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A Cost-Comparison Methodology for Selecting Appropriate Hot-Mix Asphalt Materials

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Supplementary Notes

Abstract

The Virginia Department of Transportation's (VDOT) *Road and Bridge Specifications* lists 9 dense-graded hot-mix asphalt (HMA) surface mixes (three aggregate gradations x three binder types) that could be used on Virginia's highways. VDOT's Special Provision for Stone Matrix Asphalt (SMA) provides 4 additional surface mix options (two gradations x two binder types), for a total of 13 mixes. Although the specifications offer recommendations regarding the types of facilities to program for each mix type, local conditions and experiences heavily influence the predominantly selected mix. Over the past 4 years or so, district pavement managers have routinely used only about 4 dense-graded mixes and 3 of the SMA surface mixes. As material prices continue to climb without budgets doing the same, local circumstances are more often going to contribute to the selection of the less expensive mixes, especially as long as these managers lack a defensible rationale for specifying a more expensive option.

This study offers an economic analysis procedure to help field (i.e., district) pavement engineers select the most cost-effective mix for a given application. The procedure is based on the expected performance of each mix. The performance predictions were developed using the 2006 "windshield" condition rating for Virginia's interstate and state primary roads, which reflects the performance for at least 6 years of Virginia's contemporary dense-graded HMA mixes and for up to 11 years of SMA surface mixes. Through examples using typical project families, the study demonstrated that premium prices for SMA can generally be justified by better performance. In one illustration using actual condition and awarded price data, a life cycle cost analysis revealed that the use of SMA in lieu of dense-graded mixtures on interstates might save VDOT in excess of $7,500 per lane-mile in net present value costs. Extrapolated to the entire Virginia interstate system, the net present value costs associated with an SMA-only resurfacing program would be approximately $25 million less than the next best hot-mix alternative. A final step in this illustration suggests that VDOT can afford (within the FY 2008 spending plan) to pursue an intestate resurfacing program that makes extensive (if not exclusive) use of SMA.

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ABSTRACT

The Virginia Department of Transportation's (VDOT) *Road and Bridge Specifications* lists 9 dense-graded hot-mix asphalt (HMA) surface mixes (three aggregate gradations x three binder types) that could be used on Virginia's highways. VDOT's Special Provision for Stone Matrix Asphalt (SMA) provides 4 additional surface mix options (two gradations x two binder types), for a total of 13 mixes. Although the specifications offer recommendations regarding the types of facilities to program for each mix type, local conditions and experiences heavily influence the predominantly selected mix. Over the past 4 years or so, district pavement managers have routinely used only about 4 dense-graded mixes and 3 of the SMA surface mixes. As material prices continue to climb without budgets doing the same, local circumstances are more often going to contribute to the selection of the less expensive mixes, especially as long as these managers lack a defensible rationale for specifying a more expensive option.

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INTRODUCTION

In 1997, the Virginia Department of Transportation (VDOT) began to adopt the Superpave mix-design system for the design of hot-mix asphalt (HMA) from the previously used Marshall methodology. The transition of the late 1990s started with the incorporation of performance-graded binders and later included aggregate and volumetric characteristics. The 2 to 3 years it took for VDOT to implement this new system fully were important, as many of the early Superpave-designed mixes were coarse (too much large aggregate) and dry (low asphalt binder content) and consequently delivered service lives that were less than expected. By 2000, the first year of full Superpave implementation, VDOT was moving to mixes with finer gradations, increased asphalt binder content, and improved service life.

Predating the adoption of the Superpave system, VDOT began a highly selective application of stone matrix asphalt (SMA). Although the earliest VDOT SMA specification was circa 1993, by 2002, Virginia had placed only a little more than 600,000 tons on a few interstate highway projects. In the summer of 2002, VDOT launched an initiative to implement SMA on high-volume truck and traffic routes across the state. Over the next several years, VDOT went to contract with nearly 1 million tons of SMA (Clark and McGhee, 2006).

By late 2005, although having proven itself (at least anecdotally) as the "go to" hot-mix for high-priority facilities, the premium costs for SMA were beginning to claim noticeable portions of some district pavement construction and resurfacing budgets. As the costs for all construction materials continued to rise, the cost differential between dense-graded HMA and SMA appeared to broaden. By late 2005, some localities did not think they could afford SMA and simply opted for a conventional mix (i.e., dense-graded HMA) that would at least spread further in the short term (Holden, 2006).

VDOT's *Road and Bridge Specifications* lists 9 dense-graded HMA surface mixes (three aggregate gradations x three binder types) that could be used on Virginia's highways (VDOT, 2002a). The Special Provision for SMA (VDOT, 2004) provides 4 more surface mix options (two gradations x two binder types), for a total of 13 mixes. Although the specifications offer recommendations as to the type of facilities to program for each mix type, local conditions and experiences heavily influence the predominantly selected mix. Over the past 4 years or so, district pavement managers have routinely used only about 4 dense-graded HMA mixes and 3 SMA surface mixes. As material prices continue to climb without budgets doing the same, local circumstances are going to contribute more often to the selection of the less expensive mixes, especially as long as these managers lack a defensible rationale for specifying a more expensive option.

PURPOSE AND SCOPE

This report offers an economic analysis procedure to help field (i.e., district) pavement engineers select the most cost-effective asphalt paving mixture. The procedure is based on the expected performance for each mix. The performance predictions were developed using the 2006 "windshield" condition rating for all of VDOT's interstate and state primary roads. These ratings reflect the performance for at least 6 years of VDOT's contemporary dense-graded mixes and for up to 11 years of SMA surface mixes.

