NCAT Report 13-05

THIN HMA OVERLAYS FOR PAVEMENT PRESERVATION AND LOW VOLUME ASPHALT ROADS

By
E. Ray Brown
Michael Heitzman

May 2013

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

277 Technology Parkway ■ Auburn, AL 36830

THIN HMA OVERLAYS FOR PAVEMENT PRESERVATION AND LOW VOLUME ASPHALT ROADS

By

E.Ray Brown
Emeritus Director
National Center for Asphalt Technology
Auburn University, Auburn, Alabama

Dr. Michael Heitzman, PE
Assistant Director
National Center for Asphalt Technology
Auburn University, Auburn, Alabama

Sponsored by
NAPA Education and Research Foundation

NCAT Report 13-05

May 2013

DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

Background

The cost of maintaining roads continues to escalate even at a time when roadway funds are declining. Approaches are needed for reducing the costs of roadway construction and preservation so that the highway system can be maintained in satisfactory condition. There are a lot of new concepts that have potential for reducing these construction and preservation costs including use of increased amounts of reclaimed asphalt pavement (RAP), asphalt shingles, warm mix asphalt, and finer asphalt mixtures. When used properly, these concepts will allow for reduced cost per ton of mix and allow for thinner overlays to be constructed in some cases resulting in a reduction in quantities and overall costs without reducing performance.

Most asphalt pavement research has focused on high volume roads that carry most of the daily traffic. While most of the traffic is carried by high volume roads, a higher percentage of the lane miles of roadways consists of low volume roads. Guidance for reducing the cost of maintaining and preserving these roads is needed and that is the emphasis of this report.

Objective and Scope

The objective of this report is to provide guidance for reducing maintenance and preservation costs when using asphalt mixtures on low volume roads.

This report provides information obtained from previous research efforts and provides guidance to reduce the costs of asphalt mixtures for pavement preservation or use on low volume roads. Some of the concepts for reducing costs for low volume roads have potential for use on high volume roads as well. This report discusses types of roads in the US highway system and the types of pavement surfaces suitable for use on the different classes of roads. The report also discusses developments in asphalt pavement technology that will provide for reduced costs for these applications.

CHAPTER 2 OVERVIEW OF THE U.S. ROADWAY SYSTEM

The US roadway system is made up of roads that are classified into various categories by the FHWA as shown in Figure 1. Starting with the "local" roadway classification, it is clear that close to two-thirds of the total roadway network is classified as local (Figure 1). Almost one-half of the total network is rural local roads. For comparison, a very small portion (about 3%) of the total US highway system is classified as interstate or freeway.

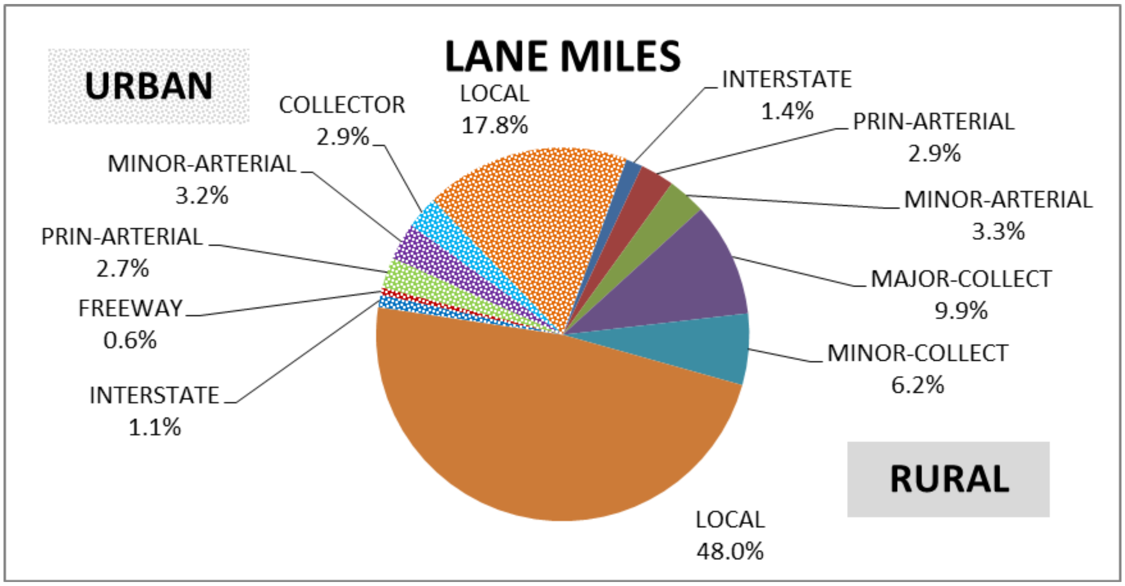

Figure 1 Comparison of Lane Miles for Rural and Local Traffic Categories *(1)*

Low volume roads have generally been defined as routes with lower than 500 average daily traffic ADT. To identify a better set of criteria, the FHWA Highway Statistics for 2008 *(1)* was used to look at lane-miles by roadway classification and vehicle-miles driven for both rural and urban areas.

In contrast, the amount of vehicle miles driven on rural local roads is only 4% of the total miles driven. The local urban roads carry approximately 9% of the traffic (Figure 2). The majority of the traffic is carried by the higher classification routes. The rural interstate carries approximately 8% of the total traffic and the urban interstate and freeways carry approximately 23% of the vehicle miles.

Combining the roadway lane-miles and vehicle-miles driven allows one to understand why it is difficult to maintain funding for the low volume roads (Figure 3). When the annual vehicle-miles per lane-mile are computed, the urban interstate and freeway system carries approximately 9.5 million vehicles annually per lane-mile. The rural interstate carries approximately 2 million vehicles per lane-mile per year. The traffic demand on the local roads is approximately 0.2 million vehicles per lane-mile per year. In fact, the rural local roadway network carries only 0.03 million vehicles per lane-mile per year.

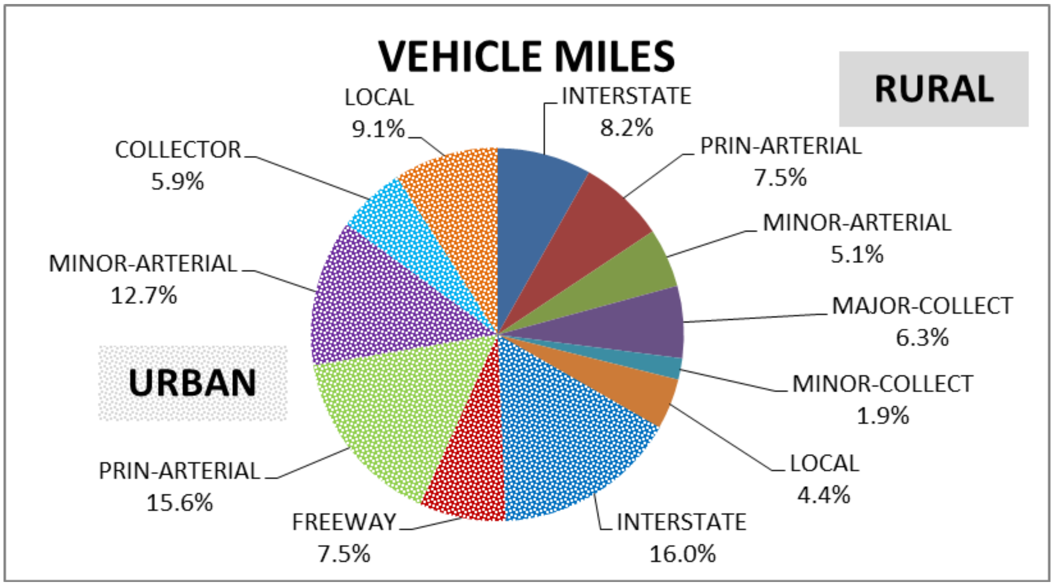

Figure 2 Comparison of Vehicle Miles Driven for Rural and Local Traffic Categories *(1)*

