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A SYNTHESIS OF TECHNICAL NEEDS OF ASPHALT PAVEMENTS FOR LOCAL ROADS

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EXECUTIVE SUMMARY

Low-volume roads (LVRs) connect farms, mines, and businesses to smaller communities and residential areas. They are an essential link in the movement of raw materials and products from rural communities to the more populated areas of society.

Low-volume roads can range from two paved lanes to a single lane with rock or native surfacing. In rural and remote areas of the U.S., these roads often follow old wagon paths or pack animal trails. However, bad locations for a roadway are often unavoidable for LVRs due to their typical rural nature. Because the network of rural roads is vast and relatively low-use, they are often built with lower-than-conventional design standards. The lack of official standards for LVRs has resulted in road designs that are not optimally engineered.

The general approach to the design of LVRs differs in a number of respects from that of high-volume roads (HVRs). For example, conventional pavement designs are generally directed at relatively high levels of service requiring numerous layers of selected materials. However, significant reductions in the cost of the pavement for LVRs can be achieved by reducing the number of pavement layers and/or layer thicknesses by using local materials more extensively as well as lower cost, more appropriate surfacing options and construction techniques.

For rehabilitating an existing road, the design engineer must also measure the strength of the existing road structure and determine the strengths and layer thicknesses required for the new structure based on the design catalogue and the associated specifications. A comparison of the existing situation with the required structure then provides the engineer with the information required to design the necessary additions and modifications.

Under this investigation, researchers conducted a search for literature relevant to pavement design and asphalt mixture design of LVRs. This investigation was complemented with a web-based survey submitted to state agencies and industry in an attempt to answer some questions that many practitioners may have related to the state-of-the-practice of LVR design.

Researchers were able to identify challenges presented by the design of LVRs in order to provide some suggestions and opportunities for improvement of this process. One of these challenges is the existence of several methodologies of conducting asphalt mixture design and pavement design. Three mixture design approaches that consider traffic level as input parameters were briefly discussed. All three methodologies were selected because they contain mixture design criteria for low-volume applications. In terms of flexible pavement design, empirical approaches were found to be the most commonly used. These tend to be simple and require few inputs, but reliability is still an issue. In addition, the number of pavement design methodologies is significantly higher compared to mixture design, to the point that several states have adopted their own methodology.

Several asphalt mix design and pavement design research studies focused on LVRs were included in this document. These studies contain relevant information that could be used as an example of guidance for state departments of transportation (DOTs) and local agencies during the mixture and pavement design process.

A “State of the Practice” section was established based on a survey that was submitted to all DOTs and their respective state asphalt pavement associations (SAPAs). State DOTs and SAPAs were asked to identify and/or specify certain mixture design and pavement design practices for LVRs. The results of this survey not only allowed the researchers of this study to summarize the current practice of designing LVRs, but also allowed researchers to identify and complement issues, gaps, and needs of typical LVRs.

Finally, researchers presented a “Proposed Actions” segment, with the objective to encourage agencies and industry to follow some of the examples presented in this document in order to establish best practices for mixture design protocols and acceptance criteria.

1. INTRODUCTION

A well planned, designed, constructed, and maintained road system is essential for economic development and the safe movement of people, goods, and services. The largest percentage of roads in the U.S. roadway network are categorized as low-volume roads (LVRs). The Federal Highway Administration defines LVRs as roads carrying less than 400 vehicles per day (FHWA 2009). Other organizations use different criteria to categorize roadways. For purpose of pavement engineering, it is more important to quantify traffic based on loads rather than number of vehicles. Many organizations utilize the concept of equivalent single axle loads (ESALs) as a pavement design input. Numerous criteria used in asphalt mix design are also based on ESAL ranges.

Low volume roads may also be described as local roads and are generally roads that provide access to residential areas, small businesses, and farms. Table 1 shows the lane miles of roadway by functional classification. It is important to note that local roads comprise nearly two-thirds of the roadway system. Furthermore, it is estimated that 2,477,434 lane miles of the local roads are unpaved (FHWA 2016).