METHODS

Performance Modeling

"Windshield" Pavement Condition Survey

To conduct an accurate cost-effectiveness assessment of a material or mix, it is first necessary to estimate its performance. In today's terms, this performance is almost entirely based on how long the mix remains in service, i.e., its service life. Ideally, HMA service life estimates would come from records that covered original installation to replacement ("cradle to grave") on a substantial dataset of mixtures. However, VDOT's history with most of its contemporary mixes goes back only to the late 1990s/early 2000s, and, fortunately, the surface history data do not yet reflect mass replacements on a substantial portion of mixes.

VDOT does conduct annual condition ratings, which offer a gauge of how the predominantly used mixes appear to be performing. Although Virginia has moved to an automated condition survey to improve accuracy and repeatability (VDOT, 2006b), the "windshield" pavement condition survey offers a source from which valuable performance trends can be extracted (VDOT, 2005). The 2006 condition survey, the last complete survey as of this writing, contains condition ratings on all interstate and primary roadways in Virginia. (VDOT, 2006a). The overall rating of a pavement section is reported as a critical condition index (CCI), which is deduced from two individual ratings that measure a pavement's load-related and non–load related distress levels. These distress levels are reported on a scale of 0 to 100. Raters and pavement managers (often many of the same people) use a rating of 100 to reflect a new or like-new condition. These same raters use a rating of 60 as a place to begin at least trying to program a surface for replacement.

Data Cleaning

The windshield survey database (VDOT's Asset Management Division) is extensive, but as with most large databases of "real" information, it contains records that are better left out of many analyses (e.g., legitimate outliers). To ensure relevance to current VDOT mixes, the first "cleaning" step was to remove all data regarding mixes that were no longer among the allowable mix types. Unfortunately, this included any number of legacy Marshall mixes that no doubt exhibited some desirable characteristics. The next cleaning step was to remove all records for pavement sections less than 0.5-mile in length. As data manipulation continued, there were 2 years in which a particular mix was represented by only one section. To prevent these two sections (one per year) from over-representing the performance of an entire class of mixes, they were eliminated. Likewise, a third section was eliminated when it was identified as an experimental mix and, consequently, not representative of the class of mixtures with which it was identified. There were situations in which it was useful, perhaps only for illustrative purposes, to leave a single-section-year example in the analysis. Those special cases are identified in later sections of this report.

Data Preparation

The first step in reducing the condition data was to separate each set of ratings by mix type. With all ratings of a given mix type in one place, the next step was to sort and separate the ratings by age (represented by "year of rehab"). In VDOT's pavement records system, pavement sections are not the same length. In order to keep the condition rating of very short sections from over-contributing relative to longer sections, the CCI values for each section were weighted by length (CCI*length). The weighted average CCI for a given mixture of a given age was then calculated by totaling the length-weighted CCI values and dividing by the total length of all the sections of this mix type and age.

From this point, the data were stratified as necessary to develop performance models within logical families. For instance, the U.S. and State Route (SR) primary data were set aside when the performance of mixes on only the interstate system were examined. When mix performance over existing bituminous structures was investigated, only projects identified as a pavement type of "BIT" were used.

Model Form

Within each family of applications (e.g., interstate, primary, bituminous over jointed concrete, etc.), the modeling of expected service life was straightforward. The weighted average CCI for each mix of each age was plotted against age, and a linear model was developed. The linear model was selected because it was the simplest of models to produce, and nothing was observed in the reduced age versus condition data that suggested that any other type of model would be more appropriate.

Apart from the selection of a linear model, the other major assumptions concerned the CCI values at the beginning and predicted end of the mix's service life. The models forced a *y*-

intercept of 100; i.e., new pavements (of age 0) should have a CCI of 100. To establish the theoretical end of a mix's service live, the terminal CCI was set at 60.

Other Assumptions and Qualifications

Age was the only predictor in these performance models. The exercise also assumed that the correct mixes were prescribed for each application (i.e., for the correct anticipated loading conditions). Likewise, except indirectly through the family groupings, no attempt was made for the performance analysis to account for underlying support conditions and overlay thickness; neither did it incorporate any directly measured quality characteristics (achieved density, asphalt binder content, and other volumetric mixture properties) that certainly impact the performance of a particular mix in a specific application.

Life Cycle Cost Methodology

Initial Cost Recovery

Having predicted service lives for the most common VDOT asphalt mixes (within logical families) made it possible to conduct an analysis of relative cost-effectiveness. This analysis was carried out on two levels. The first and simplest method focused only on the initial costs for each mix. Using a nominal project size and a series of possible contract prices ($/ton), a series of initial costs figures was calculated. Using the expected service life of each mix, an equivalent uniform annual cost (EUAC) formula was developed for each mix using Equation 1. By comparing the EUAC formula, an estimate of the relative value (cost-effectiveness) of each mix is obtained. These relative values can be used as a first screening to determine how much additional investment is justified for one mix versus another.

$$EUAC_i = \frac{P * r}{1-(1+r)^{-n}} \qquad \text{[Eq. 1]}$$

where

$EUAC_i$ = equivalent uniform annual cost based on initial costs ($/yr)
P = initial costs ($)
r = discount rate (4%)
n = predicted service life (yr).