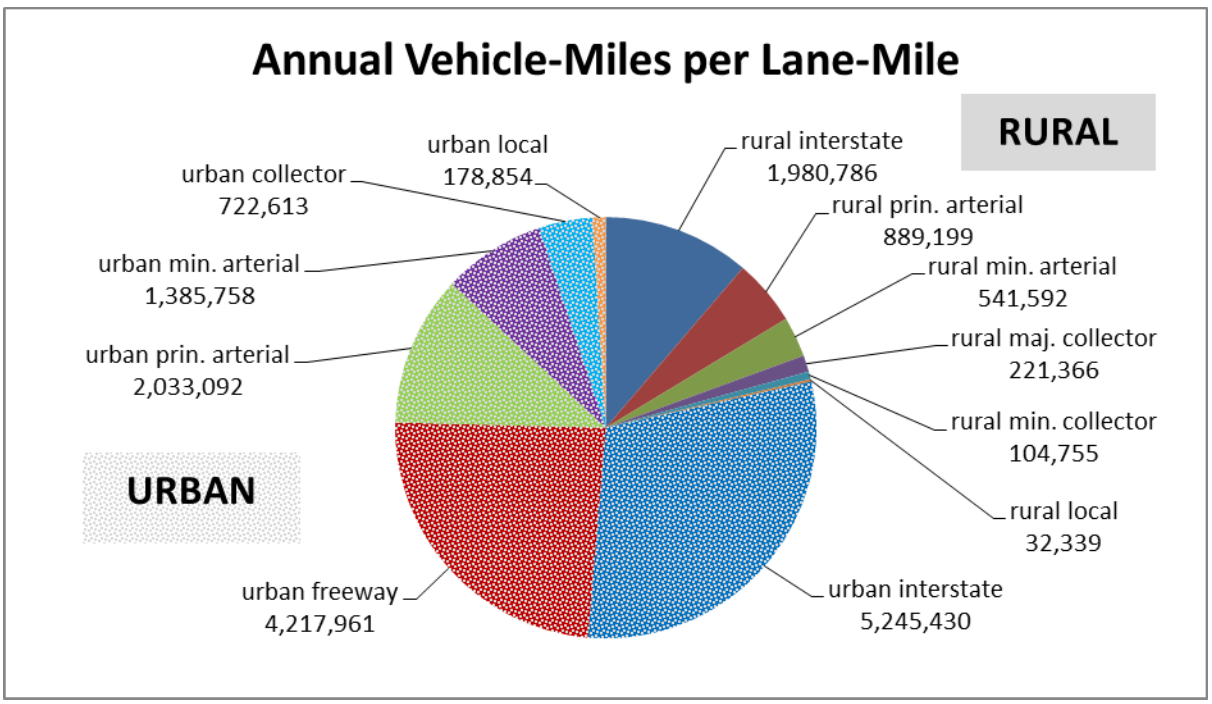

Figure 3 Comparison of Vehicle-Miles Per Lane-Mile *(1)*

Using the statistics from 2008, the average annual daily traffic (AADT) per lane is about 500 for urban local roads and 100 for rural local roads. For the purposes of this report, the definition of low volume roads is those roads that have 1000 two-way AADT or less which will include rural local and collector routes and urban local routes. This group of rural roads is 64% of the total lane-miles, but carries only 12% of the traffic. The urban local roads, as discussed earlier, are 18% of the total lane-miles, but carry only 9% of the vehicle-miles. Table 1 provides a summary of the roadway system discussed above.

TABLE 1 Summary of the U.S. Roadway System

RURAL	LANE-MILES		VEHICLE-MILES (millions)		VEHICLE-MILES per LANE-MILE		AADT (per lane)
INTERSTATE	122,825	1.4%	243,290	8.2%	1,980,786	11.3%	5,427
PRINCIPAL-ARTERIAL	249,998	2.9%	222,298	7.5%	889,199	5.1%	2,436
MINOR-ARTERIAL	280,608	3.3%	151,975	5.1%	541,592	3.1%	1,484
MAJOR-COLLECTOR	840,864	9.9%	186,139	6.3%	221,366	1.3%	606
MINOR-COLLECTOR	525,215	6.2%	55,019	1.9%	104,755	0.6%	287
LOCAL	4,072,433	48.0%	131,697	4.4%	32,339	0.2%	89
URBAN							
INTERSTATE	90,763	1.1%	476,091	16.0%	5,245,430	29.9%	14,371
FREEWAYS	52,780	0.6%	222,624	7.5%	4,217,961	24.0%	11,556
PRINCIPAL-ARTERIAL	227,520	2.7%	462,569	15.6%	2,033,092	11.6%	5,570
MINOR-ARTERIAL	272,077	3.2%	377,033	12.7%	1,385,758	7.9%	3,797
COLLECTOR	242,715	2.9%	175,389	5.9%	722,613	4.1%	1,980
LOCAL	1,506,171	17.8%	269,385	9.1%	178,854	1.0%	490

Maintaining 82% of the total lane-miles for only 21% of the vehicle-miles creates several challenges. These low-demand routes receive limited funding. Engineers must maintain the pavements beyond traditional fatigue life limits without robust design and preservation guides. Further, many of these lane-miles carry significant truck loads during agricultural harvest seasons.

Types of Pavement Surfaces and Preservation Procedures

While this combined group of low volume roads (1000 AADT) is 82% of the total lane-miles, not every lane-mile is paved with a hard surface. According to the FHWA US Highway Statistics 2008, about 40% of the rural local lane-miles are paved and almost 95% of the urban local roads are paved (Figure 4). The balance of the rural low volume routes are collectors and 80% of the rural collectors are paved (Figure 5).

The low volume routes that are unpaved are commonly granular surfaced and require regular annual maintenance to retain a reasonable level of surface. Most of the agencies with jurisdiction over unpaved low-volume routes have motor-graders and operators on their staff to manage these lane-miles.

The amount of lane-miles on low volume roads (less than 1000 AADT) is a majority of all the pavements in the US roadway system. About 2/3 of all low volume roads are paved *(1)*. Hence, any decrease in construction, maintenance, and preservation costs resulting in equal or improved performance can result in considerable overall savings.