Table 1. Lane Miles of Roads by Functional Classification (FHWA 2016)

Roadway Classification	Rural Lane Miles	Urban Lane Miles	Total Lane Miles	Percent
Interstate	118,989	105,229	224,218	2.6%
Other Freeways and Expressways	24,542	57,621	82,163	0.9%
Other Principal Arterial	231,412	235,426	466,838	5.4%
Minor Arterial	276,234	293,956	570,190	7.5%
Major Collector	818,554	278,414	1,096,968	12.6%
Minor Collector	516,954	35,817	552,771	6.3%
Local	4,005,756	1,712,171	5,717,927	65.6%
Total	**5,992,440**	**2,718,635**	**8,711,075**	**100%**

LVRs are typically managed by local agencies with limited resources. In many cases, the pavement structures and road geometries of the paved local roads evolved over decades without thorough engineering designs or construction control. Although pavement design procedures and guidance have historically focused on higher volume, higher classifications of roads, some organizations such as the FHWA, Transportation Research Board, and U. S. Army Corps of Engineers have proposed simplified design methods and materials specifications for low-volume roads. Some local agencies may simply refer to their state department of transportation (DOT) standards for materials, design guides, and construction standards that may not be appropriate for low-volume roads.

Therefore, there is a need for guidance on materials, pavement design, and construction standards specifically tailored for LVRs. This document begins that effort by preparing a synthesis of the current practices for asphalt mixture and pavement design of LVRs based on a literature review and a survey of state agencies and the asphalt pavement construction industry.

1.1 Scope

This document summarizes existing guidance for the design of asphalt pavements for LVRs based on a review of the available literature regarding asphalt mix design and pavement design procedures. Information was gathered from AASHTO, the National Center for Asphalt Technology (NCAT), the Asphalt Institute, and state DOTs, as well as information from published journals, technical reports, articles, and presentations. A web-based survey was also conducted to obtain information from state DOTs and state asphalt pavement associations (SAPAs) in order to establish the current state of the practice and to help identify issues, gaps, and needs.

This synthesis is organized into five topics: (1) challenges in management of LVRs, (2) asphalt mixture design methods, (3) flexible pavement design methods, (4) a summary current practices for LVRs, and (5) recommended actions.

2. CHALLENGES IN DESIGN, CONSTRUCTION, AND MANAGEMENT OF LVRS

Because the network of LVRs is vast and relatively low-use, they have often been built without appropriate design standards. The lack of a single, comprehensive guide specifically for LVRs often results in costly under-designed, poor performing pavements due to inadequate pavement structures for the actual traffic, or poor quality materials and construction. This section examines some challenges presented by the design and construction of LVRs.

2.1 Lack of Pre-construction Design

Alinements for major highways are based on surveys to choose the best path over waterways and over/around changes in terrain. However, LVRs often have evolved from existing paths that followed natural terrain or property boundaries. Engineering of roadway drainage, geometry, and pavement layers for local roads is often an afterthought rather than an integral part of the process. This results in roads that are built along streams, creeks, swamps, variable soils, or areas prone to slope collapse (Keller and Sherar 2003). Since many LVRs are narrow and winding routes, the safety of small vehicles and large transport trucks is a significant concern. LVRs often involve hairpin turns and narrow bridges, which pose hazards to all vehicles that traverse them. Local road agencies often lack the resources needed to address safety problems on LVRs (i.e. surface friction).

2.2 Limited Financial Resources

Since many LVRs serve less populated areas, funding for their construction and maintenance is often deficient. Even though many LVRs serve as major corridors for raw goods such as lumber, coal, oil, and crops, sharing of the profitability of these goods is insufficient to warrant improving the existing roadway surface. The scarcity of funds for road improvement projects frequently results in minimal engineering design and low cost construction methods (Coghlan 2000). Local road agencies often lack the resources to gather and analyze the condition of local roads. Without accurate records and historical data, it is challenging to justify the need for increased funding or demonstrate priorities.

