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Asphalt.

PAVEMENT TYPE SELECTION

A POSITION PAPER BY

THE ASPHALT PAVEMENT ALLIANCE

Asphalt.

CONTENTS

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Preface

In general, there are no greater investments made by a transportation agency than the construction or reconstruction of pavements. The financial and highway user impacts are great and far-reaching. Pavement type selection deserves analysis commensurate with such investment. Pavement selection involves many factors, as you will learn from this synthesis. One thought, however, must always take precedence: that is, pavements are intended to serve highway users. To the extent that the pavement selection serves users, by ensuring that they travel on pavements that are safe, smooth, quiet, durable, economical, and constructed of sustainable materials, the designer has succeeded in meeting this important objective.

Pavement type selection processes are universally utilized by state departments of transportation and other agencies responsible for roadway construction to identify and select the most durable, cost-effective, highest-performing pavement structure for a new roadway. These processes are intended to be free of bias and provide an analytical review of environmental and performance factors such as soil type, climate, traffic volume, life cycle, constructability, and cost. All these factors are weighted in a uniform, repeatable process with the singular goal of selecting the best pavement type at the greatest overall value to the taxpayer and with a service life which provides the maximum return on the public's investment.

In addition to technical and performance factors, roadway owners have been confronted with the need to consider secondary qualitative factors while selecting a pavement material type. These factors include consideration of such issues as tire-pavement noise generation, surface smoothness, and environmental sustainability. Asphalt pavements meet these needs and studies have conclusively shown asphalt pavements provide the smoothest, quietest ride with the greatest overall satisfaction for the motoring public. Asphalt is both a recyclable and a reusable resource. Innovations such as warm-mix asphalt and use of reclaimed asphalt pavement (RAP) have placed the industry as a leader in improving air emissions and in conserving virgin aggregates and natural resources.

This document was prepared by the Asphalt Pavement Alliance to provide a synthesis of the primary items for consideration when selecting a pavement type and to present the advantages of asphalt pavement in their conformance to these criteria. It is based on the American Association of State Highway and Transportation Officials (AASHTO) *1993 Guide for the Design of Pavement Structures* and the new AASHTO *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures.* Asphalt pavements have a proven record of long-life performance for all levels of traffic, different subgrade types, and all types of climates. They have a history of economy, speed of construction, and flexibility of construction scheduling. Finally, asphalt pavements are sustainable structures due to their recyclability, low greenhouse gas generation, and long life. Asphalt pavement should be considered in any pavement type selection process.

Introduction

Pavement type selection is a process used by a pavement authority such as a state highway agency to identify the most beneficial type of pavement structure for a given set of traffic, soils, climate, and other factors. It is sometimes as simple as specifying a certain type of pavement on the basis of traffic level, or it may be as complicated as assigning weighting factors to more than a dozen characteristics and evaluating the outcome through a scoring system. Whatever process is used, it should be a rational and explainable methodology in which the effects of different variables on decision making may be determined. Information used to develop the process should reflect documented historical performance and cost records.

Although the method for selecting a type of pavement varies greatly from agency to agency, the American Association of State Highway and Transportation Officials (AASHTO) provides broad guidance. The *1993 AASHTO Guide for the Design of Pavement Structures* outlines the considerations for pavement type selection in its Appendix B. The primary factors to be considered include traffic, soils characteristics, weather, construction considerations, recycling, and cost comparison. The secondary factors include performance of similar pavements in the area, adjacent existing pavements, conservation of materials and energy, and availability of local materials, among other issues. Appendix B of the new AASHTO *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures* (AASHTO M-E PDG) lists factors encompassing considerations for engineering, traffic, environmental, construction, economic, and other factors. Fundamentally, although there is a difference in the presentation of the factors between the old and new AASHTO *Guides,* there are no real differences in the basic considerations.This position paper was prepared in order to discuss the primary considerations in pavement type selection as presented in the two AASHTO *Guides* in detail, and to present the advantages available from asphalt pavements in each of these. Other considerations include the issues of tire-pavement noise generation, ride quality, and safety, and the advantage asphalt has in these characteristics.

Principal Factors

Traffic

The AASHTO *Guides* point out that traffic forecasts have been notoriously inaccurate in the past, despite the best efforts to accommodate changes in land-use planning. The changes in traffic patterns brought about by the construction of new roadways and the decline in rail freight service are mentioned as contributing factors in the underestimation of traffic. The *Guides* also suggest that increased truck loads may become a reality as fuel costs increase. The 1993 *Guide* states that a margin of safety should be employed when designing pavements to account for the uncertainty in traffic projections. AASHTO encourages comparisons of alternate strategies including initial design, rehabilitation, and maintenance which can be evaluated to provide for equivalent service over a given period of time. Finally, the need for long pavement life with minimal traffic disruption is paramount on congested roadways. In the new AASHTO *Guide,* the roadway geometrics and roadway features are mentioned specifically as having a potential impact on the speed and channelization of traffic. The concerns expressed include the possibility for increased repetitions of loading over a given point in the pavement and the potential for larger deformations under slower loads.