Agency Life Cycle Cost Analysis

In order to produce a more thorough life-costing comparison, it is important to look beyond the initial construction costs. The analytical methodology in this work follows the life cycle cost principles prescribed by the Federal Highway Administration (FHWA) (FHWA, 2002; Walls and Smith, 1998) and VDOT's Materials Division (VDOT, 2002b). In fact, this research simply applies the standard VDOT life cycle cost analysis spreadsheet (VDOT, 2002b) with appropriate modification given the service lives as predicted through this work. Several example comparisons are made using the EUAC-produced justifiable first-cost figures.

RESULTS AND DISCUSSION

Mix Service Lives

After cleaning and screening, the database used to conduct the performance analyses included ratings from the five most commonly prescribed mixes of the past decade. Table 1 lists those mixes, three additional surface mixes, the total number of sections included in the analysis, and the total length of each type of mix that had been rated. The ratings apply only to the *rated* lane (usually the right-most lane). For that reason, the total lane length of each mix actually in service is much higher than is represented in Table 1.

Table 1 also reports the predicted terminal age (the end of life) for each mix type. It is important to emphasize here that this table represents the most common mixes being placed on Virginia's interstate and primary highway systems. The analysis assumes that each mix was applied as recommended and, in that sense, was an appropriate choice for the given situation. Since the data behind Table 1 included no stratification by underlying structure, even indirectly, it would be unwise to draw sweeping conclusions from anything presented in this most aggregate of summaries.

Figure 1 illustrates a step in the performance modeling process that produces the "predicted terminal age" values in Table 1. The trends provided here are intended as examples, but they do offer a qualitative perspective on the relative observed performance of mixes on a statewide basis. Clearly, the SMA mixes are providing the flatter deterioration trends and the dense-graded HMA mixes (using the D binder designation or PG 70-22) account for the steeper descents. The limited number of samples makes it difficult to conclude much about the performance of the two mixes using the E binder designation binder or PG 76-22. There are no more than two data points (mix ages) from which to develop a trend for either E-mix.

Table 1. Predicted Life: All Mixes, All Systems (2006)

Mix	No. Sections	Total Length (mi)	Predicted Term Age (yr)
SM 9.5A	46	115	10.4
SM 9.5D	702	1416	9.1
SM 12.5A	165	415	11.3
SM 12.5D	382	858	8.4
SM 9.5E	10	12	4.0
SM 12.5E	4	11	13.7
SMA 9.5	14	49	18.9
SMA 12.5	129	384	14.2
Total	1438	2244	10.4[a]

A = Superpave binder grading of PG64-22; D = PG70-22; E = PG76-22 with polymer modification. Many SMA mixes predate performance grading (PG), so no PG designation was reported for SMA.

[a]Average predicted life, weighted by length.

