value - Rehab year, Fill the gap for Chip Seal			
ODOT Standard 5/8" chip seal (5-yr)	27,633	6	1
OGFC (10-yr)	29,111	6	2
1" Hot Mix Asphalt mill/inlay (10-yr)	30,871	6	3

CONCLUSIONS

Economic and engineering technical data gathered from pavement preservation field trials can be quantified and correlated to produce meaningful, standardized economic and life cycle cost analysis information that furnishes pavement managers measurable failure criteria to estimate extended service lives of pavements. This research produced a previously unpublished EUAC-based model for LCCA that specifically addresses the nature of pavement preservation treatments and develops LCCA-based pavement preservation treatment design. The model's *fixed flexibility* offered via continuous and terminal scenario allow it to adhere to engineering economic principles and provide the pavement manager project-level evaluation within a wider spectrum of pavement manager expertise. The research also developed a methodology for developing pavement preservation treatment-specific deterioration models and demonstrated how these provide a superior result to those based on empirical service lives. Finally, the research demonstrated how the new model could be utilized to assist a pavement manager in selecting the most economically efficient pavement preservation treatment for a given pavement management problem.

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