» ASPHALT PAVEMENTS CAN HANDLE HEAVY LOADS

Asphalt pavements have demonstrated outstanding performance across the spectrum of traffic loadings and conditions. Asphalt is by far the most popular pavement material for low- and medium-traffic roadways, and has proven itself over time under heavy truck traffic in urban and rural settings. Even under heavy, static, and channelized loadings such as those at port facilities and commercial airports, asphalt pavements have provided excellent service.

In heavy-duty highway pavements, asphalt is often the pavement of choice such as I-695, the Baltimore Beltway, which has an annual average daily traffic (AADT) of 215,000 vehicles. The Washington D.C. Beltway (I-495), Atlanta's I-285, San Antonio's loop I-410, and I-80 in Oakland are all examples of high-traffic roadways where asphalt was selected as the pavement type of choice. The Baltimore-Washington International (BWI) Airport, the Port of Seattle, and the Port of Portland, Oregon are examples of heavy-duty asphalt pavements subjected to extreme loads. It should be noted that the BWI Airport was presented with a Perpetual Pavement Award from the Asphalt Pavement Alliance in 2002 for two long-life asphalt runways that are now (in 2010) over 60 years old.

Many technological improvements in asphalt pavements have been made in order to handle increased loads. These improvements have included the introduction of polymer-modified binders, the development of Superpave binders and mix design, and the introduction of stone-matrix asphalt (SMA) as a premium surface material.

» ASPHALT OFFERS FLEXIBILITY IN CONSTRUCTION, MAINTENANCE, AND REHABILITATION

One of asphalt's primary advantages is that it allows for a number of construction scenarios. Staged construction allows a pavement structure to be built up over time, meaning that expenditures for a road take place gradually when total funding may not be available all in one year, or if it is anticipated that traffic will be gradually added to the road because of circumstances such as the completion of bridges. Because asphalt can be constructed during off-peak traffic times, the stages of construction can be accomplished with minimal traffic disruption. When comparing the impact of off-peak traffic construction to a 24-hour lane shutdown, the user-delay costs can be as much as three orders of magnitude lower with the off-peak-hour option than with the full-day closure option.

» ASPHALT PROVIDES FOR EASY MAINTENANCE AND REHABILITATION

Asphalt provides unequaled ease of maintenance and rehabilitation. The most popular option for surface renewal of asphalt pavements is the "mill and fill" process, which allows close-coupling milling and paving operations, and this minimizes the area of lane closure. As with staged construction, the ability to perform these operations during periods of below-peak traffic provides a great benefit to road users. Using echelon paving, as well as night and weekend scheduling of work, means minimal inconvenience to traffic. The road can be opened to traffic in a matter of hours, rather than days or weeks. Again, the user-delay costs associated with the shorter work time means a tremendous saving for the traveling public and shipping businesses. Shorter lane closures also mean greater safety for vehicles traversing the work zone.

» ASPHALT PAVEMENTS LAST AND STAY SMOOTH

Asphalt has a proven track record when it comes to long life and smoothness. A study of asphalt pavements on interstate highways in Oregon and Washington State shows that the average age of the asphalt pavements on these systems is about the same as or greater than the concrete pavements (Figure 1). A graph showing the smoothness of interstate highways in Washington is presented in Figure 2. Here the International Roughness Index (IRI) versus the number of kilometers for asphalt and concrete roads illustrates that asphalt pavements are generally smoother than concrete pavements (*Mahoney et al., 2007*). In other words, asphalt pavements have lower IRI values. Similar results were reported in an FHWA publication (2002) where it was reported that 80 percent of the asphalt pavements had an IRI of less than 1.5 m/km whereas 80 percent of the concrete pavements had an IRI of less than 2.0 m/km. This type of asphalt pavement performance on interstate highways has also been documented in Connecticut, Kansas, Minnesota, New Jersey, and Ohio. All of these studies have shown that well-designed and well-built asphalt pavement structures can remain in place with only infrequent resurfacing.

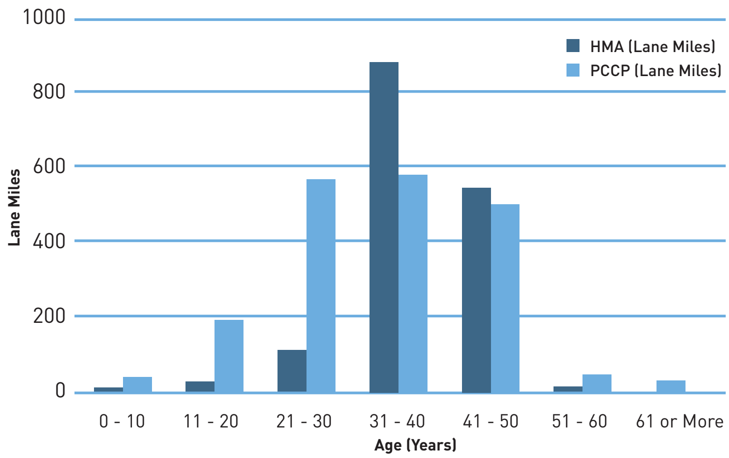

FIGURE 1: AGE DISTRIBUTION FOR INTERSTATE PAVEMENTS IN WASHINGTON STATE.