2.3 Lack of Skills and Technology

Little attention has been given to LVR design and construction as well as technical training for the current and future workforce. Skills and knowledge needed in the LVR sector often come through years of experience rather than formal training. This knowledge is typically lost when these workers retire or lose their jobs due to downsizing. Local agencies frequently continue to utilize outdated specifications and design methods. Time and financial resources required to train workers creates additional burdens on local highway agencies. In addition, state DOT training for certification purposes may not be detailed enough for quality assurance purposes (FHWA-HRT 2016).

Several organizations are working to increase interest in the LVR sector, including the Transportation Research Board (TRB) Committee on Low-Volume Roads, ASCE, the FHWA's Local Technical Assistance Program, the APWA's Transportation Committee and the National Association of County Engineers (Keller and Sherar 2003).

2.4 Suitable Materials

Although most materials specifications for higher road classifications can be applied to LVRs, the higher cost and/or limited availability of such materials can challenge local agencies to explore the use of marginal or unconventional materials (Jayasinghe and Tokashiki 2010). Since LVRs carry much fewer loads, mix design requirements can be less restrictive than for higher volume roads. Aggregate requirements for LVR mix designs may allow the use of more rounded particle shapes which can often be obtained at lower cost than more angular aggregates. Polymer modified asphalt binders are not normally used for LVR mixtures. LVR mixtures can utilize moderate amounts of reclaimed asphalt pavement (RAP). However, LVRs need to be engineered even if the process/design is less intense. Many low volume roads have heavy weight vehicles, and allowing rounded aggregate may lead to increased rutting.

2.5 Mix Design Methods

Asphalt mixture design is concerned with developing of an economical blend of aggregates and asphalt binder that will result in a pavement layer that can carry the expected traffic and climate without being damaged. Several different procedures are currently used to design LVR mixtures. It is important that mix design and materials criteria appropriate for LVRs be used with each method.

2.6 Pavement Design Methodologies

The design of pavement structures is concerned with determining appropriate thicknesses of pavement layers based on the strengths of materials in each layer, load bearing capacity of the soils, expected traffic, and environmental factors.

3. MIXTURE DESIGN APPROACHES FOR LVRS

Historically, asphalt mix designs were conducted using either the Marshall or the Hveem design method. Some local road agencies still use these methods. The Marshall and Hveem methods base criteria for materials selection, compactive effort, and mix properties on the expected traffic for the roadways. In general, mixture requirements are relaxed for low traffic applications. In 1995, the Superpave mix design procedure was introduced, building on the knowledge from the Marshall and Hveem procedures and advancing several criteria for the component materials and their proportions. Many of the criteria in the Superpave mixture design system are also based on expected traffic loadings (ESALs) with the lowest traffic level (less than 0.3 million ESALs) used for low-volume road applications.

The objective of a mix design method is to determine the mixture proportions that will provide an asphalt mixture with the following characteristics:

- Resistant to permanent deformation so that the asphalt layer will not be distorted when subjected to traffic loads. The resistance to permanent deformation is more critical at high temperatures.
- Resistant to fatigue cracking due to repeated traffic loads over the design period.
- Resistant to low temperature cracking for pavements in cold regions.
- Durable. The mix should contain sufficient asphalt to ensure an adequate coating on the aggregate particles. The compacted mix should not have very high air voids, which accelerates the aging process.
- Resistant to moisture-induced damage. Additives may be necessary to achieve good adhesion of the asphalt binder to aggregate in the presence of moisture.
- Skid resistant. For surface layers, the aggregates must be selected to avoid a loss of friction.
- Workable. The mixture must be capable of being placed and compacted with reasonable effort.