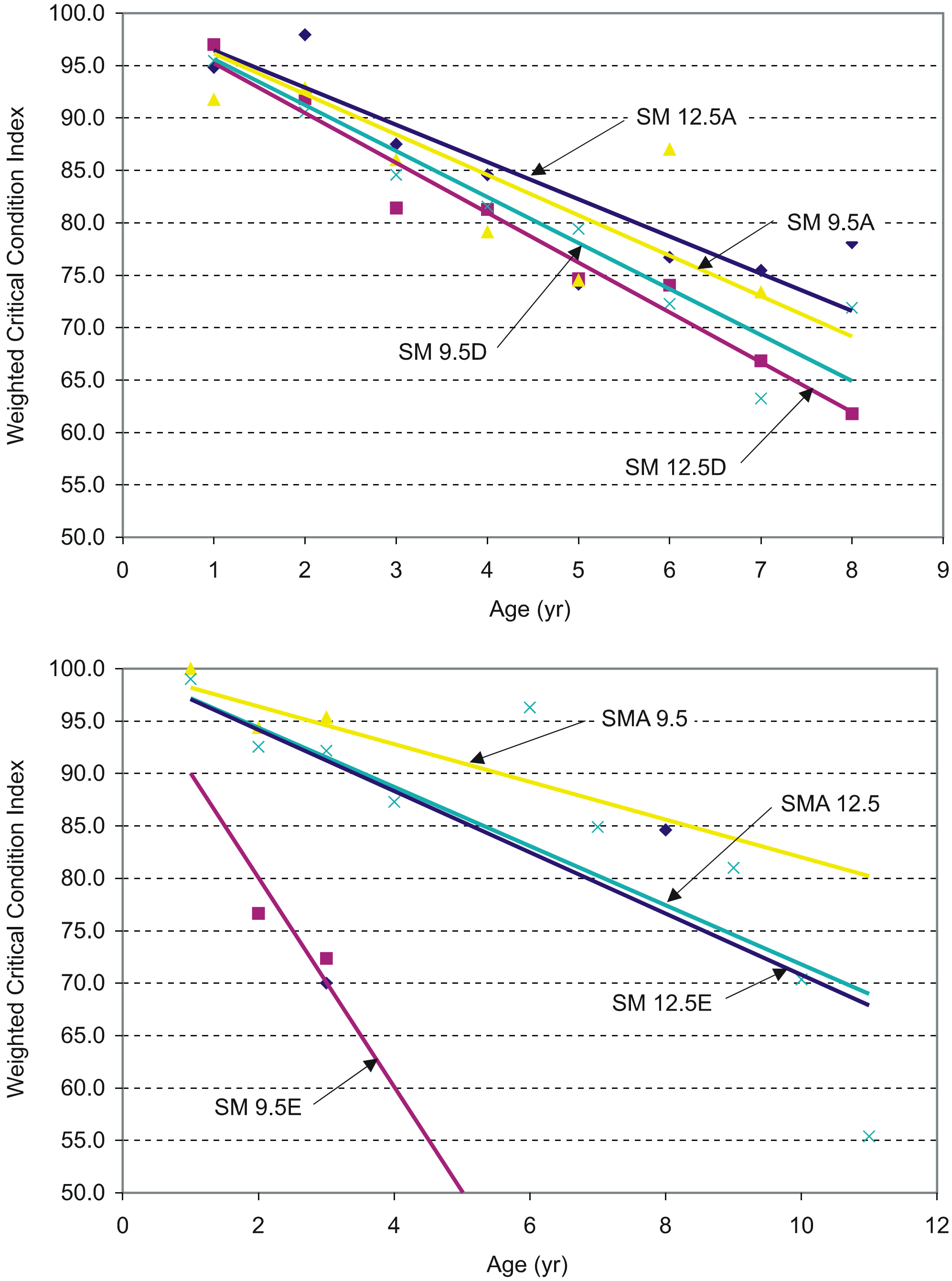

Figure 1. ***Top:*** **Performance trends for commonly used dense-graded mixes (2006).** ***Bottom:*** **Performance trends for SMA and "E" mixes (2006).**

Table 2 summarizes the expected life by mix for the three families that are defined by the general pavement type that was overlaid. At this "bird's-eye" perspective, the mixes that use the A binder designation, or PG 64-22, and the SMA mixes are the best performers over bituminous pavements; the SMA mixes also hold some performance advantage over the dense-graded HMA mixes when used over concrete pavement structures of both the jointed and continuous varieties. None of the mixture types demonstrates as much as a 10-year predicted service life advantage over that of jointed concrete, although SMA holds an approximate 2-year advantage.

Table 2. Predicted Life (Years): General Pavement Type (2006)

Mix	Underlying Surface		
	BIT	BOJ	BOC
SM 9.5A	10.5		
SM 9.5D	8.2	7.6	12.1[a]
SM 12.5A	11.3		
SM 12.5D	7.6	7.6	18.2[a]
SMA 9.5	22.2		
SMA 12.5	17.7	9.4	23.1

BIT = bituminous; BOJ = bituminous over jointed concrete; BOC = bituminous over continuously reinforced concrete.
[a]Only 1 representative section per year in database.

Table 3 reports expected performance by highway system: a coarse but indirect stratification by underlying structure (interstates are typically thicker structures with higher traffic volumes than lower-volume primaries). The SM 9.5A mixes are not recommended for interstates with typical traffic volumes or even high-volume primary routes. The number of SMA 9.5 samples remains very low but was sufficient by 2006 to allow the development of some low-confidence trends. The amount of SMA 12.5 mixture on non-interstate facilities is also very limited.

Referring again to Table 3, the predicted life trends continue to indicate that the Superpave D mixes are not performing as well as the other mixes. This may be due to these mixes being placed under conditions (heavy loads, weak underlying structures) that lead to a shorter service life.

Table 4 shows the performance trends for particular interstate corridors. These corridor analyses attempted to combine sections with similar loading (traffic volumes) and underlying structure.

SMA mixes appear to hold an advantage in predicted service life for all three corridors. It is important to point out that the SMA mixes on the I-95/495/66 corridor were almost exclusively used over jointed concrete (BOJ) pavement structures.

Table 3. Predicted Life (Years): Highway System (2006)

Mix	System	
	Interstate	Primary
SM 9.5A	N/A	10.4
SM 9.5D	7.7	8.5
SM 12.5A	7.8	11.4
SM 12.5D	8.6	8.3
SMA 9.5	13.5	18.3
SMA 12.5	14.2	18.8

Table 4. Predicted Life (Years): Interstate Corridors (2006)

Mix	Corridor		
	I-95/495/66	**I-81/77**	**I-64/295/85**
SM 9.5D	6.6	6.6	9.5
SM 9.5E	4.0	N/D	N/D
SM 12.5A[a]	N/D	I/D	10.0
SM 12.5D	6.4	10.2	7.3
SM 12.5E	I/D	N/D	N/D
SMA 9.5	I/D	N/D	I/D
SMA 12.5	8.0[b]	14.4	23.5[c]

N/D = no data; I/D = insufficient samples for trend.
[a]Only 9 SM 12.5A sections in entire interstate database: 6 on I-64/295/85 corridor.
[b]Almost exclusively bituminous over jointed concrete pavement types.
[c]Predominately bituminous over continuously reinforced concrete pavement types.

Mix Cost-Effectiveness

Service life is certainly an important ingredient for determining the relative value of alternative hot-mix designs. However, to obtain a more complete picture, it is also necessary to explore the costs, both up-front and any future costs, that can be anticipated.

Initial Cost Recovery

An $EUAC_i$ analysis was applied to each of the families described previously. Figure 2 illustrates an interim step in the initial cost recovery exercise. It plots functions that represent the EUAC (for initial costs only) over a spectrum of possible unit prices. This example figure applies the predicted service lives for interstate mixes with an assumed discount factor of 4%. The dashed line in the figure demonstrates how to determine the amount of additional (or