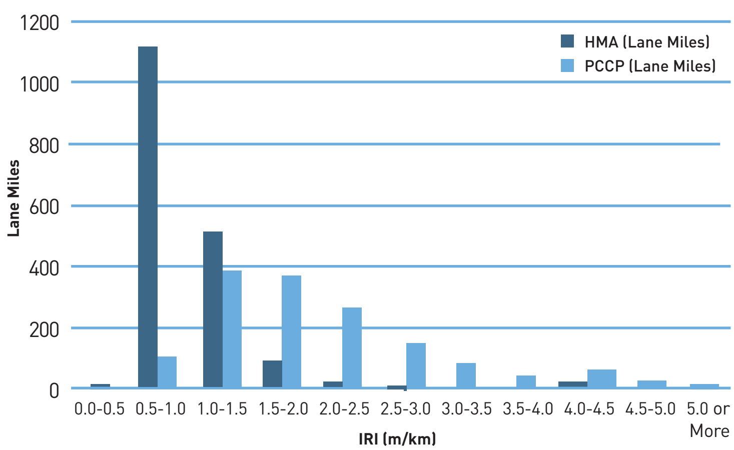

FIGURE 2: INTERNATIONAL ROUGHNESS INDEX FOR INTERSTATE PAVEMENTS IN WASHINGTON STATE.

To highlight the performance of properly designed asphalt pavements, the Asphalt Pavement Alliance has presented the Perpetual Pavement Award to agencies with pavements that are at least 35 years old, with intervals between overlays of no less than 13 years on average and with no structural failures. Between 2001 and 2010, 69 highway and airfield pavements have received this award, and there are many more that have yet to be nominated. The ability to provide long service life while avoiding the need for costly and time-consuming reconstruction is the hallmark of a Perpetual Pavement.

Soil Characteristics

The AASHTO *Guides* emphasize the importance of the underlying soil characteristics to pavement performance. Both geographical variability and seasonal variability are mentioned as being primary concerns in the design of the pavement structure. The *Guides* also state that the nature of the soil in a given area may dictate the economic viability of a pavement type. As an example, they mention the use of staged construction to achieve satisfactory ride quality over a soil subject to volume change. The importance of the foundation in terms of construction and performance of the pavement cannot be overemphasized. The stiffness of the working platform must be sufficient to allow compaction of the overlying pavement structure in order to obtain adequate density in the granular and asphalt layers to ensure performance.

» ASPHALT IS USED ON ALL TYPES OF SOILS

Asphalt pavements have been successfully employed over any type of soil on which a pavement may be constructed, from gravel to peat. The type of soil will dictate what type of treatment might be employed to obtain the desired performance regardless of what type of pavement is to be built. For instance, because of long-term settlement concerns, a lightweight fill may be used over peat formations prior to constructing an asphalt pavement. Lime treatment of expansive clays is often used to minimize volume change in certain areas. A combination of undercutting and mechanical stabilization is sometimes used in areas with frost heave. There are numerous techniques that can be used to improve subgrade behavior in all types of pavements. Asphalt provides an additional advantage in being able to accommodate a certain amount of settlement or displacement in the underlying soil without a significant loss in serviceability.

Weather

AASHTO discusses the effects of weather on both the subgrade and the wearing course of the pavement. In the new AASHTO *M-E PDG*, these are referred to as environmental considerations. Precipitation in the form of snow, ice, and rainfall affects the strength of soils on a seasonal basis. Likewise, moisture and temperature, in terms of freezing and thawing, have an impact on the road surface. The ability of the surface to facilitate snow clearing operations through solar absorption and its resistance to wear from clearing equipment can both factor into the type of surface selected.

» ASPHALT PAVEMENTS CAN BE DESIGNED FOR ANY WEATHER

In climates ranging from the cold of Alaska to the warmth of Florida, asphalt has been specified for the vast majority of pavements. Seasonal weakening in subgrade soils can best be handled through a thickness design procedure that will provide enough stress reduction on the subgrade to prevent permanent deformation in the soil or base materials during critical periods. In the past, CBR (California bearing ratio) and R-value tests were used to obtain subgrade strength measurements in a saturated condition, which insured that the pavement thickness determination was conservative. With the AASHTO *M-E PDG*, thickness design focuses on the soil resilient modulus as the measure of pavement bearing capacity. The advantage of using resilient modulus is that the value may be adjusted according to season to better characterize a pavement's responses to loads throughout its life.

As for surface characteristics, asphalt provides a variety of effective options to handle warm climates. Rut-resistant SMA and Superpave surfaces have performed very well in warm weather, as evidenced by the rutting performance of asphalt mixtures at the National Center for Asphalt Technology (NCAT) Test Track in Alabama. Over the course of 10 million equivalent single axle loads, the rut depth of all the mixtures came out to be less than 0.3 in., with the average of rutting in all the test sections being slightly more than 0.1 in. (*Brown et al., 2002*).

While rutting resistance is also a characteristic of open-graded friction courses (OGFCs), the main advantage of OGFCs is the ability to drain water from the road surface, increasing the skid resistance and reducing the splash and spray. This type of surface should be considered an elective, life-saving safety feature to be used whenever feasible on high-speed roadways. OGFCs have been used on freeways in cold-weather states such as Massachusetts, New Jersey, and Wyoming, and in warmer climates such as Arizona, California, Florida, Georgia, North Carolina, and Texas.