3.1 Marshall Method

The Marshall method was developed in the 1940's and was the most common method for the design of dense-graded asphalt mixtures in the United States for nearly 50 years. It is still widely used in many other countries around the world. The Marshall method consists of six steps:

1. Selection of component materials (asphalt binder, aggregates, and RAP (optional))
2. Determination of aggregate bulk specific gravities
3. Selection of aggregate (and RAP) blend to meet the desired gradation range
4. Batching, mixing, and compacting specimens at four to five asphalt contents
5. Determination of volumetric properties and Marshall Stability and Flow
6. Selection of the optimum binder content.

The Marshall method and criteria are described in the Asphalt Institute's MS-2, *Asphalt Mix Design Methods*. Specimen compaction is accomplished with the Marshall hammer; the number of blows of the hammer is based on the pavement's design traffic. Table 2 shows the Marshall mix design criteria based on three traffic levels. Low volume roads will be in either the light or medium traffic categories as defined by the 20 year design ESALs. In general, the lower compaction efforts for light and medium traffic mix designs will result in higher asphalt contents.

Table 2. Marshall Mix Design Criteria (Asphalt Institute 2015)

Mix Criteria	Light Traffic (< 10^4 20-yr. Design ESALs)		Medium Traffic (10^4 – 10^6 20-yr. Design ESALs)		Heavy Traffic (> 10^6 20-yr. Design ESALs)	
	Min.	Max.	Min.	Max.	Min.	Max.
Compaction (number of blows on each end of the sample)	35		50		75	
Stability (minimum)	3336 N (750 lbs.)		5338 N (1200 lbs.)		8006 N (1800 lbs.)	
Flow (0.25 mm (0.01 inch))	8	18	8	16	8	14
Air Voids (percent)	3	5	3	5	3	5

3.2 Hveem Method

The Hveem method for designing dense-graded asphalt mixtures was popular among many western states. Hveem's mix design philosophy was that a sufficient asphalt binder content is needed to satisfy aggregate absorption and provide a minimum asphalt coating thickness on the surface of the aggregates (Roberts et al. 2009). In order to carry the load, the aggregates must have adequate internal friction (measured by the Hveem stabilometer) and a minimum tensile strength to resist turning movement (measured by the cohesiometer). Stability and cohesion are influenced by the aggregate properties and the amount of asphalt binder. For durability, Hveem also developed the swell test and moisture vapor sensitivity test to measure the reaction of the mix to water although these tests were rarely used in the U.S.

The Hveem mix design method consists of 6 basic steps:

1. Aggregate selection,
2. Asphalt binder selection,
3. Sample preparation (including compaction),
4. Stability determination using the Hveem Stabilometer,
5. Density and voids calculations, and
6. Optimum asphalt binder content selection.

Compaction of test specimens is accomplished with the Hveem kneading compactor. The Hveem stabilometer provides the key measure of resistance to permanent deformation. Table 3 shows Hveem mix design criteria recommended by the Asphalt Institute. The cohesiometer test has a number of issues and this property is no longer used by most agencies in evaluating the quality of asphalt mixture. Low volume roads will typically be in either the light traffic or medium traffic categories.

Table 3. Typical Hveem Design Criteria (Asphalt Institute 2015)

Mix Criteria	Light Traffic (< 10^4 ESALs)	Medium Traffic (10^4 – 10^6 ESALs)	Heavy Traffic (> 10^6 ESALs)
Min. Stability	30	35	37
Air Voids	Approximately 4%		

3.3 Superpave Method

The Superpave method is used by all state DOTs except for Tennessee which still uses the Marshall method. The Superpave mix design method is contained in AASHTO R 35 *Standard Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA).* The criteria for Superpave mixtures are contained in AASHTO M 323 *Standard Specification for Superpave Volumetric Mix Design*.