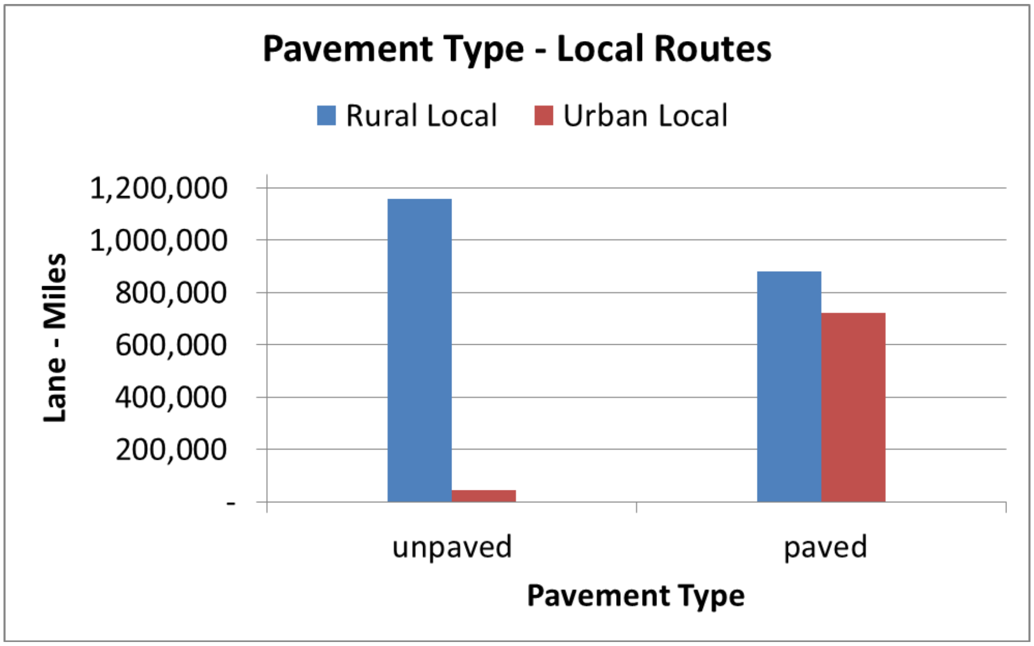

Figure 4 Lane Miles of Pavement Types for Local Routes *(1)*

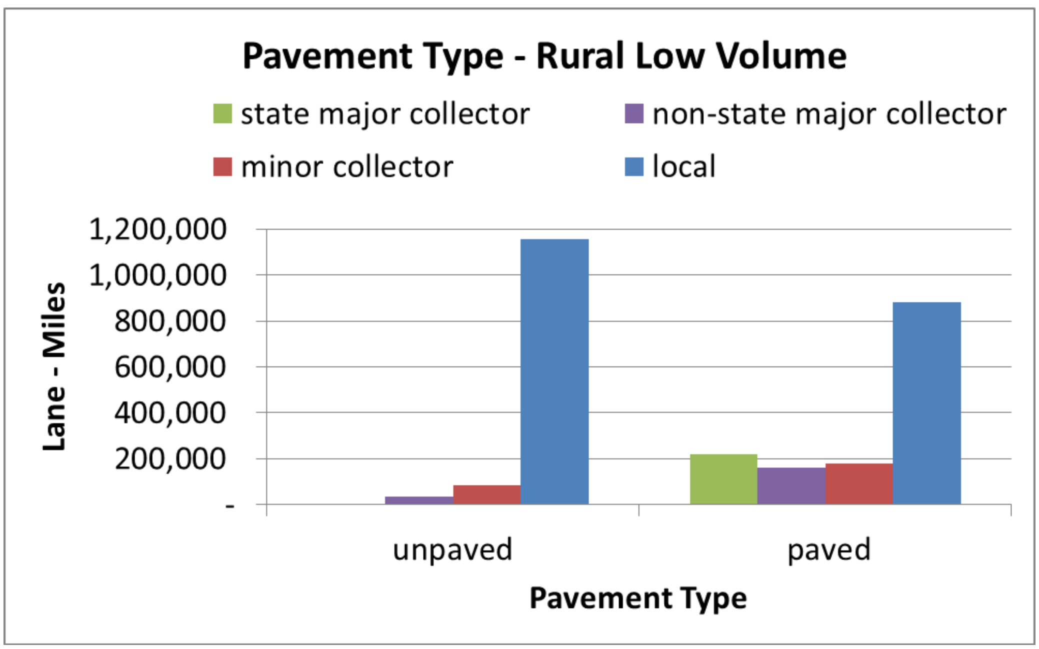

Figure 5 Lane Miles of Pavement Types for Rural Low Volume Roads *(1)*

Once the pavement is surfaced, typically with an asphalt-bound treatment, both the rural and urban agencies rely on regional contractors to maintain the surface. Typical asphalt-bound surfaces are chip seals and hot mix asphalt (HMA). Chip seals are more prevalent on local and minor-collector rural routes. Major-collector rural routes are predominantly HMA.

The HMA is generally the preferred surface by the traveling public but the cost is typically higher than for chip seals. Once a pavement is surfaced with a chip seal or hot mix asphalt, it is generally maintained as a paved surface after that. Once the surface is covered with dense asphalt mixture, future preservation or rehabilitation procedures generally use dense graded asphalt mixture. However, as the price of asphalt binder has increased and roadway funding has decreased there have been a few occasions where an existing paved surface has been reverted back to a granular or chip seal surface due to limited funds. The FHWA statistics do not include the percentage of low volume roads that are surfaced with asphalt mixture compared to the percentage of roads that are covered with chip seals or granular surface.

The amount of pavement for low volume roads is a large percentage of the total pavement constructed and maintained. Developing mixes and procedures to help preserve and maintain these roads will provide significant savings to the taxpayers.

Asphalt Mixture

An asphalt mixture is generally considered to be a dense-graded asphalt mixture produced in a hot mix plant. This includes asphalt mixtures produced using hot and warm mix asphalt technologies. Some types of asphalt mixtures, such as stone matrix asphalt (SMA) and open graded friction courses (OGFC) are generally used on high traffic roads and are beyond the scope of this paper.

Using asphalt mixtures has some advantages and disadvantages when compared to a gravel surface or chip seal. Asphalt mixtures will provide the smoothest surface that will allow for moving traffic at higher speeds. This is an all-weather surface that should perform well in all weather conditions. There are few loose particles on the surface of an asphalt mixture and the potential for broken windshields is very low. User costs are lower on asphalt mixture surfaces, than on either of the other two surface types, primarily due to the smooth, tight surface and the good long term durability. Also asphalt mixtures provide increased structural value to a pavement structure thus allowing for increased traffic. However, the initial cost of an asphalt pavement surface is generally greater than options such as chip seals and gravel surfaces so these improvements in performance must exceed the increased initial cost.

Implementing methods to reduce the cost of a particular pavement surface type, without reducing performance will ensure that more of that pavement surface type is used. Routine maintenance for asphalt roads generally includes sealing cracks, patching potholes, and maintaining drainage during the life of the pavement. There are pavement preservation approaches that are sometimes used such as fog seals and rejuvenators, but these products are spray applications and are meant to preserve the condition of the surface but do nothing to improve the structural capacity of the road. Pavement preservation with slurry seals and micro-surfacing can improve the surface, but cannot fully restore the smoothness.

Properly designed and constructed overlays on low volume asphalt pavements will perform for up to 20 years. The time between overlays will depend on many variables such as adequacy of the underlying pavement, climate, traffic, quality of materials, and quality of construction.

Chip Seals

For this paper chip seals refer to products that include an asphalt spray application followed with an application of aggregate. This is also referred to as a surface treatment. Multiple layers of chip seals / surface treatments are sometimes used. This product provides a watertight layer that provides an acceptable riding surface in wet and dry conditions. Travel speeds on chip seal surfaced roads is about the same as that for asphalt mixture surfaces, but the riding surface for chip seals tend to be rougher and tire-pavement noise is greater. The primary disadvantage of this surface type is the loose aggregate particles that typically remain after a chip seal has been placed. These loose particles can be picked up and slung by tires. When this happens there is a significant risk of the loose aggregate particles becoming projectiles which can cause damage to other vehicles (such as broken windshields) or injure cyclists or pedestrians on or adjacent to the roadway. Potholes caused by poor base support will typically occur quicker in chips seals compared to asphalt mixture surfaces.

Roads with chip seal surfaces will generally have to be resealed on a 5-10 year interval. Generally the initial cost of a chip seal will be somewhere between the cost of a gravel surface and an asphalt mixture surface.

Granular Surface

For this paper, granular surfaces refer to any crushed or natural granular material that is used as a riding surface. These are sometimes referred to as gravel roads or native surfaced roads.

Granular surfaces are the cheapest of the surfaces to construct but require routine maintenance work to keep the road reasonably smooth and in acceptable shape. The speeds are generally slower on granular surfaced roads than on paved surfaces and there is a higher risk to break windshields when two vehicles meet or when one vehicle is following closely behind another vehicle. The user costs are greater for this type of pavement surface since these surfaces can be rough and cause more vehicle maintenance than either of the two other surface types. These roads can also affect traffic in wet weather due to standing water and lower friction in both wet and dry conditions. While there are problems during wet weather, these gravel roads do generally allow traffic to continue to operate but often at lower speeds. Washboarding is a problem that sometimes occurs with this surface type and this can cause significant problems with traffic. When washboarding and potholes occur, regrading of the surface is needed.

Maintenance of gravel roads is a big cost item. Regrading will have to be done on a regular basis to keep the road surface reasonably smooth. Additional gravel will have to be added and regraded from time to time as some of the aggregate is lost under traffic. While this type surface is used on many roads it is clearly not the preferred surface by the users.

Cost and Performance of Paved Surfaces

While there is still a lot of new pavement construction in the US, most money is spent in preserving and maintaining existing pavements. Although, selecting preservation treatments would ideally be based on life cycle costs of the potential treatments, this is challenging since the cost depends on many things including application rate, location, size of project, etc., and the expected life of the treatment options also vary considerably based on the condition of underlying layers, quality of construction, traffic, and weather. In 2010, FHWA *(2)* reported typical cost and performance data for the different types of treatments. The data was reviewed, analyzed, and a summary is provided in Table 2. While this report reports typical costs, local data, where available, may be more appropriate for agencies to use in making decisions about pavement preservation treatments.

The most common approaches for constructing and/or preserving paved low volume roads are chip seals and thin lifts of HMA. Other preservation treatments, like slurry seals, fog seals, and microsurfacing are shown in Table 2. These treatments are used also, but most rehabilitation and preservation work on paved surfaces consists of chip seals and HMA. Average cost estimates, based on 2009 dollars, of the preservation treatment options shown in Table 2 are based on analysis of detailed responses provided to FHWA by five selected state DOTs *(2)*. Although there were significant variations in cost and performance data based on the responses, using average numbers provides a useful comparison among treatments. The authors recommend gathering local data for analysis of treatment options. It is important to note that the expected performance life is tied to selection of the correct treatment for the existing pavement conditions. If the correct treatment is not selected the performance life will be adversely affected.