A study of the Long-Term Pavement Performance Program's SPS-9 test sections showed that the relatively new PG (performance-graded) asphalts have resulted in improved thermal cracking resistance of asphalt pavements in cold weather (Kavanaugh, 2004). As for snow removal, asphalt pavements continuously prove their ability to resist the wear of snowplow blades, and asphalt's dark color promotes earlier melting of ice and snow.

Construction Considerations

The 1993 AASHTO *Guide* states that the option of staged construction may dictate the type of pavement chosen in a given situation. Other factors such as speed of construction, access to businesses, maintenance of traffic during construction, safety, ease of placement, accommodation of future widening, and timing of construction during the year are also important in the selection of pavement type.

» ASPHALT ALLOWS STAGING OPTIONS

Asphalt pavements allow for flexibility in construction, both in the ability to stage the construction sequence and in the ability to minimize the time for lane closures. Staging construction is often advantageous when funding levels or weather do not allow for a facility to be completed in a single year. The ability to build a substantial portion of the structure and then to finish it later helps agencies stretch budgets to take care of more projects in tight times. Also, if construction happens to start later in the year, and finishing it would push the schedule into cold weather, then letting traffic use the road over the winter and waiting for the next season to put on the wearing course allows maximum use of the facility.

» ASPHALT PAVEMENTS CAN BE BUILT FAST

Speed of construction is one of asphalt's primary advantages. Asphalt does not need a cure time of days or weeks, it merely needs to cool to a temperature that allows it to support loads, usually only a matter of hours after final compaction. There are numerous examples of freeway and airport pavement projects where asphalt pavements were completed in a matter of weekends with minimal disruption of traffic. This minimizes the cost of delays to pavement users, whether they are highway drivers and passengers, freight truckers, or airlines and airline passengers. It also helps to minimize the amount of emissions that result from traffic delays on highways due to idling engines. Thirty-two lane-miles of I-285 in Atlanta were constructed with asphalt using full shutdown for 56-hour work windows on weekends over a period of 22 weeks (*Public Works, 2002*). A similar strategy was employed in the rehabilitation of the I-710 freeway near Long Beach, California in 2003. In this case, weekend shutdowns were used to crack and seat the existing concrete pavement, which was then overlaid with asphalt. The traffic on I-710 at that time consisted of about 150,000 vehicles per day with 15 percent trucks. This project is notable because I-710 is the main corridor between the Port of Long Beach and the main railhead to transport goods across the country.

Warm-mix asphalt technology was used to reconstruct the main runway at the international airport in Frankfurt, Germany, which is the tenth largest air cargo hub in the world. This involved the mobilization of equipment late each night, removal of a portion of the concrete pavement, the placement and compaction of the warm mix, and having the pavement ready for air traffic by 6:00 a.m. every day.

» ASPHALT CONSTRUCTION TIMING IS A MATTER OF FLEXIBILITY

Because asphalt does not need to cure, traffic can be allowed during peak hours and construction can take place during off-peak periods. As with the examples in Atlanta and Long Beach, a series of complete weekend closures allows lanes to be available during weekday traffic, or if traffic dictates, the pavement can be closed and work can be accomplished during the night and reopened for traffic during the day as was done at the Frankfurt International Airport. A detailed traffic study, including hourly volumes and alternate routes, and a public information campaign will help to minimize user cost and inconvenience. In any case, long, user-expensive shutdowns are not needed to construct asphalt pavements.

Recycling

According to the 1993 AASHTO *Guide*, the option of recycling the existing pavement or material from other sources may be a reason to select a particular type of pavement. Future recycling opportunities may also factor into the decision.

» ASPHALT IS AMERICA'S MOST RECYCLED MATERIAL

Asphalt is unique in composite construction materials in that when it is recycled back into a new asphalt mix, the binder is reused as well as the aggregate. Reclaimed asphalt pavement (RAP) saves on the amount of new binder needed in an asphalt mixture because the RAP binder still functions to coat the RAP aggregate and when it bonds to the new asphalt, it helps create the needed cohesion. This saves the need for both new asphalt and new aggregate, creating a more sustainable product.

About 90 percent of the asphalt pavement that is removed is recycled back into pavement. This amounts to about 100 million tons of material annually that is saved from landfills. Recycling saves resources in terms of virgin asphalt and aggregate, resulting in simultaneous savings in energy and cost. The "mill and fill" operation, frequently used in the surface renewal process, allows properly sized recycled material to be taken from the roadway and placed in a stockpile ready for use.

» OTHER REUSED MATERIALS CAN ENHANCE ASPHALT PERFORMANCE

There is a variety of by-products from other industries that can serve useful functions in asphalt pavements. For instance, roofing shingles provide asphalt, fine aggregate, and fibers. The asphalt binder available in roofing shingles has been especially crucial in certain areas in reducing the demand for new asphalt. Adding as little as 5 percent waste roofing shingles to an asphalt mixture can save as much as 20 percent of the total binder needed in the mix. Also, steel slag has been used for many years as a hard, durable aggregate in asphalt pavements. Rubber from waste tires is being successfully used in asphalt mixtures in a number of states, most notably Arizona, California, Florida, and Texas. Sand from foundry castings can be used as a portion of the fine aggregate in the mix.