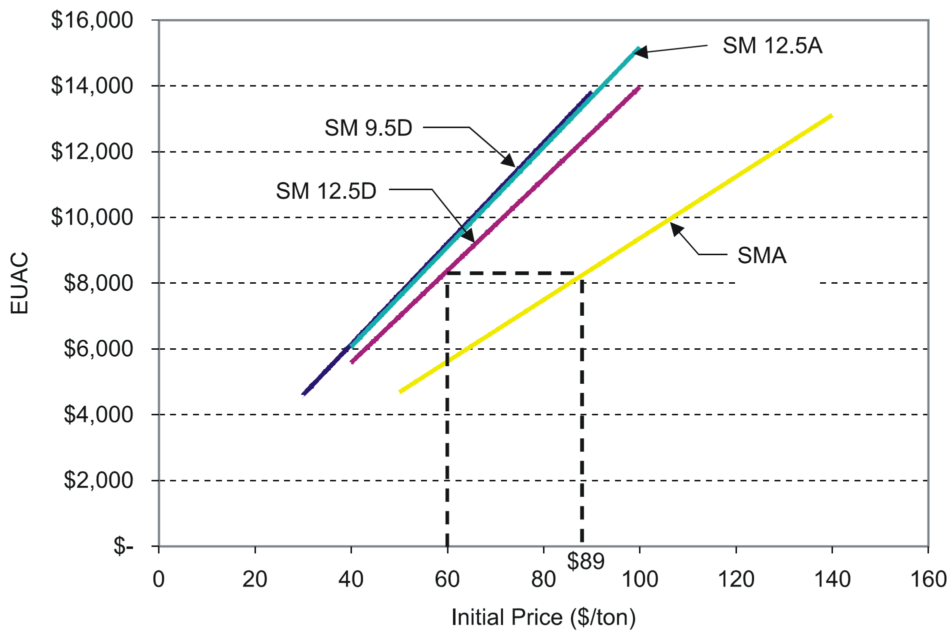

Figure 2. Equivalent Uniform Annual Costs (EUAC): Interstate (2006)

perhaps lower) initial cost that can be justified for opting for one mix versus another. In this example, if the agency believes they can purchase SM 12.5D for $60/ton, they can justify as much as $89/ton for SMA (on a first-cost basis alone).

Using the functions illustrated in Figure 2, it was possible to determine the additional per-ton price (in percentages) that could be justified for any of the families identified earlier. Tables 5 and 6 show the results of that exercise for six of those families. As long as the analysis is kept current, this sort of table provides an easy first-screening tool to determine whether one mix is cost-competitive with an alternative.

Since the most pressing concern at this point is how SMA prices (and performance) compare with those of alternative dense-graded mixes, the comparisons drawn in Tables 5 and 6 emphasize mixes and families that are associated with high-volume facilities and high-traffic mixes.

Table 5. Break-even Price Differential (%) for Interstate Over Existing Bituminous, Jointed, and Continuously Reinforced Concrete Pavements (2006)

Default Mix (A)	Comparison Mix (B)	BIT	BOJ	BOC[a]	Interstate
SM 9.5D	SM 12.5D	–6	0	35	10
SM 9.5D	SMA 12.5	82	20	58	64
SM 12.5D	SMA 12.5	94	20	17	49

BIT = bituminous; BOJ = bituminous over jointed concrete; BOC = bituminous over continuously reinforced concrete.
[a]See Table 2 regarding limited dataset for SM-D mixes.

Table 6. Break-even Price Differential (%) for Major Interstate Corridors Over Existing Bituminous, Jointed, and Continuously Reinforced Concrete Pavements (2006)

Default Mix (A)	Comparison Mix (B)	I-95/495/66	I-81/77	I-64/295/85
SM 9.5D	SM 12.5D	–3	45	–21
SM 9.5D	SMA 12.5	18	89	105
SM 12.5D	SMA 12.5	21	31	158

Note: Mix B is worth the price of Mix A plus the percentage shown.

Agency Life Cycle Cost Comparison

The initial costs recovery exercise is more economically correct than a simple comparison of bid prices, but it does not tell the whole story when it comes to lifetime agency costs. At this point, the best tool for that analysis is VDOT's *Guidelines for Life Cycle Cost Analysis* (VDOT, 2002). Table 7 summarizes the present worth analysis for the bituminous over continuous concrete (BOC) family. The total present worth (cost) values represent 1 mile of two 12-foot lanes of pavement at a thickness of 1.5 inches. The analysis starts with the SM 9.5D (the most used VDOT mix) price of $52.50, which was about average as of February 2006 (Kiefer, 2006). It then inserts the break-even unit costs for the two most realistic alternative mixes: SM 12.5D and SMA 12.5. Finally, the analysis uses the predicted service life estimates for each mix and the assortment of life-time maintenance activities (and costs) shown in the Appendix. The analyses do not incorporate replacement of intermediate or base mixes, assuming that the need (and costs) for such replacements would be the same for each project.

Table 7. VDOT Life Cycle Cost Analysis Results for Mixes Over Continuous Concrete (2006)

Mix Type	Estimated Price ($/ton)	Present Worth[a] ($/mi)
SM 9.5D	52.50	167,203
SM 12.5D	70.88[b]	155,398
SMA 12.5	82.95[b]	149,732

[a]4% discount rate.
[b]Calculated using "break-even" differential prices (see Table 5).

The present worth totals in Table 7 are important because they demonstrate the short-sightedness of the initial costs recovery analysis. Had the EUAC been sufficient for comparing cost-effectiveness, the total present worth values in Table 7 would be equal. One more cost to consider—if not quantitatively, at least qualitatively—is the user cost associated with the alternatives. Depending on the various assumptions that must be made when considering traveler impacts, the user-cost component can be anywhere from negligible to an order of magnitude greater than the agency costs. In any case, that component will always factor in to favor the longer service life options. Therefore, as far as Table 7 is concerned, any credit given user costs will always make the SMA mixes appear more cost-effective as compared to the dense-graded HMA mixes.