TABLE 2 Typical Unit Costs (2009) and Pavement Life for Specific Maintenance and Preservation Treatments *(2)*

Treatment	Initial Costs $/sq.yd.	Expected Extended Life of Pavement, yrs	Annualized Cost $/sq.yd/yr
Crack Treatment	0.32	2	0.16
Fog Seals	0.99	4	0.25
Chip Seals	1.85	6	0.31
Microsurfacing	3.79	6	0.63
Slurry Seals	4.11	5	0.82
Thin HMA Overlay	5.37	13	0.41

Note: In areas where the use of one of these treatments within the state DOTs was limited, the unit price may be significantly different than otherwise expected. For example, the cost for slurry seal which was only used on 3 projects within one state DOT appears higher than typical. All of the other treatments had at least 6 projects and was produced in at least 2 state DOTs.

As can be seen in Table 2, there are three treatments that have lower cost per year than that for HMA. Two of these treatments, crack treatment and fog seals, have limited benefits to the entire pavement structure. Crack treatments only result in the sealing of cracks and don't provide other benefits such as correcting ruts, improving smoothness, improving friction, etc. The fog seals involve spraying an asphalt emulsion on the surface resulting in partial sealing of the surface. This will result in a reduction in the oxidation process of the surface layer.

However, it can temporarily reduce friction and does not solve other problems such as rutting and raveling. It may reduce additional raveling, but it does not mitigate raveling that has already occurred. So while these treatments are cheaper, they don't provide all of the benefits of HMA or chip seal. The initial cost of the chip seal treatment is approximately 25% cheaper than the reported cost of HMA, but there are additional benefits when using HMA. As mentioned earlier, the HMA will provide a smoother, quieter pavement surface and will have very little loose aggregate that may result in broken windshields. Based on the reported typical cost per ton of HMA, the approximate thickness of the asphalt mixture used to determine the unit cost of the HMA for these 5 states is between 1 inch and 1.5 inches. If the HMA thickness is reduced, this will result in a lower cost per year and make it more competitive with other preservation treatments.

FHWA *(3)* has evaluated crack sealing, slurry seals, chip seals, and thin lifts of HMA for pavement preservation. Clearly chip seals and thin lifts of HMA are the two most promising methods based on observed performance in LTPP test sections on preventive maintenance. Based on the report, HMA generally costs more per square yard but provides for better rutting resistance, smoother ride, and is free from loose aggregates.

It is important to consider User Costs when evaluating the life cycle costs of pavements *(4)*. The user cost will include maintenance of vehicles due to condition of road and cost for work zone delays. The User Cost can often exceed the Agency cost for preserving and maintaining roads, hence maintaining roads in good condition and minimizing work zone delays are very important steps in selecting the best pavement preservation techniques. Using thin lifts of HMA will reduce user costs resulting from vehicle maintenance (less vehicle maintenance required) and work zone delays (minimum construction time and increased pavement life).

CHAPTER 3 PROCEDURES FOR REDUCING COSTS OF ASPHALT MIXTURES FOR LOW VOLUME ROADS AND PAVEMENT PRESERVATION

In recent years, there has been a substantial amount of research on 4.75 mm nominal maximum aggregate size (NMAS) asphalt mixtures. As a result of some of the research findings, a number of state DOTs have placed a significant amount of these mixes for various purposes. Generally, these mixes are used for leveling, patching, and surface courses. As mentioned, these mixtures can be placed thinner than larger NMAS mixes without violating the thickness to NMAS ratio recommended for placement and compaction *(5)*. The guidance states that the layer thickness should be at least 3-4 times the nominal maximum aggregate size, hence using a 4.75 mm mixture will allow a thickness of less than an inch to be placed and adequately compacted.

The use of recycled asphalt shingles (RAS) or increased amounts of reclaimed asphalt pavement (RAP) content has become more attractive as the price of asphalt binder has increased. One of the problems in using high amounts of RAP is the high percentage of material passing the No. 200 sieve in the RAP materials. The 4.75 mm NMAS mixtures accommodate higher percentages of material passing the No. 200 sieve. As RAP fractionation has become more popular, using finer RAP material, which has higher amounts of material passing the No. 200 sieve and higher asphalt content, makes ideal for use in 4.75 mm mixes. The coarse fraction of the RAP, which has a lower percentage passing the No. 200 sieve, can be used in coarser asphalt mixtures.

The use of warm mix asphalt (WMA) has increased in recent years and is generally believed to improve workability of high RAP mixtures and mixtures containing RAS. The use of WMA allows more time for compaction during cooler weather since the cooling rate is decreased at these lower mix temperatures. Some WMA technologies have also been shown to slightly reduce the production cost of the asphalt mixture due to the reduction in fuel costs required to dry and heat the aggregate. Many state DOTs allow the use of higher RAP and RAS contents when WMA is used. Finer mixtures should provide good performance when combined with WMA technology.

Reducing Layer Thickness

In many cases, thinner overlays can be used to provide a good performing pavement surface if they can be properly placed and compacted. The thickness of most mixes being used can't be reduced much below 1-1/2 to 2 inches since they are already at the minimum thickness to nominal maximum aggregate size ratio *(5)*. Using smaller NMAS mixes will allow thinner layers to be properly placed and compacted to an acceptable density. Thinner sections do cool quicker during construction so one has to be careful since the amount of rolling time prior to the mix cooling below an acceptable temperature is reduced.

NAPA has provided a guide for mix type selection *(6)*. This document provides guidance in determining the mix type and nominal maximum aggregate size for HMA for various applications. This guide will provide help in selecting the best nominal maximum aggregate size for specific projects.

Smaller NMAS mixtures typically have higher asphalt contents which can result in a significant increase in cost per ton of mix. Good mix design practices should avoid excessive asphalt contents by controlling VMA with the total amount of material passing the Number 200 sieve. High filler content also improves stability of the mix by stiffening the asphalt binder. These mixtures are also often designed at higher air void contents to avoid excessive optimum asphalt contents and to ensure adequate mix stability. With these adjustments, fine mixtures will exhibit adequate mixture stability and durability and contain slightly more asphalt binder than typical 12.5 or 19.0 mm NMAS mixtures.

Newcomb *(6)* provided guidance on the use of thin lifts of asphalt mixture for pavement preservation. Some of the advantages of using think lift asphalt mixtures include:

- improved ride quality,
- reduced noise levels (Hanson et al *(7)* showed a very good correlation between fineness modulus of aggregate in asphalt mixtures and noise generated under traffic),
- reduced life cycle costs,
- no loose stones, and
- no curing time required

Newcomb also points out that most asphalt maintenance is needed to address functional issues and not structural issues. Hence, increasing the thickness of the pavement is not necessary and thin overlays are often sufficient to improve the surface smoothness and quality. If placed and compacted properly, good performance should be obtained.

Thinner layers are not always an option, but may be appropriate for overlays of low volume roads and for pavement preservation of all asphalt roads. For original construction, the pavement thickness is determined by structural design. Layer thicknesses are typically based on the desire to build the cross section in as few layers as possible for construction expediency and cost. This often results in thicker layers being used and is not often applicable to thin lifts of HMA. However, for pavement preservation, thinner overlays have a lot of potential to reduce cost and provide a long lasting surface. Fine-graded, small-NMAS mixes that can be placed in thin layers are a great option for pavement preservation needs because they can be competitive with other pavement preservation options and they can provide good performance.

A 2004 survey was conducted to determine the use of 4.75 mm NMAS mixtures and to identify the applications for which these mixtures were being used. Based on the response from 21 state DOTs *(8)*, it was shown that 10 of these states had used 4.75 mm or similar mixture types (Figure 6). While a number of state DOTs had used these 4.75 mm mixtures, many of them had limited the use to patching and leveling. Certainly the 4.75 mm mixture would be good for leveling and patching since it has very good workability and it can be placed in very thin sections for leveling operations.