Simply viewing asphalt mixes as a depository for waste materials is not the goal the industry is striving to achieve. As long as waste materials provide improved economy, environmental friendliness, future opportunities for asphalt recycling, and engineering performance, their use in asphalt mixes should be encouraged. Each of these considerations should be weighed before introducing them.

Cost Comparison

The AASHTO *Guide* states that cost comparison can be used to aid in decision making when several pavement types could perform well and there are no other dominant factors.

The *Guide* acknowledges there are instances when initial cost may preclude other cost considerations, but it encourages life-cycle cost analysis. Initial costs, the cost of staging, the predicted performance life, maintenance costs, and salvage value are mentioned as factors in the *Guide*. It also states that user delay costs can be factored into the decision process. The length of the analysis should be long enough to incorporate a representative rehabilitation or reconstruction for each alternative.

» LIFE-CYCLE COST ANALYSIS IS IMPORTANT

The Asphalt Pavement Alliance supports the determination of life-cycle costs of alternative pavement types as part of a rational means for decision making. An appropriate and non-biased method for life-cycle cost analysis is promoted by the Federal Highway Administration (FHWA) in Demonstration Project No. 115 (*FHWA, 1998*). It uses the net present value approach for determining the costs of several alternatives. Using this procedure, all of the considerations in the AASHTO *Guide,* including user delay cost, can be accommodated. The APA has developed software capable of performing life-cycle cost analysis using the FHWA procedure. This software can be downloaded for free from **http://www.asphaltroads.org/why-asphalt/economics.html.**

A simplified sketch of how the net present value method of life-cycle cost analysis works is shown in Figure 3. The initial cost, the rehabilitation costs, and salvage value are all entered according to what their values would be in terms of the present value of money. Then a discount rate is applied to account for the time value of money and the anticipated rate of inflation, and the future rehabilitation costs and salvage value are discounted back to the present. The life-cycle cost is the sum of the initial costs and discounted future costs and salvage value.

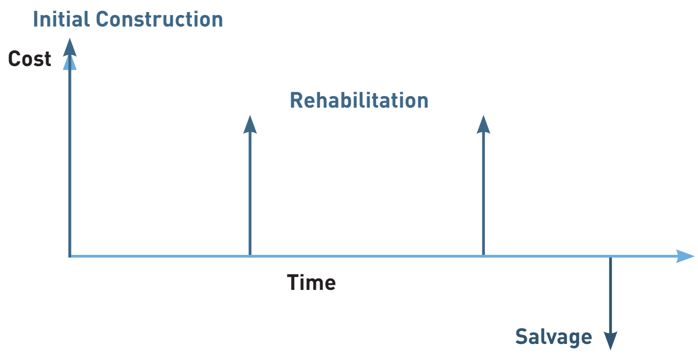

FIGURE 3: SKETCH OF NET PRESENT VALUE APPROACH TO LIFE-CYCLE COST ANALYSIS.

A summary of different state practices pertaining to life-cycle cost analysis is given in Appendix A. Here, the times to first, second, and third overlays are presented along with discount rates and total analysis period lengths. These were based on a survey of state asphalt pavement associations and contractors.

In determining the life-cycle cost of a pavement, it is important to include only those costs which pertain to the pavement. In other words, costs such as striping, sod, guardrails, etc., should not be included unless the difference in pavement type causes a cost differential in these items.

» INITIAL COST

The basis for initial cost should be unit prices from bid records of recent construction projects. An average price for projects constructed over the last two or three years is a fairly common approach. Care should be taken that only representative prices are included. For example, very small projects or projects where paving is only a minor component of the total cost may cause unit prices to be skewed.

It is realistic to consider the initial cost both by itself and as part of the life-cycle cost analysis. This recognizes that the agency is constrained by an annual budget, and needs to examine the short-term ramifications of expenditures as well as the long-term impact of pavement type decisions. For example, while a higher initial cost option may have a more attractive maintenance schedule, selecting it may mean that fewer projects get completed in a given year.

» STAGING COSTS

If staged construction is to be used, then its cost should be discounted from the planned time back to present in terms of the net present value, and not included in the initial cost. In other words, the future stages should be considered as future costs in the life-cycle cost analysis.

» PREDICTED PERFORMANCE LIFE

In putting forth a scenario for performance life, it is important that the agency refer to its past experiences with different pavement types. With respect to the performance of asphalt pavements, it is recommended that at least two categories be used: asphalt pavements less than 8 inches thick over granular base and asphalt pavements thicker than 8 inches. It is important to document the performance from the time of original construction or reconstruction until the next reconstruction. It is worth noting that simple overlays and mill and fill operations are rehabilitation activities and do not mark the end of the pavement life.

The analysis period should be long enough to capture major rehabilitation or reconstruction activities for all pavement options. It should be noted that when the Perpetual Pavement concept is used, reconstruction occurs well outside the normal analysis period of 30 to 50 years. The Asphalt Pavement Alliance recommends that the analysis period be no less than 40 years and that it include at least one rehabilitation activity for each pavement option. This complies with the FHWA-recommended minimum of 35 years. The data in Appendix A suggest that the average analysis period used is about 38 years, with the most frequently used value being 40 years.