COSTS AND BENEFITS ASSESSMENT

Net Present Value Costs

To illustrate the cost implications of a systematic application of the methodology outlined in this report, it is perhaps helpful to consider what the benefits might be to one of the broader families of projects discussed earlier in the report. For instance, the latest available mileage tables indicate that VDOT is maintaining approximately 5,375 lane-miles of interstate highway (VDOT, 2007a). Approximately 85% of that, or 4,570 miles, is surfaced with hot-mix asphalt. In 2006, the average price for each of the most commonly used mixes (for interstate work) was $53.51 per ton for SM 9.5D; $56.37 per ton for SM 12.5D; and $83.55 per ton for SMA 12.5 (Kiefer, 2006). Using these actual costs, the service-life estimates for interstate pavements (from Table 3), and the LCCA procedures as outlined in the Appendix, it is fairly easy to calculate the net present value costs for the three mixes (Table 8, Column 4). Clearly, even at the higher initial prices, the per-lane-mile net present value costs for the SMA work is estimated to be the lowest of the three mixes: $8,667 per mile lower than for SM 9.5D, and $7,788 per mile lower than for SM 12.5D.

Before these "per-mile" costs can be translated into "entire system" costs, it is important to account for the fact that resurfacing programs that are built around mixes with different service lives have different annual resurfacing needs. A simple way to estimate the annual resurfacing requirements is to use the "predicted life" data shown in Table 8 (based on the 2006 condition survey) for each mix and assume that the resurfacing program has reached a steady state (i.e., a repeating cycle of replacement in kind). Working with these data, the cost of long-term and exclusive use of each mix can be estimated (Table 8, Column 5). Using this annual

Table 8. VDOT Life Cycle Cost Analysis Results ($) for Interstate Mixes

Mix (Program)	2006 Price ($/ton)	Predicted Life[a] (years)	Net Present Value Cost (per lane-mile)	Annual Resurfacing[b] (miles per year)	Resurfacing Cost[c] ($ per year)	Net Present Value Cost (system)
SM 9.5D	53.51	7.7	107,474	594	19,055,119	63,786,497
SM 12.5D	56.37	8.6	106,595	531	17,972,853	56,644,340
SMA 12.5	83.55	14.2	98,807	322	16,133,387	31,799,299

Note: The interstate mixes as summarized comprise a different family than that used as an example in the Appendix, which relates to performance over concrete.
[a]*Based on 2006 Condition Survey Data*
[b]Annual resurfacing required = Total system length (e.g., 4,570 lane-miles)/Predicted life.
[c]This assumes 600 tons of HMA per mile.

program and the previously calculated per-mile present value cost for each mix, the total present value cost can be calculated for each annual program (Table 8, Column 7). In this illustration, the net present value cost associated with an SMA 12.5-only resurfacing program would be approximately $25 million less than for a SM 12.5D program and approximately half ($32 million less than) that of an SM 9.5D-only program. In terms of annual required investment, the SMA program would be $3 million less expensive than the least attractive option, i.e., the SM 9.5D program.

Relevance to Actual Needs and Available Resources

The ability of VDOT to consider seriously an interstate resurfacing program that puts a priority on these more robust materials (e.g., SMA) has everything to do with whether a realistic maintenance budget could support the required investment. One important complication to matching real-life budgets and hot-mix material requirements is the high proportion of work, especially for interstates, in which the existing surface must be removed before it is replaced (i.e., mill-and-replace). To address this reality, the per-mile cost of resurfacing must incorporate a typical cost for pavement milling (to the necessary depth). VDOT's Scheduling & Contracts Division provides an estimated unit cost for milling of $2 per square yard when milling to a depth of 1.5 to 2 inches (Thompson, 2007). This per-square-yard cost translates into an additional per-mile cost of just over $14,000, regardless of the new material being placed. If deep milling and a thick inlay (3 to 4 inches) are warranted, then the price of material and the milling process goes up accordingly. Table 9 summarizes the approximate per-mile cost for each of the three relevant mix types.

Table 9. Estimated Cost ($) Per Mile

Mix (Program)	Overlay[a]	Mill and Overlay[a]	Mill and Thick Overlay[b]
SM-9.5D	32,106	46,186	107,767
SM-12.5D	33,822	47,902	111,771
SMA 12.5	50,130	64,210	149,823

[a]Assumes 600 tons of HMA per mile (unit HMA prices per Table 8).
[b]Assumes 1,400 tons of HMA per mile and additional milling costs proportional to the additional quantity of replaced material (no reduction for less expensive lower layer).

These per-lane-mile cost estimates make it easy to convert system-wide budget numbers quickly into miles of new surface. The most current budget figures (for FY 2008) are available from VDOT's Operations Planning Division and are provided in Table 10 (VDOT, 2007b). Table 10 also uses the per-lane-mile cost estimates just developed to show the size program that can be supported with this planned spending.

A summary of the 2006 condition survey also provides information that helps to match available funding against apparent need. Remember that the original condition survey database underwent several iterations of "data cleansing" (discussed earlier) before it was suitable for generating basic predicted life trends. A revisit to that database at an early phase of this cleaning process provides condition ratings that represent approximately 2,650 of the 4,500 miles (60 percent) of flexible interstate pavement in Virginia. Granted, many of these unaccounted-for miles are likely ramps and miscellaneous facilities that are not rated anyway. Still, if the assumption is made that the available ratings are representative of the entire interstate system, then the needs of the overall system can be estimated using these ratings. Table 11 summarizes the actual (sample) ratings and the estimated ratings for the entire population of interstate pavements from 2006. Recalling that VDOT targets pavements with ratings of 60 and below for some sort of treatment (also discussed earlier), it appears that at least 366 miles of interstate would warrant some attention in the upcoming resurfacing cycle.