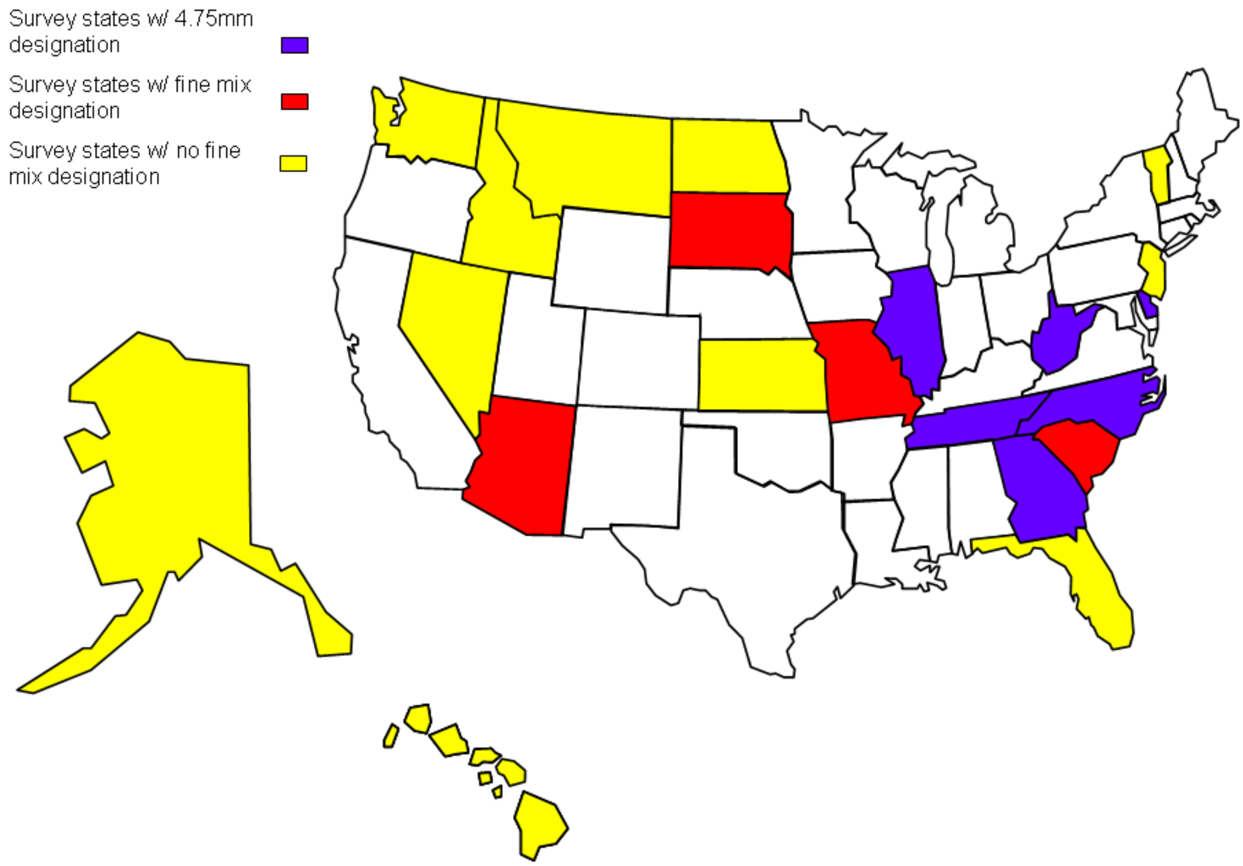

Figure 6 Response of 21 States Concerning Use of 4.75mm Mixes in 2005 *(8)*

Some highway agencies were not using 4.75 mm mixture due to issues with rutting under heavy traffic. In past years when finer mixtures were used a significant amount of the aggregate consisted of natural sand. This natural sand which tended to be rounded increased the potential for rutting and the problem was blamed on the 4.75 mm mixture. The problem was the rounded aggregate and not the gradation of the aggregate. A 4.75 mm mixture using a more angular crushed sand is not expected to have significant rutting issues if properly designed and constructed. A good example of the rutting resistance of a 4.75 mm mixture is a 2003 test section constructed on the NCAT test track. Thus surface layer was placed ¾ inch thick and has supported 30 million ESALs of traffic over a 9 years period without performance problems *(9)*. This good performance at the test track shows the potential for using properly designed small NMAS ,fine mixtures on high volume roads.

The amount of natural sand in 4.75 mm mixes should be limited to no more than 15% of the total aggregate and the fine aggregate angularity should equal or exceed 45 for 0.3 million ESALs or greater traffic *(8)*.

Generally when using 4.75 mm mixes for leveling courses the thickness of the layer will vary as needed to level up an existing surface. In this case the thickness may vary from approximately zero inches up to an inch or more where a thicker layer is needed. These fine-graded mixtures work very well for this application.

In addition to patching and leveling, some state DOTs *(8)* use 4.75 mm mixtures for surface course applications (Table 3). As shown, the spread rate for the surface may vary from 50 lb/sy up to 125 lb/sy. These spread rates result in a range in thickness from less than ½ inch up to a little more than 1 inch.

TABLE 3 Summary of Responses From States Using 4.75 mm Mix *(8)*

State	Design Method	Thickness or Spread Rate	Density Rqmt.	Use Expected to:	Primary Uses
Arizona	Arizona Method	50 lb/sy	none	decrease	Surface mix
Delaware	Superpave	Varies	none	increase	Leveling mix
Georgia	Superpave	85 lb/sy	none	N/A	Leveling mix
Illinois	Superpave	3/4"	94%	increase	Leveling mix
Missouri	Marshall	1"–1.75"	no	remain steady	Surface, leveling
N. Carolina	N/A	1"	85 or 90%	remain steady	N/A
S. Carolina	Marshall	125 lb/sy	none	remain steady	Surface mix
S. Dakota	Marshall	150 ton/mi	none	remain steady	Leveling mix
Tennessee	Marshall	35 lb/sy	none	remain steady	Leveling mix
Washington	N/A	N/A	N/A	N/A	N/A
W. Virginia	Marshall	70 lb/sy	92%	increase	Surface mix

Most state DOTs generally agreed that there could be greater use of 4.75 mm mixtures and they would like to see more development of the mixture requirements so that it would become a typical mix available to them and one that they would expect to perform well. Alabama, Georgia, and Maryland have all indicated that they have used these mixes for thin overlays and pavement preservation with good results *(8)*. Other states such as Texas are known to use a significant amount of 4.75 mm mixes and have observed good performance.

Most states do not specify density requirements for thin-lift mixtures due to difficulty in obtaining accurate density measurements from density gauges or cores. Fortunately, as shown in Figure 7, 4.75 mm mixtures remain relatively impermeable with in-place air void contents well beyond the point where larger NMAS mixes have permeability problems *(9)*. The most common approach to compaction for 4.75 mm mixes is to set a roller pattern based on peaking the uncorrected density measurements using a thin-lift nuclear density gauge. These mixtures should be placed at a thickness of ¾ inch to 1 inch.

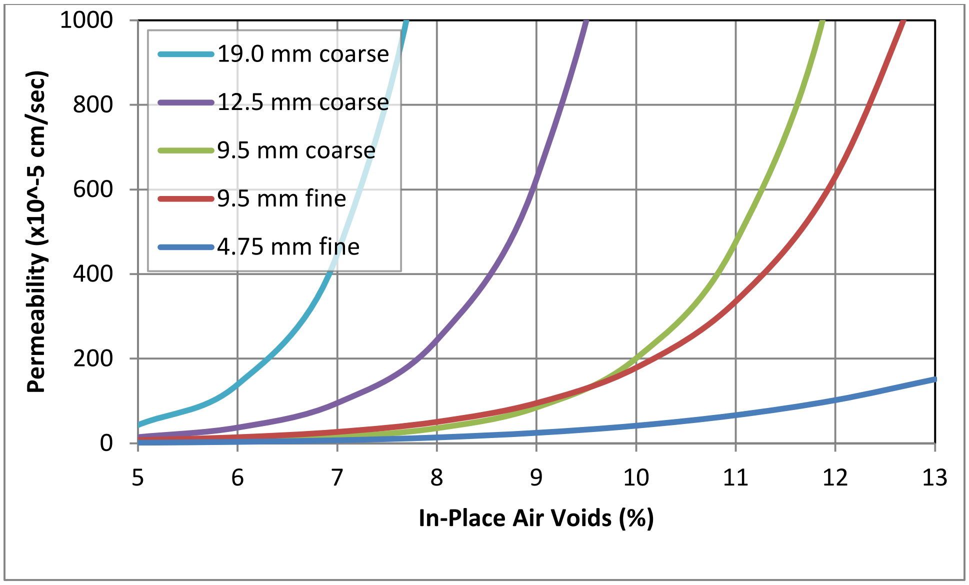

Figure 7 Effect of Air Voids and NMAS on Mixture Permeability *(9)*

One of the problems with some 4.75 mm mixtures is that the VMA tends to be high resulting in the need to add too much asphalt binder thus increasing the mix cost. Increasing the amount of minus Number 200 material used in the mixture will help lower the VMA and reduce the optimum asphalt content. However, even with higher amounts of minus Number 200 material, many of the 4.75 mm mixes evaluated by West and others *(8)* required too much asphalt binder to meet the volumetric requirements. They also recommended specifying a range of 4.0 to 6.0 for the design air void content instead simply fixing the design air void content at 4.0 percent.