In life-cycle cost analysis, it is very important that the timing and extent of the first rehabilitation be based upon actual construction and pavement management data rather than memory or judgment. Appendix A shows that, on average, the time to first overlay is 15.1 years, according to the survey of state practices. However, the most frequently occurring interval to first overlay among states is 20 years. The average time to the second overlay is 27.2 years. These figures correspond well with an FHWA study of asphalt overlay performance from the Long-Term Pavement Performance Program study which showed that most overlays lasted for over 15 years and many lasted for more than 20 years before significant distress was noted (*FHWA, 2000*).

It should be noted that most of the above data and policies reflect averages, and, in some cases, engineering judgment in place of data over a number of decades and rehabilitation practices in different jurisdictions. Most do not account for recent improvements in the selection of materials, mix-design procedures, and pavement-design methods. The implementation of Superpave occurred in the mid-1990s, and SMA was adopted by a number of agencies throughout the 1990s, so the impacts of these improvements on performance have not been fully realized. Such improvements come at higher costs for materials, so it is logical to give some conservative credit for performance although it may not be completely documented. When performing an analysis of pavement performance, it is important to differentiate between new construction and various rehabilitation strategies. For example, the time to the first overlay is often different from the time to the second overlay. Also, there will be differences in performance between thick and thin overlays. Another factor relating to performance is whether the overlays are placed on asphalt or unfractured concrete. It is advisable for an agency to conduct its own analysis of pavement performance and to determine its own strategies for life-cycle cost analysis. Using Perpetual Pavement concepts, it is possible for a state to go longer than 60 years using only periodic overlays on an existing structure.

» MAINTENANCE COSTS

Maintenance costs are frequently difficult to define because of either a lack of record keeping or because of accounting practices that do not appropriately discriminate between different types of maintenance activities (e.g., between restoration of side slopes and shoulder sealing). Maintenance costs in a life-cycle cost analysis (LCCA) usually have minimal impact when compared to the initial and first rehabilitation costs. If maintenance costs are used in an LCCA procedure, then historical documentation of actual pavement activities and expenditures should be used. As with rehabilitation, unrealistically frequent or inappropriate maintenance activities can artificially increase life-cycle cost.

» SALVAGE VALUE

Because some or all of the pavement structure continues to serve its purposes beyond the analysis period, it is important to account for its condition at the end of the analysis period. Salvage value is typically the term used in life-cycle cost analysis, but FHWA chooses to use the term remaining service life (RSL) value to distinguish the idea that the pavement will continue to serve beyond the end of the analysis period. The RSL value, according to the FHWA, should be considered as a ratio of the period of time from the last rehabilitation to the end of the analysis period, and from the last rehabilitation to the next projected rehabilitation, times the cost of the last rehabilitation (*FHWA, 1998*). Another method used is to consider the salvage value as some percentage of the initial pavement construction cost.

The use of Perpetual Pavement concepts would allow for the maximum salvage value in life-cycle cost analysis. In this case, it is suggested that the salvage value would be the value of the structure plus the value of the remaining pavement surface life times the discount rate.

» DISCOUNT RATE

The 1993 AASHTO *Guide* does not specifically mention the issue of discount rate, but the new *M-E PDG* does. The selection of a discount rate in life-cycle costing can be contentious because there is a great deal of uncertainty associated with future interest rates and inflation. However, the time value of money has been historically established to reflect that money loses its relative value with time. An unreasonably low or negative discount rate essentially means that it would not matter financially if a project were to be constructed today or 10 years from now and overemphasizes the influence of uncertain future costs. Too high a discount rate would overemphasize the importance of the initial cost and not allow the proper influence of future maintenance and rehabilitation costs over the analysis period. FHWA (1998) recommends using a discount rate between 3 and 5 percent, and the *M-E PDG* recommends establishing the discount rate according to that set by the federal Office of Management and Budget Circular A-94 which is updated annually. This circular may be accessed online at **http://www.whitehouse.gov/omb/rewrite/circulars/a094/a094.html.**

Appendix A shows that for the states surveyed, an average discount rate of 3.8 percent is used, with a range between 2.3 and 7.1 percent. It is interesting to note that 23 states have chosen to use a discount rate of 4 percent when performing life-cycle cost analysis.

» ASPHALT PAVEMENTS COST LESS

The economics of pavement type selection vary according to jurisdiction because of issues such as material availability, specification requirements, design methodologies, etc. It is important for each agency to conduct a realistic assessment of pavement economics in order to provide objective input into the life-cycle cost analysis. Examples of asphalt pavement's economic advantages are cited below.

In a comparison of costs for reconstructing highways in Colorado (*CTL Thompson, 2002)*, it was shown that, on the basis of initial cost, asphalt pavements were 14 percent less costly than concrete.

A study of the cost of interstate pavement ownership in Kansas (*Cross, 2002*) found that asphalt pavements were 22 percent cheaper to build and 60 percent cheaper to operate over a 40-year period.