Fortunately, referring back to Table 10, it appears that VDOT's spending plans can accommodate this level of need. In fact, it appears that VDOT can afford to pursue these needs with its most robust (and expensive) hot-mix alternative, i.e., SMA. The "Thin Resurfacing" spending program alone could finance approximately 431 lane-miles of SMA (at average 2006 prices). The "Mill and Thick Overlay" program provides for an additional 123 miles of more substantial activity.

Table 10. FY 2008 Planned Flexible Pavement Spending for Interstate System

Activity	FY 08 Budget	Resurfacing Possible within Budget (lane-miles)		
		SM 9.5D	SM 12.5D	SMA 12.5
Overlay (Activity 72233)	$10,813,567	337	320	216
Mill and Overlay (72239)	$13,815,095	299	288	215
Total "Thin" Resurfacing	**$24,628,662**	**636**	**608**	**431**
Mill and Thick Overlay (73355)	$18,483,252.00	172	165	123
Total Resurfacing	**$43,111,914.00**	**807**	**773**	**554**

Table 11. 2006 Condition Survey Summary

CCI[a]	Sample (lane-miles)	Estimated Population (lane-miles)
40 and less	18	31
41 to 50	80	137
51 to 60	116	198
61 to 70	509	866
71 to 80	479	816
81 to 90	748	1272
91 to 100	696	1184
Total	2647	4503

[a]Critical Condition Index: deduced from two individual ratings that measure a pavement's load-related and non–load related distress levels.

CONCLUSIONS

- *Annual pavement condition ratings can be used to project reasonable service life expectations for Virginia's most common HMA types*. Using average condition indices for each age and simple straight-line projections, the overall expected service life for each mix within a logical family (e.g., interstate only) of projects can be predicted.

- *Equivalent uniform annual cost comparisons are a good tool for screening expected initial costs of competing HMA alternatives.* Given a predicted service life, an estimated per-ton price, and an assumed discount rate, simple engineering economics can be applied to determine the expected equivalent annual cost of alternative mixes. These annual costs can be compared in order to screen for justifiable first-cost differentials.

- *Total present worth (cost) analysis using VDOT's Guidance on Life Cycle Costs Analysis for Pavements (VDOT, 2002b) provides a rational method for determining the relative cost-effectiveness of competing HMA alternatives.* The total present worth analysis incorporates anticipated future maintenance costs and initial costs. A comprehensive analysis may also incorporate expected lifetime user costs.

- *Stone matrix asphalt outperforms dense-graded hot-mix asphalt in Virginia when placed in similar conditions.* In most cases, a premium price for SMA is justified by the anticipated increase in performance.

- *SMA is the most cost-effective hot-mix material for use in maintaining pavements on Virginia's interstate system.* This conclusion is based on a comparison of net present value costs for the most common hot-mix asphalt alternatives (as determined using 2006 condition survey data and 2006 unit price data).

- *VDOT's Maintenance Program appears capable of funding an adequate interstate resurfacing program through exclusive use of its most robust (i.e., SMA) hot-mix asphalt material.* The planned spending for FY 2008 is sufficient to meet the flexible pavement needs for the interstate system as identified in the 2006 condition survey. Of course, the estimates generated in this report contain no project-level design or construction detail; they are based purely on high-level (reasonable) network assumptions.

RECOMMENDATIONS

1. *VDOT's Asset Management Division should routinely generate service life predictions by mix type using annual condition survey records.* This report demonstrates a simple approach for conducting this analysis and producing rudimentary performance comparisons. Engineers and analysts are urged to revisit this exercise with input from the more automated condition survey (VDOT, 2006b) conducted presently on some Virginia systems (i.e., interstate).

2. *VDOT pavement engineers, managers, and district coordinators (VDOT's Materials Division and Asset Management Division) should use the "justifiable initial cost differences" from Tables 5 and 6 to screen expected bid prices for alternative mixes.* The district officials who are ultimately responsible for mix selection are encouraged to work with VDOT's Asset Management Division to "customize" the service life analyses to maximize the relevance to the given selection.

3. *When expected price differences between alternative mixes (baseline price plus justifiable additional) are close to those shown in Tables 5 and 6, district pavement officials should conduct a whole-life economic comparison using VDOT's Life Cycle Costs Analysis for Pavements (VDOT, 2002b; see the Appendix).* The decision regarding the final mix selection should not ignore user and administrative costs, which will always favor the option with the longest anticipated service life.

4. *VDOT's Materials Division, VDOT's Asset Management Division, and the Virginia Transportation Research Council should develop better tools for tracking performance and predicting mix service life.* The analysis presented here applies no direct accounting for underlying support conditions or expected traffic loading. At a minimum, some mechanism to represent structural sufficiency and traffic loadings (e.g., axle loading spectra) objectively should be incorporated into future performance models.

5. *Decision makers from VDOT's Construction Districts, Materials Division, and Asset Management Division should pursue an interstate resurfacing program that makes extensive (if not exclusive) use of stone matrix asphalt (SMA).* Preliminary calculations suggest that VDOT can afford (and justify) an adequate SMA-based interstate resurfacing program within the planned FY 2008 maintenance spending.