Another performance concern for 4.75 mm mixtures is their resistance to rutting. In 2003, the Mississippi DOT elected to place approximately ¾ inch thick section of 4.75 mm mix on the NCAT test track *(10)*. It was produced at the properties shown in Table 4 and compacted to an average density of 92.2%. The gradation of the mixture, which consisted of 69% limestone, 19% gravel, and 12% natural sand, is provided in Table 4. The grade of asphalt binder used was a PG 76-22. The mix design met the current AASHTO standards for 4.75 mm mixes.

TABLE 4 Properties of 4.75 mm Asphalt Mixture Placed ¾-inch Thick on NCAT Test Track *(10)*

Property		Gradation	
Asphalt content, %	6.1	9.5 mm	100
Air voids, %	4.0	4.75 mm	98
VMA, %	16.0	2.36 mm	75
		1.18 mm	50
		0.60 mm	35
		0.30 mm	22
		0.15 mm	15
		0.075 mm	11.3

The test section has now been subjected to approximately 30 million ESALs over a nine year period. There has been no cracking in the surface of the mixture. Rut depths are approximately 7 mm which is slightly over ¼ inch which would not even be considered rutting by most DOTs. The IRI has remained very smooth, about 50 inches/mile through the nine years of heavy trafficking. Based on this proven performance some state DOTs have begun to use more 4.75 mm mixtures.

AASHTO (specification M 323) specification requirements for 4.75 mm mixtures are summarized in Table 5. Many state DOTs continue to use their own specifications. NCAT's recommended revisions of the AASHTO specification requirements based on research are provided below *(8)*:

- An FAA of at least 45 is recommended for over 0.3 million ESALs. Alternatively, the percentage natural sand should be limited to 15 percent maximum.
- The gradation requirements should be changed to 30-55% passing the 1.18 sieve and 6-13% passing the 0.075 mm sieve.

TABLE 5 AASHTO M 323 Recommended Material and Mixture Requirements for 4.75 mm Mix *(8)*

Design ESALs 20 yr design life (millions)	**N_{design}**	**FAA Depth from Surface, mm**		**SE**	**VMA**	**VFA**	**$N_{initial}$**
		Less than 100	**More than 100**				
Less than 0.3 million	50	-	-	40	16.0	70-80	≤91.5
0.3 to 3.0	75	40	40	40	16.0	65-78	≤90.5
3.0-10.0	75	45	40	45	16.0	65-78	≤89.0
Sieve Size	Min	Max	V_a = 4.0%				
12.5 mm	100	100	Dust/binder 0.9 to 2.0				
9.5 mm	95	100					
4.75 mm	90	100					
1.18 mm	30	60					
0.075 mm	6	12					

It is essential during construction that these mixes be compacted to a density that will ensure that they are not permeable to water. Work performed by Mallick and others *(9)* showed that finer mixtures (down to 9.5 mm size) are not permeable to water until the air voids get up to above the 8-10 percent range whereas coarser mixtures are permeable to air and water at a much lower void level (Figure 7). The 4.75 mm mixture would require significantly more air voids than the 9.5 mm mixture before becoming permeable. The reason for this is that with the finer mixtures there are many small voids but they don't tend to be interconnected. However, with coarser mixes the voids are larger even though the total void content may be smaller and the voids tend to be interconnected.

Another fine mixture was placed at the track in 2003 and it also has provided good performance through 3 traffic cycles *(10)*. This second fine mix (9.5 mm mix) was a little coarser than a 4.75 mm mix but it is very similar. The properties of this mix are shown in Table 6. The mixture was produced using a PG 76-22 and it contained 19 percent natural sand. The mix was compacted to a density of 93.7 percent of maximum theoretical density at a thickness of approximately 1 inch.

TABLE 6 Properties of 9.5mm Mix Placed 1-inch Thick at NCAT Test Track *(10)*

Property		**Gradation**	
Asphalt content, %	6.1	3/8 inch	100
Air voids, %	5.5	No. 4	81
VMA, %	19.0	No. 8	61
		No.16	49
		No. 30	37
		No. 50	21
		No. 100	12
		No. 200	6.7

The performance has been good to date with an average rut depth of less than 5 mm. Again, this indicates that the amount of rutting was insignificant. The IRI has stayed at slightly over 50 for the last few years. There is some slight cracking in one area of the test section but this is not significant.

Using finer mixtures allows the layer thickness to be reduced and this provides a number of opportunities for using 4.75 mm mixtures. Using thinner overlays reduces the costs and makes the use of asphalt mixture more competitive for pavement preservation and other uses. While most mixes in the past were placed at 1 to 2 inches thick, 4.75 mm mixes can be produced and placed at approximately ¾ inch thickness for many applications. That is the thickness that was used at the test track and the performance has been excellent. On many projects, this will allow thinner layers and less total materials to be used for maintaining existing pavements resulting in significant savings.

A decision has to be made about what type of mix to be used for original construction of a pavement or for maintaining pavements. The Georgia DOT guidance for low volume roads is shown in Table 7 *(11)*. This guidance identifies the traffic level ranges as a function of various mix types. For example, for traffic with less than 100 trucks (or 800 ADT) per day, GDOT recommends that a bituminous surface treatment be used. For roads having traffic over 100 trucks or 800 ADT, an asphalt mixture is specified and the NMAS depends on the amount of traffic. For a traffic count above 800 ADT and less than 1000 ADT, the DOT recommends that a 4.75 mm HMA mixture be used.

TABLE 7 Guidance by Georgia DOT for Selection of Mix on Low Volume Roads *(11)*

Volume	Traffic Count	Surface Type
Low to Medium	Trucks/Day< 100 or ADT < 800	Bituminous Surface Treatment
	Trucks/Day < 100 or ADT < 1,000	4.75 mm NMAS HMA
	Trucks/Day < 200 or ADT < 2,000	Type 1, 9.5 mm NMAS HMA

The various mix types have a range of thicknesses that are suggested for use. As can be seen (Table 8) the 4.75 and 9.5 mixes can both be placed at thicknesses less than 1 inch, however, the guidance recommends that the layer thickness for the 4.75 mm mix should be 7/8 inch and the layer thickness for the 9.5 mm mix be 1-1/8 inches. Some DOTs place and control mix quantity by spread rate, (lbs per square yard) and others control the quantity by the layer thickness.

TABLE 8 Georgia DOT Recommended Maximum and Minimum Layer Thickness *(11)*

Mix type	Minimum Layer Thickness	Recommended Layer Thickness	Maximum Layer Thickness
4.75 mm	¾ in 85 lbs/sq yd	7/8 inch 90 lbs/sq yd	1-1/8 in 125 lbs/sq yd
9.5 mm	7/8 in 90 lbs/sq yd	1-1/8 in 125 lbs/sq yd	1-1/4 in 135 lbs/sq yd

Use of High RAP and RAS

The use of RAP and RAS also has the potential to reduce the cost of asphalt mixtures. Most contractors routinely use 15-20% RAP during the production of asphalt mixtures. There is a trend toward using more RAP which should allow even more savings when using asphalt mixtures.

Some agencies are reluctant to use RAS and higher amounts of RAP because of the concern that this might affect the quality of mix and result in some loss in performance. However more and more data is being produced to show that mixtures with RAS and relatively high amounts of RAP provide performance similar to mixtures with lower amounts of reclaimed materials. WMA has been shown to facilitate the construction and performance of mixes with higher amounts of RAP and RAS and hence many state DOTs allow higher percentages of RAP and RAS when WMA is used.