The first step includes selecting the asphalt binder and aggregates for the mix design. One of the most significant changes with the Superpave system was the change to the Performance Grading (PG) system for asphalt binders. PG binder grades are based modern rheological tests. The selection of the appropriate grade depends on the climate and traffic volume. In general, asphalt binder grades used for LVRs will not need to be polymer modified to meet the criteria for low traffic roadways. Polymer modification is typically necessary for improved deformation resistance of high traffic roadways or high stress applications. It is also important to acknowledge that the Superpave consensus aggregate properties were a significant change with the Superpave system compared to previous systems.

To select the design aggregate structure, trial blends are established by combining the gradations of individual stockpiles into a single gradation. The blended gradation is compared to the gradation specification limits. Other aggregate criteria depend upon the expected traffic and the layer in the pavement structure. Table 4 shows the Superpave consensus aggregate requirements for the two lowest traffic categories. Almost all LVRs will be in the lowest traffic range (< 0.3 Million ESALs). Most of the aggregate requirements are not applicable (N.A.) for mixtures used for this category of pavements.

Table 4. Consensus Aggregate Requirements (AASHTO M323)

20-yr Design Traffic (Millions of EASLs)	Fractured Faces Coarse Agg. Min. %		Uncompacted Voids Fine Agg. Min. %		Sand Equiv. Min. %	Flat & Elong. Max. %
	Depth from Surface		Depth from Surface			
	≤ 100 mm	> 100 mm	≤ 100 mm	> 100 mm		
< 0.3	55	N.A.	N.A.	N.A.	40	N.A.
0.3 to <3	75	50	40	40	40	10

Once the aggregate proportions are determined, specimens are compacted at varying asphalt binder contents. The Superpave mix design procedure recommends several compaction levels (varies by state) that are based on the project's expected traffic. LVRs will nearly always fall in the lowest traffic category (less than 0.3 million design ESALs), so the recommended mix design compactive effort is 50 gyrations with the Superpave Gyratory Compactor (SGC). The AASHTO Superpave procedure sets the design asphalt content corresponding to 4.0% air voids, except for 4.75 mm mixes, provided that the other criteria are met. Table 5 shows the volumetric criteria for the two lowest traffic levels from the Superpave mix design method.

Table 5. Superpave Mix Design Volumetric Criteria (AASHTO M323)

20-yr Design Traffic (Millions of ESALs)	Design Air Voids (%)	Minimum VMA (percent)						VFA Range (%)
		4.75 mm (0.1875 in.)	9.5 mm (0.375 in.)	12.5 mm (0.5 in.)	19.0 mm (0.75 in.)	25.0 mm (1 in.)	37.5 mm (1.5 in.)	
< 0.3	4.0*	16.0	15.0	14.0	13.0	12.0	11.0	70 – 80*
0.3 to < 3								65 – 78

Note: For 4.75 mm mixtures, the deign air voids may be between 4.0 and 6.0 percent and the VFA range shall be between 67 and 79 percent.

The final step in the Superpave mix design method is to evaluate the moisture sensitivity of the proposed design mix using AASHTO T-283, commonly referred to as the Tensile Strength Ratio (TSR) test.

In summary, the Superpave mix design method uses criteria based on the project climate and traffic. For LVRs, asphalt binder, aggregate, and mixture volumetric requirements can often be met with materials that are more readily available. The lower compaction effort typically results in higher optimum asphalt contents that can improve mixture workability and durability.

3.4 Relevant Mix Design Studies

This section reviews several research studies that were conducted to evaluate and compare asphalt mixture design methods for LVRs. This section includes lessons learned that may help establish a universal mix design method for LVR applications.

Study 1. Habib et al. (1998) presented a comparison of Superpave and Marshall mixtures for low-volume roads and shoulders. The comparison showed that Superpave mix designs for low-volume roads and shoulders had lower asphalt contents (between 0.4 to 0.7%) than the Marshall method. The authors indicated that the required asphalt content increased as the proportion of coarse river sand increased in the mix and suggested lowering the design number of gyrations (N_{des}) by at least 25% to increase the asphalt content (up to 0.5%) for the Superpave mixture with a given gradation.