A comparison of asphalt and concrete interstate pavements in Ohio (*Gibboney, 1995*) showed that asphalt pavements cost less to build initially and required only small incremental investment in the form of overlays, compared to the cost of reconstruction for concrete pavements. Asphalt pavements were up to 20 percent cheaper to build and between 30 and 80 percent cheaper to maintain

At the end of a pavement's service life, the question arises as to whether rehabilitation or reconstruction is needed. As discussed above, reconstruction is normally used when the existing pavement is concrete, and this is extraordinarily expensive when compared to the rehabilitation processes normally used for asphalt pavements. When the concepts of Perpetual Pavements are employed, then the future rehabilitation costs are minimized, making the economics even more attractive.

Further advantages in asphalt pavement economics can be realized in the preservation of existing grade lines in urban areas and in the vicinity of overpasses. The use of mill and fill rehabilitation means that the pavements on streets with medians, curbs, and gutters can be maintained at their current elevations without complete removal, as opposed to concrete pavements that would need to be removed or undergo very expensive and time-consuming patching operations. The mill and fill approach to rehabilitation is especially attractive under existing overpasses where elevating the road profile would require expensive efforts to raise the bridges.

Other Considerations

There are considerations beyond those discussed above that may be used in determining the type of pavement appropriate for a given situation. It is important to review these in order to develop a holistic justification for pavement type selection decisions.

Sustainability

It is becoming increasingly important to consider the environmental and economic impacts of pavement type selection and construction both now and in the future. Many of the practices used in the construction of asphalt pavements over the last few decades are recognized as sustainable.

It has been common practice to incorporate recycled materials in asphalt mixtures since the late 1970s. Recycling has important implications on the consumption of raw materials and the processing it takes to incorporate them into the pavement. By reusing the asphalt binder in the RAP, it is possible to consume less virgin binder, which conserves petroleum. The reuse of aggregate allows for less mining. Currently, there are about 18 billion tons of asphalt mixtures in place on U.S. roadways. Virtually all of this material is available for future generations to use. Furthermore, waste materials from other industries such as waste shingles, slag, foundry sand, and tire rubber can all be beneficially incorporated into asphalt mixtures.

Emissions from asphalt mix plants have improved dramatically over the years, declining by 97 percent since 1970, while the production of asphalt mixtures increased by 250 percent. The emissions improved to the point that the Environmental Protection Agency removed them from the list of major sources of hazardous air pollution. Newly available warm-mix asphalt technologies can reduce the temperatures required to produce and place the material, reducing fuel consumption as well as emissions.

The speed of construction and flexibility in timing rehabilitation also contributes to an improved environment. Because roadway work on asphalt pavements is frequently accomplished during off-peak traffic hours, it is possible to significantly reduce congestion and reduce the accompanying vehicle emissions.

The construction of Perpetual Pavements is a very sustainable practice because the design is such that the overall structure remains intact with only infrequent resurfacing required. This reduces the materials consumed over the long term and results in a low life-cycle cost.

Asphalt pavements have a low carbon footprint compared to other pavement types. While a certain amount of atmospheric carbon is generated in the production of raw materials and mix production, it is far lower than the amount generated in the production of portland cement concrete when one considers the amount of carbon dioxide released in the manufacturing of the cement. The carbon contained in the asphalt binder is also bound in the product rather than being released to the atmosphere through burning.

Noise

Noise generation can be considered on high-speed roadways. At speeds over 50 mph, the predominant traffic noise comes from tire-pavement interaction. Using a low-noise surface reduces traffic noise at the source. Studies have shown that dense-graded asphalt mixtures can reduce the noise level by 2 to 3 dBA compared to concrete pavements. A reduction of 3 dBA from 76 to 73 has the same effect as either reducing the traffic by half or doubling the distance from the source of the noise (*Wayson,1998*). A noise reduction of up to 5 dBA can be obtained by using an SMA surface, and a reduction of up to 9 dBA can be obtained by using an open-graded friction course (*Wayson,1998*).

Roughness

Asphalt pavements are generally very smooth upon construction. If they are properly designed structurally, they maintain their smoothness better than if they are under-designed. Asphalt pavements are built in lifts instead of all in one layer like concrete pavements. Each lift provides the opportunity to obtain a better ride quality in the final product. Thus, it is easier to obtain a smooth pavement with asphalt. Furthermore, an FHWA study (*Perera et al.,1997*) of the data from the Long-Term Pavement Performance Program shows that asphalt overlays provide excellent smoothness, regardless of the pavement roughness prior to rehabilitation. Data from the WesTrack experiment (*FHWA, 2000*) show that smoother pavements can save highway users fuel and maintenance costs. It was noted that after rehabilitation of rough pavement sections, fuel costs for the trucks used in this field study decreased 4.5 percent and the number of vehicle fatigue failures decreased drastically.
As shown in the Washington State study (Figure 2), interstate asphalt pavements are smoother than interstate concrete pavements. Given that the rolling resistance of a vehicle will be primarily affected by the pavement's roughness, the smoother pavement will promote lower fuel consumption (*Marks, 2009*).