Mogawer and others *(12)* showed that a fine asphalt mixture could be produced with high RAP content, RAS, and WMA to produce a satisfactory combined binder property when using one grade softer on the high PG end and the same PG grade as for standard mixes on the low temperature end. Mixes were prepared with up to 40% RAP, 5% RAS, and 1% WMA additive (Table 9). As shown in the Table, mixes were prepared as control (virgin mixture with no RAP) and mixtures were prepared with 40% RAP, 5% RAS, 35% RAP and 5% RAS and then 1% WMA additive was added to the same mixtures. The additive used was a wax based WMA technology. The normal grade of asphalt binder in the area where the research was conducted was PG 58-28 and that grade was used for the control. A PG 52-28 virgin asphalt was used in the recycled mixtures. This approach, of dropping one binder grade, follows the procedure that many state DOTs have used in the past when using above 20-25% RAP. However, here the amount of RAP was significantly higher and the PG grade added was one grade softer on the high temperature side only.

TABLE 9 Extracted Binder Grading Results *(12)*

Mixture	**Continuous Grade**	**PG grade**
Control	62.2-31.2	58-28
40% RAP	72.4-27.9	70-22
5% RAS	65.6-32.2	64-28
35% RAP + 5% RAS	77.5-25.9	76-22
Control + 1% WMA	56.4-32.6	52-28
40% RAP + 1% WMA	64.2-30.9	64-28
5% RAS + 1% WMA	60.9-32.7	58-28
35% RAP + 5% RAS + 1% WMA	71.1-27.9	70-22

The data in Table 9 shows that the low temperature grades of the recovered binders are close to or equal to the low temperature grades of the control mix. In the worst case, the low temperature grade is one grade stiffer. The high temperature grade is 1 to 3 grades higher than that of the control mix. Being stiffer at higher temperatures should be beneficial since this will help improve rutting resistance. Hence dropping only one grade on the high PG side for the virgin binder produces an acceptable combined asphalt binder for high RAP content that has properties of the combined binder close to that desired for a binder in a virgin mixture.

The addition of RAS has a much greater effect on the mixture properties than adding an equal amount of RAP. In fact, adding 5% RAS has been equated to adding approximately 20% RAP. Hence, adding 35% RAP and 5% RAS is approximately equivalent to adding 55% RAP. Even with this high amount of recycled material the binder properties are still within one grade of the control binder properties at the low temperature.

All of these mixtures were tested to evaluate potential for rutting, moisture susceptibility, reflective cracking, and thermal cracking *(12)*. The results showed that the mixes with recycled materials performed better in rutting and moisture susceptibility. The results between control and recycled mixtures were about the same for thermal cracking. And, the results indicated that the recycled mixture was more likely to experience reflective cracking. There is not a good way to prevent reflective cracking with any mix type, so this is not seen to be a major issue; reflective cracks will occur in virgin mixtures as well as recycled mixtures. It is important however that raveling at these cracks does not occur so keeping these cracks sealed is important. Sealing is probably more important for the recycled mixtures with high RAP since they tend to be stiffer and will be more likely to breakoff adjacent to the crack if not sealed.

Fractionation of RAP has become commonplace in some locations. Fractionation involves screening a stockpile of RAP into two or more sizes. Most often the RAP is separated into a fine and a coarse size material. In some cases, fractionated RAP is separated into more sizes. Properties of fractionated RAP, from two locations, are provided in Table 10 *(13)*.

TABLE 10 Gradation and Asphalt Content for Two Sources of Fractionated RAP *(13)*

	RAP from Source 1		RAP from Source 2	
Sieve	**-3/8" RAP**	**+3/8" RAP**	**-3/8" RAP**	**+3/8" RAP**
1 in	100	100	100	100
¾ in	100	97	100	99
½ in	100	82	100	91
3/8 in	99	65	99	79
No. 4	69	43	72	39
No. 8	47	31	49	26
No. 16	34	25	33	19
No 30	26	20	24	15
No 50	20	14	17	11
No. 100	13	9	13	8
No. 200	9.6	7.0	10.1	6.0
Asphalt Binder, %	5.1	4.2	5.5	3.9

It is clear from the data in Table 10 that the asphalt content is higher and the amount of material passing the No. 200 sieve is higher for the minus 3/8 inch RAP. In fact the difference in asphalt content is approximately 1.2% between the fine and coarse RAP. The percent passing the No. 200 sieve is approximately 3.2% higher for the finer RAP. Often, the amount of RAP that can be used in an asphalt mixture is limited by the percentage of material passing the No. 200 sieve (dust). However, 4.75 mm mixes can use RAP with higher minus 200 content and higher asphalt content and still meet the specification requirements. The coarse RAP can be used in larger NMAS mixes.

Often these mixes are placed on low volume roads that are likely to have higher deflection than higher volume roads that tend to be stronger and more resistant to deflection. It is important to ensure that these mixtures continue to be flexible when using RAP and RAS. This flexibility can be controlled in a way similar to mixtures with larger maximum aggregate size. The total binder properties can be controlled or some type of cracking index test can be conducted to help ensure good flexibility.

Use of WMA

The use of WMA has increased significantly during the last 2-3 years. By the end of 2011, it was estimated that approximately 20% of all asphalt paving was done with WMA. The use of WMA can reduce the cost of asphalt mixture slightly for some technologies. WMA when used with RAP and RAS is generally believed to produce a more workable mixture that can effectively be placed and compacted *(14)*. Hence, a review of state DOT specifications shows that many state DOTs allow an increase in the amount of RAP and/or RAS when used with WMA.

Tests conducted by Mogawer *(12)* showed that using WMA resulted in a softer recovered asphalt binder when compared to using hot mix. Hence, using WMA will allow more RAP or RAS to be used with a given grade of virgin asphalt binder.

Both the agency and contractor must be knowledgeable of production and placement procedures to properly introduce, mix, transport, place, and compact mixtures combining these technologies (4.75 mm mix, RAP, RAS, WMA).

Analysis of Cost Reduction

It is clear that using finer mixtures, more RAP, RAS, and WMA have the potential to reduce the cost of asphalt mixtures. The savings will vary from project to project depending on a number of factors such as: size of project, amount of RAP, amount of RAS, reduction in layer thickness, and use of WMA.

Several approaches that have been discussed in this report provide opportunities to reduce the cost of asphalt mixtures in place. In addition, the changes in the asphalt mixture and reduced thickness must achieve a level of performance that maintains the anticipated life-cycle cost effectiveness. The most significant cost reduction opportunities that have been mentioned include:

- Reducing construction costs by reducing layer thickness of overlays
- Increasing use of RAP and RAS to reduce cost per ton of asphalt mix
- Using WMA to facilitate the use of higher RAP and RAS and improving mixture workability

Expected Savings by Reducing Thickness of Asphalt Mixture

Using thinner overlays can result in significant project savings. Thin asphalt overlays used as a pavement preservation treatment are typically placed 1 inch or slightly more than 1 inch thick. Using smaller NMAS mixtures can allow the overlay thickness to be reduced to approximately ¾ inch and still provide good performance. In 2003, the 4.75 mm section at the NCAT test track was placed ¾ inch thick and has provided excellent performance while being subjected to 30 million ESALs.

When overlay thickness can be reduced by only 10% the square yard cost will be reduced by approximately 7% if it is assumed that 70% of the cost of the overlay is material costs. This small reduction in thickness makes asphalt overlays more competitive with other pavement preservation treatments.

Typical minimum asphalt mixture layer thicknesses in many state DOTs are in the range of 1 to 1-1/4 inch. If a 9.5 mm NMAS mixture is placed, it should be placed at a minimum thickness of approximately 1.2 inches just to meet the thickness to NMAS requirements necessary to obtain good compaction *(5)*. If a 12.5 mm NMAS mixture is used, it should be placed a minimum thickness of approximately 1.5 inches to allow adequate density to be obtained.

The Georgia DOT has a recommended minimum layer thickness of 7/8 inch for 4.75 mm mixtures and 1-1/8 inch for the 9.5 mm mixtures. Significant savings can be realized from using 4.75 mm mix overlays rather than 9.5 mm mix overlays. This is a 22% reduction in layer thickness and based on materials alone (assuming 70% of asphalt mixture cost is materials) this results in a 15% reduction for the in-place cost of the overlay. Of course, care has to be taken to ensure that the surface being overlaid is smooth and structurally adequate so that a thin overlay would be sufficient to provide a reasonably smooth, durable surface when completed.