Study 2. Prowell and Haddock (2002) evaluated the use of the Superpave mixture design procedure for LVRs and base mixtures. This study evaluated the Virginia Department of Transportation's (VDOT's) Marshall designed subdivision surface mixture, SM-1, and base mixture, BM-2 using Superpave criteria. Rut testing indicated that SM-1 mixtures were generally very rut resistant and the authors suggested lower laboratory compaction levels than those traditionally used for Virginia’s low-volume roads in order to improve durability.

Study 3. Mogawer and Mallick (2004) evaluated mix design criteria for LVRs in New England. The authors stated that LVR performance is primarily affected by the environment and not by traffic. A limited experiment with 9.5 mm and 12.5 mm NMAS mixtures were designed and tested using laboratory performance tests. The Asphalt Pavement Analyzer (APA) test was used to evaluate rutting, and the resilient modulus test before and after long-term aging along with indirect tensile strain at failure after aging were used to evaluate durability. Based on the results of performance tests, the authors recommended a film thickness of 11 microns and a design VMA of 16% for producing durable and stable mixes for LVRs. In general, there was an increase in tensile strain at failure and an increase in rutting with an increase in film thickness. On the other hand, the change in modulus due to aging tended to decrease with an increase in film thickness. The study also evaluated mixes from a few “good performing” (low severity fatigue cracking and permanent deformation) 10 to 12-year old LVR surface layers. Based on compaction tests with materials recovered from these projects, the authors recommended an N_{design} of 50 gyrations for LVR mixtures.

Study 4. Vitillo et al. (2006) compared four fine-graded 9.5 mm NMAS Superpave and Marshall mixtures designed for LVRs in New Jersey. The comparisons showed that the design methods generally yielded mixes with similar volumetric properties, asphalt film thicknesses, APA rut test results, bending beam fatigue results, and permeabilities. The effort to find a number of gyrations that would provide the same density with the Marshall hammer was not successful; results showed that a different N_{design} was needed to for each mixture to obtain the same air void content as the Marshall hammer. Overall, this research study provided useful information (comparable volumetric results and laboratory performance results) for local agencies in New Jersey to assist in the transition from Marshall to Superpave mixture design for low-volume roads.

Study 5. West et al. published a report in 2011 related to asphalt mixtures with low-volume road applications. The main objective of this study was to refine procedures and criteria for 4.75 mm NMAS Superpave designed mixtures. For this study, twenty-nine 4.75 mm NMAS Superpave mix designs were prepared in the laboratory with materials from nine states. Each mix design was tested for permanent deformation, permeability, moisture damage susceptibility, and durability. Plant-produced mixtures from four other states were evaluated and served as baselines for performance. After the laboratory study was completed, four of the original nine participating state highway agencies decided to incorporate the proposed procedures and criteria as part of their current design practice. These four states started off this incorporation process by constructing projects to validate the proposed mix design criteria and establish field construction criteria.

3.4.1 Summary of Asphalt Mix Design Studies

Several studies have been conducted comparing traditional Marshall designed mixtures with Superpave design methods for LVRs. The general concern was that Superpave designed mixtures would have significantly lower optimum asphalt contents and reduces durability. Several researchers determined the number of gyrations that would provide asphalt contents and volumetrics similar to Marshall designed mixtures that had good performance histories. Prowell et al. (2002) found that 68 gyrations provided binder contents similar to a 50 blow Marshall design with optimum binder content selected at 6% air voids. Mogawer et al. (2004) recommended an N_{des} of 50 gyrations for a low-volume road in New England. West et al. (2011) recommended an N_{des} of 50 gyrations for 4.75 mm mixtures for a low-volume road. Habib et al. (1998) suggested that N_{des} values in Superpave were about 20% higher than needed.