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APPENDIX
TOTAL LIFE CYCLE COST ANALYSIS

Alternative 1

SM 9.5D (Observed Performance for BOC Pavements - 2006 Windshield)

Project Length = 5,280 Feet
Analysis Base Year = 2006
Discount Rate = 4%

Total Travel Lanes Width =	**24**	**Feet**
Inside Shoulder Width =	**0**	**Feet**
Outside Shoulder Width =	**0**	**Feet**
Mainline Area =	**126720**	**Sq. Ft.**
Inside Shoulder Area =	0	**Sq. Ft.**
Outside Shoulder Area =	0	**Sq. Ft.**

Analysis Year	**Calendar Year**	**Activity**	**Thick (inches)**	**Quantity**	**Unit**	**Unit Cost ($)**	**Total ($)**	**PWC ($)**
0	2006	Mainline - AC Surface	1.5	1,162	Tons	53	60,998	60,998
					Cost Estimate		60,998	60,998
12	2018	Mainline - Pre-Overlay Full-Depth Patching (1%)	0	0	Tons	0	0	0
		Mainline - Mill	1.5	21,120	SY-in	1	21,120	13,191
		Mainline - Replace AC Wearing Course	1.5	1,162	Tons	53	60,998	38,099
					Cost Estimate		82,118	51,291
24	2030	Mainline - Pre-Overlay Full-Depth Patching (5%)	0	0	Tons	0	0	0
		Mainline - Mill	1.5	21,120	SY-in	1	21,120	8,239
		Mainline - Replace AC Wearing Course	1.5	1,162	Tons	53	60,998	23,797
					Cost Estimate		82,118	32,036
36	2042	Mainline - Pre-Overlay Full-Depth Patching (1%)	0	0	Tons	0	0	0
		Mainline - Mill	1.5	21,120	SY-in	1	21,120	5,146
		Mainline - Replace AC Wearing Course	1.5	1,162	Tons	53	60,998	14,863
					Cost Estimate		82,118	20,010
48	2054	Mainline - Pre-Overlay Full-Depth Patching (5%)	0	0	Tons	0	0	0
		Mainline - Mill	1.5	21,120	SY-in	1	21,120	3,214
		Mainline - Replace AC Wearing Course	1.5	1,162	Tons	53	60,998	9,284
					Cost Estimate		82,118	12,498
50	2056	Salvage Value (portion remaining life)	0.83	1	Lump Sum	(82,118)	(68,432)	(9,629)
					Cost Estimate		(68,432)	(9,629)
						Initial Const.		**$ 60,998**
						Total PW		**$ 167,203**

Alternative 2
SM12.5D (Observed Performance for BOC Pavements - 2006 Windshield)

Analysis Year	Calendar Year	Activity	Thick (inches)	Quantity	Unit	Unit Cost ($)	Total ($)	PWC ($)
0	2006	Mainline - AC Surface	1.5	1,161.86	Tons	70.88	82,347	82,347
					Cost Estimate		82,347	82,347
18	2024	Mainline - Pre-Overlay Full-Depth Patching (1%)	0	0.00	Tons	-	-	-
		Mainline - Mill	1.5	21,120.00	SY-in	1.00	21,120	10,425
		Mainline - Replace AC Wearing Course	1.5	1,161.86	Tons	70.88	82,347	40,649
					Cost Estimate		103,467	51,074
36	2042	Mainline - Pre-Overlay Full-Depth Patching (5%)	0	0.00	Tons	-	-	-
		Mainline - Mill	1.5	21,120.00	SY-in	1.00	21,120	5,146
		Mainline - Replace AC Base	0	0.00	Tons	-	-	-
		Mainline - Replace AC Intermediate	0	0.00	Tons	-	-	-
		Mainline - Replace AC Wearing Course	1.5	1,161.86	Tons	70.88	82,347	20,065
					Cost Estimate		103,467	25,212
50	2056	Salvage Value (portion remaining life)	0.22	1.00	Lump Sum	(103,467)	(22,993)	(3,235)
					Cost Estimate		(22,993)	(3,235)
							Initial Const.	**$ 82,347**
							Total PW	**$ 155,398**

Alternative 3

SMA12.5 (Observed Performance for BOC Pavements - 2006 Windshield)

Analysis Year	**Calendar Year**	**Activity**	**Thick (inches)**	**Quantity**	**Unit**	**Unit Cost ($)**	**Total ($)**	**PWC ($)**
0	2006	Mainline - AC Surface	1.5	1,162	Tons	83	96,377	96,377
					Cost Estimate		96,377	96,377
23	2029	Mainline - Pre-Overlay Full-Depth Patching 1%	0	0	Tons	0	0	0
		Mainline - Mill	1.5	21,120	SY-in	1	21,120	8,569
		Mainline - Replace AC Wearing Course	1.5	1,162	Tons	83	96,377	39,103
					Cost Estimate		117,497	47,671
46	2052	Mainline - Pre-Overlay Full-Depth Patching 5%	0	0	Tons	0	0	0
		Mainline - Mill	1.5	21,120	SY-in	1	21,120	3,477
		Mainline - Replace AC Base	0	0	Tons	0	0	0
		Mainline - Replace AC Intermediate	0	0	Tons	0	0	0
		Mainline - Replace AC Wearing Course	1.5	1,162	Tons	83	96,377	15,865
					Cost Estimate		117,497	19,342
50	2056	Salvage Value (portion remaining life)	0.83	1	Lump Sum	(117,497)	(97,062)	(13,658)
					Cost Estimate		(97,062)	(13,658)
							Initial Const.	**$ 96,377**
							Total PW	**$ 149,732**