One of the best uses of 4.75 mm mixtures is in pavement preservation work. In this case, the primary purpose of the treatment is to cover the existing pavement surface to reduce the rate of deterioration and preserve the pavement in good condition. This concept has not been around for a long time but it is time to adopt the concept of using various treatments that are available to prolong the life of the pavement infrastructure. There are many miles of paved roads and anything that can be done to help extend the life of the pavement just a small amount will provide significant savings in the total cost being spent on the roadway system. Using thinner asphalt overlays is an option for pavement preservation that has significant advantages and can be competitive with other treatment options.

There are situations where thicker overlays are needed such as the need to add structure for the expected traffic or the need to correct significant pavement profile issues. The appropriate overlay thickness needs to be selected any time an overlay is being planned.

Expected Savings Using RAP and RAS

Actual savings for using RAP and RAS depend on a number of factors including location, technologies used, availability of RAP and RAS, and many other factors. Hence, a general estimate of the savings to the construction project when using RAP is one half of the percentage of RAP *(15)*. For example if 30% RAP is used, the estimate of savings is 15% when comparing this mixture with RAP to another mixture without RAP. For the use of RAS, the savings is primarily a result of the contribution of asphalt binder from the RAS. RAS typically contains more than approximately four times the asphalt content of RAP, but the savings due to aggregate replacement is much less than the aggregate savings when using RAP. Typical savings is approximately equal to twice the percentage of RAS used. For example, using 5% RAS in the asphalt mixture will likely result in a savings of approximately 10%.

Expected Saving Using WMA

Savings from the use of WMA is typically very small or none at all. Energy savings associated with lower mixing temperatures for WMA are generally offset by increased costs for equipment or additives. However, there are still a number of advantages of using WMA that may provide some indirect savings. There are environmental advantages for using WMA. WMA generally serves as a compaction aid and reduces oxidation during production so many believe that it will result in improved performance of the asphalt mixture. Some state DOTs allow higher RAP and RAS contents when WMA is used. So while there is assumed to be no monetary savings to using WMA, there still exists a number of benefits to its use, especially when used in combination with recycled materials.

Example of Potential Savings

It is reasonable to expect that the cost of thin overlays can be reduced when using finer mixtures. 4.75 mm mixes are not recommended for every project, but may be the best option for many low volume road and pavement preservation applications.

As an example, assume that a state DOT or county agency has a plan to overlay an existing low volume road. The road does not have any structural problems and only needs the surface improved to address minor cracking, raveling, and other minor issues. The agency elects to place an asphalt overlay as the pavement preservation approach. This example will evaluate two possible preservation alternatives: (1) placement of 1.5 inches of HMA with no RAP and (2) placement of 1.0 inch of HMA with 25% RAP. Both of these alternatives are expected to provide adequate performance.

Reducing the overlay thickness by ½ inch is a material savings of approximately 33%, which is generally equivalent to a 22% total pavement construction savings assuming that 70% of cost is in materials. Using 25% RAP further reduces the material cost, which reduces the total pavement construction cost by approximately 12.5%. Using a total pavement construction cost for the 1.5 inch layer of 100 percent, the cost of the 1.0 inch overlay is 68 percent [100 x (1-0.22) x (1-0.125)]. Hence there is a 32 % savings in project pavement construction cost when using the 1.0 inch thick overlay with 25% RAP compared to the 1.5 inch overlay with no RAP. If used in the proper application and designed and constructed correctly, this thinner surface with 25% RAP should provide equal performance as the thicker surface with no RAP.

CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS

Over 82% of the lane miles of pavement in the US are low volume roads (1000 AADT or less for this report). Approximately 2/3 of these low volume roads are paved primarily with asphalt mixtures or chip seals. Slightly reducing the cost to construct and preserve these low volume roads will provide tremendous savings for agencies with limited funding.

There are a number of ways to reduce the cost of asphalt mixtures without reducing the expected performance. Some of these methods include using thinner overlays with smaller NMAS mixes and using RAP, RAS, and WMA. There are projects where using thinner sections would be acceptable as long as the thinner sections can be properly placed and compacted. Using smaller NMAS mixtures, such as 4.75 mm mixtures, will allow for proper placement and compaction of these thinner overlays. A significant application of these 4.75 mm mixtures is in pavement preservation.

Asphalt mixtures using 4.75 mm NMAS aggregates have been successfully used for low volume roads. These mixtures have been shown to be resistant to rutting and have low permeability if compacted to 12% air voids or less. 4.75 mm mixtures can be properly placed and compacted in thinner sections and are ideal for areas needing thin surface preservation. 4.75 mm mixes have also been shown to perform well at the NCAT test track where the mix was subjected to high traffic volume.

Additional savings can be realized by proper use of RAP, RAS, and WMA. Using the finer portion of fractionated RAP produces a material (high asphalt content and high minus 200 material) that is ideally suited for 4.75 mm mixtures. The coarse fraction of RAP is more easily used in larger NMAS asphalt mixtures.

This paper has offered a number of approaches to reduce the cost of asphalt mixtures used for low volume roads and pavement preservation. Adopting these options should be done in a way that ensures the contractor and the government agency have the opportunity to gain the knowledge to be successful. Adopting too much too fast can lead to construction or performance issues for early projects that can stifle progress.

REFERENCES

1. FHWA Highway Statistics for 2008, website: http://www.fhwa.dot.gov/policyinformation/statistics/2008/
2. Wu, Zheng, Jonathan Groeger, Amy Simpson, Gary Hicks, "Performance Evaluation of Various Rehabilitation and Preservation Treatments," Federal Highway Administration Report FHWA-HIF-10-020, January 2010.
3. FHWA, "Results of Long-Term Pavement Performance SPS-3 Analysis: Preventive Maintenance of Flexible Pavements", FHWA-HRT-11-049, FHWA Turner Fairbank Research Center, McLain, Virginia, June 2011.
4. Delmar, M., and A. T. Papagiannakis, "Relative Importance of User and Agency Costs in Pavement LCCA", 5th International Conference on Managing Pavements, 2001.
5. Brown, E R; Hainin, M R; Cooley, A; Hurley, G, "Relationships of HMA In-place Air Voids, Lift Thickness, and Permeability, Volumes one through four. NCHRP Report No. 531, National Cooperative Highway Research Program, 2004.
6. Newcomb, David, "Thin Asphalt Overlays for Pavement Preservation," National Asphalt Pavement Association (NAPA), Lanham, Maryland, IS 135.
7. Hanson, Doug, Robert James, and Christopher NeSmith, "Tire/Pavement Noise Study," National Center for Asphalt Technology, Report No. 04-02, August 2004.
8. West, Randy, Michael Heitzman, David Rausch, and Julian Grant. Laboratory Refinement and Field Validation of 4.75 mm Superpave Designed Asphalt Mixtures, National Center for Asphalt Technology, Report No. 11-01, March 2001.
9. Mallick, R. B., L. A. Cooley, M. R. Teto, R. L. Bradbury, and D. Peabody. An Evaluation of Factors Affecting Permeability of Superpave Designed Pavements. National Center for Asphalt Technology, Report 03-02, June 2003.
10. Data from website: Pavetrack.com.
11. Georgia DOT, "Asphalt Pavement Selection Guidelines", Nov 2006.
12. Mogawer, Walaa S, Alexander J. Austerman, Ramon Bonaquist, and Michael Roussel, "Performance Characteristics of Thin-Lift Overlay Mixtures", *Transportation Research Record: Journal of the Transportation Research Board,* No. 2208, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 17–25.
13. Al-Qadi, Imad, Qazi Aurangzeb, Samuel Carpenter, William Pine, and James Trepanier, "Impact of High RAP Content on Structural and Performance Properties of Asphalt Mixtures", Federal Highway Administration Research Report FHWA-ICT-12-002, May 2012.
14. Prowell, Brian, Graham Hurley, Bob Frank, "Warm Mix Asphalt—Best Practices," National Asphalt Pavement Association (NAPA), Lanham, Maryland, QIP 125
15. Epps, Jon, Presentation at RAP Summit, National Center for Asphalt Technology, October 2009.