4. FLEXIBLE PAVEMENT DESIGN APPROACHES FOR LVRS

A typical asphalt pavement for an LVR consists of a relatively thin asphalt-concrete wearing course, lower layer of asphalt concrete, and an aggregate base course constructed on a compacted subgrade. The asphalt layers provide a good riding surface and moisture protection for the base course and subgrade.

The purpose of a pavement design, also referred to as a structural design, is to determine the appropriate thicknesses of the pavement layers based on the strengths of materials in each layer, the expected traffic, environmental factors, and the reliability of these inputs. By definition, LVRs carry relatively few vehicles. However, low traffic counts do not necessarily mean lighter vehicles. In some cases, low volume roads carry heavy vehicles such as trucks hauling agriculture products, timber, mining products, and materials to and from oil fields. Yet, since the roads service fewer vehicles, it is generally understood that there are lower risks associated with pavements in poor condition. Therefore, in engineering practice, it is generally understood that a tolerance for higher risk translates to economic decisions that allow less conservative designs.

The principal methods of structural design in use today are (from simplest to most complex) design catalogs, empirical methods, and mechanistic-empirical methods (Huang 2004). Historically, most pavement structural design procedures have been empirically based, meaning that the relationships between design inputs (e.g., loads, materials, layer configurations, and environment) and pavement damage were determined from experience, experimentation, or a combination of both. The simplest approach to flexible pavement structural design involves using a design catalog that includes a listing of common loading conditions, environmental factors, and service regimes, to arrive at a recommended pavement structure. State and local agencies often include catalogs in their design manuals for low traffic roadways.

More recently, mechanistic-empirical design approaches have begun to be utilized by several state highway agencies. A mechanistic-empirical approach calculates critical stresses and strains in a given pavement structure based on load inputs and environmental conditions to estimate the accumulation of damage that result in pavement distresses. Mechanistic-empirical design methods utilize sophisticated software that require detailed inputs that are generally beyond the engineering resources of agencies that deal mostly with low volume roads. A brief description of several pavement design methods appropriate for low-volume roads or low traffic applications follows.

4.1 AASHTO 1993 Design Guide

AASHTO pavement design guides have included methods for low-volume roads that are similar to those used for high-volume roads. Many states currently use the 1993 AASHTO Guide for Design of Pavement Structures for the design of pavement structures. In this method, a road is considered to be low-volume when the expected traffic over a 20-year period is between 50,000 and 1,000,000 ESALs (AASHTO 1993). The required inputs include the subgrade resilient modulus (M_R), design reliability (set to 50% for LVRs), traffic (ESALs), and structural layer coefficients (a_i) for each layer.

The 1993 AASHTO guide relates pavement performance to a single measure known as the present serviceability index (PSI). The deterioration of PSI for a pavement structure is computed from an empirical relationship derived from a road test experiment in Ottawa, IL in the late 1950s (AASHO Road Test). It relates the cumulative ESALs to the corresponding change in pavement serviceability, ΔPSI. A limitation of this short-term experiment was that the effect of the environment was underestimated. Nevertheless, this experiment generated the first substantial database of pavement performance observations under controlled traffic. Seasonally adjusted subgrade resilient moduli and layer drainage coefficients account to some extent for environmental conditions.

4.2 United States Army Corps of Engineers Procedure

The U. S. Army Corps of Engineers (USACE) pavement design procedure is particularly appropriate for low-volume road applications because it was developed from traffic tests using relatively low traffic volumes and thin pavement sections on low-strength subgrades. The flexible pavement criteria are most appropriate for thin asphalt pavements on granular base courses and subbases. The USACE design method for LVRs is an abbreviated method of the procedure developed for airfield pavements. The two primary inputs for this method are traffic load (in terms of 18-kip ESALs) and soil strength (in terms of California Bearing Ratio, CBR). This procedure is relatively simple to use but is limited in some respects. With only two input factors, varying environmental effects and other uncertainties may not be adequately covered. This procedure is based on equations that give a required thicknesses for the material to be placed over another material of a known strength (in terms of CBR), provided that the placed material has greater CBR strength than the underlying material (USACE 1980).