Safety

Each time a new asphalt surface is applied to an existing pavement, an opportunity presents itself to renew the friction and water-handling characteristics of the roadway. The use of hard, durable aggregates, combined with technology designed to reduce rutting and consequently reduce hydroplaning, will enhance the skid resistance of the pavement. Furthermore, if a new generation open-graded friction course is applied to the surface, not only are the skid resistance and rutting resistance improved, but the amount of splash and spray during rainstorms is also reduced, which improves driver visibility. Delineation of lanes and pavement markings is enhanced with asphalt pavements.

Summary

In making a decision concerning the type of pavement to use on a roadway, an agency is obligated to get the best value for the taxpayers. It is up to contractors to provide the pavement that gives the best possible performance at the lowest possible price. Thus, pavement type selection should be a road user-oriented process, not an industry-oriented process.

In order to accomplish this, the system used to select pavement type should be:

1. Objective
2. Defensible
3. Understandable
4. Based on historical records
5. Primarily driven by economics
6. Periodically reviewed

Asphalt pavements possess many advantages in the primary factors listed in the *AASHTO Design Guides.*

Among these are low initial cost, low maintenance costs, flexibility and speed of construction, the ability to handle heavy loads, a long life, and complete recyclability. Furthermore, asphalt pavements allow an opportunity to reduce traffic noise at the source and improve ride quality. Asphalt pavements should be considered in every pavement type decision. A check list is enclosed as a handy reference when considering the pavement type to be selected.

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Appendix A

Summary of Life-cycle Cost Inputs from Various States

State	Year at 1st Overlay	Year at 2nd Overlay	Year at 3rd Overlay	Year at 4th Overlay	Total Years	Discount Rate
Alabama	12.0	20.0			28.0	4.0
Alaska-North	10.0	20.0			20.0	
Alaska-South	15.0	30.0			30.0	
Arizona	15.0	20.0	30.0		35.0	4.0
Arkansas	12.0	20.0			30.0	3.8
California	20.0	25.0	30.0	35.0		4.0
Colorado	10.0	20.0	30.0		40.0	3.5
Connecticut	15.0					
Delaware	12.0	20.0			30.0	3.0
Florida	14.0	28.0			40.0	4.0
Georgia	10.0	20.0			40.0	3.0
Hawaii	17.0	35.0			40.0	4.0
Illinois	20.0	40.0			40.0	3.0
Indiana	20.0	35.0				4.0
Iowa	20.0	40.0			40.0	
Kansas	12.0	22.0	32.0		40.0	3.0
Kentucky	10.0	20.0	30.0		40.0	4.0
Louisiana	15.0	30.0			30.0	4.0
Maine	16.5	25.5				4.0
Maryland	14.8	26.6			40.0	4.0
Massachusetts	18.0	34.0				3.0
Michigan	13.0	26.0			26.0	2.8
Minn < 7 MESALs*	20.0	35.0			50.0	3.5
Minn > 7 MESALs*	15.0	27.0	40.0		50.0	3.5
Mississippi	12.0	22.0	30.0		40.0	4.0
Missouri	20.0	33.0			45.0	2.3
Montana	15.0	27.0				4.0
Nevada	20.0				35.0	4.0
New Hampshire	20.0	31.0				4.0

Appendix A (continued)

State	Year at 1st Overlay	Year at 2nd Overlay	Year at 3rd Overlay	Year at 4th Overlay	Total Years	Discount Rate
New Jersey	15.0	30.0			40.0	4.0
Nebraska	20.0	35.0			50.0	2.4
North Carolina	10.0	20.0			30.0	4.0
Ohio	12.0	22.0	34.0		35.0	2.8
Oklahoma	15.0	30.0	45.0			
Oregon	20.0	40.0				4.0
Pennsylvania	10.0	20.0			35.0	6.0
Rhode Island	20.0	31.0			20.0	4.0
South Carolina	12.0	22.0			30.0	
South Dakota	16.0	32.0			40.0	7.1
Tennessee	10.0	20.0	30.0		40.0	4.0
Texas**						
Vermont	17.5	31.0				4.0
Virginia	12.0	22.0	32.0	44.0	50.0	4.0
Washington	15.0	30.0	45.0		50.0	4.0
West Virginia	22.0	26.0	50.0		50.0	3.0
Wisconsin	18.0	30.0	42.0	54.0	50.0	5.0
Wyoming	20.0	35.0				4.0
Average	15.1	27.2	35.4	42.8	37.9	3.8
Minimum	10.0	20.0	30.0	35.0	20.0	2.3
Maximum	22.0	40.0	50.0	54.0	50.0	7.1

*MESAL = MILLION EQUIVALENT SINGLE AXLE LOADS
**TEXAS INPUTS WERE UNDER REVIEW AT THE TIME OF PUBLICATION (SUMMER 2010)

Appendix B

Pavement Type Selection Checklist

Consideration	Alternate 1	Alternate 2	Alternate 3	Alternate 4
COSTS				
Initial				
Future				
User Delay				
CONSTRUCTABILITY				
Speed of Construction				
Timing of Work Zones				
PERFORMANCE				
Frequency of Rehabilitation				
EASE OF REHABILITATION				
NEED FOR RECONSTRUCTION				
SUSTAINABILITY				
Recyclability				
Carbon Footprint				
Conservation of Materials				
OTHER				
Noise				
Roughness				
Safety				

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