4.3 National Crushed Stone Association Procedure

The National Crushed Stone Association (NCSA) design catalog method adapted from the CBR-based USACE procedure (NCSA 1973). This procedure only applies to asphalt pavements on a good crushed stone base. This is a relatively simple four-step procedure. First, soil support must be evaluated according to a soil classification system (AASHTO or Unified methods) and approximate CBR strength. The soil is given a support category of excellent, good, fair, or poor. Next, a Design Index (DI) category is assigned to the road based on expected traffic. Most low volume roads would correspond to DI-1 or DI-2 categories. For roads expected to carry heavy vehicles, other Design Index categories may need to be considered. The third step of the design procedure is to select a basic design thickness from a Flexible Pavement Design Table. The selected thickness is the total combined thickness of the crushed stone base and either a surface treatment or an asphalt mixture surface. The decision to use a surface treatment or asphalt concrete is typically based on local experience and cost factors. The final step in this procedure is to check the basic design thickness for severe conditions such as frost damage and drainage problems. A subgrade soil frost group is determined and a 'new' thickness is chosen from another Flexible Pavement Design Table based on this frost group. The thicker section of step 3 or step 4 is selected for the pavement design.

4.4 The Asphalt Institute Procedure

The Asphalt Institute design procedure is a mechanistic-empirical design procedure based on a layered elastic analysis (Asphalt Institute 1981). The design procedure for low-volume roads is similar of that used for high-volume roads (similar design charts or software and input requirements are used). Required inputs are the subgrade resilient modulus and traffic, in terms of 18-kip ESALs. The procedure is applicable to full depth asphalt pavements, asphalt over emulsified asphalt stabilized base pavements, and asphalt over granular base pavements. Simplified methods to calculate ESALs and the subgrade resilient modulus are provided. This procedure is relatively simple to use, but it is limited by not allowing use of other stabilized layers or subbase layers.

The Asphalt Institute design procedure uses a layered elastic analysis to calculate the tensile strain at the bottom of the asphalt pavement for fatigue cracking, and the compressive strain at the top of the subgrade for rutting in the subgrade were created by the Asphalt Institute. Inputs are the subgrade resilient modulus (M_r) and the ESALs anticipated over the life of the pavement. Nomographs are provided for different base layer thicknesses and material type (untreated base and emulsified asphalt stabilized base), as well as for three distinct mean annual air temperatures. It is important to mention that there is much room for subjectivity when using the nomographs and the subtle differences can result in increased/decreased layer thickness, which may increase risk of failure or increase cost.

4.5 AASHTOWare Pavement ME Design

The National Cooperative Highway Research Program released the Guide for Mechanistic-Empirical Pavement Design of New and Rehabilitated Pavement Structures in 2004 (AASHTO 2004). This guide, commonly known as the MEPDG, is a mechanistic-empirical approach to pavement design, has been widely investigated by many researchers.

The MEPDG simultaneously considers multiple performance failure criteria (e.g., rutting, cracking, and roughness) for flexible pavements. The program predicts performance for a given pavement structure. If the result is not satisfactory, the pavement structure is modified and analyzed until an acceptable design is reached.

The MEPDG requires many more input parameters than the 1993 AASHTO Design Guide, especially environmental conditions and material properties. It also employs a hierarchical concept in which the user selects different quality levels of inputs depending upon the information and resources available, technical issues, and the importance of the project. The MEPDG utilizes project-specific climate data (air temperature, precipitation, wind speed, relative humidity, etc.) to adjust material properties for temperature and moisture influences. Instead of using ESALs to define traffic levels, the MEPDG uses a more detailed load spectra concept. As pavement materials respond differently to load magnitudes, frequency, temperature and other seasonal effects, these factors can be most effectively considered using the load spectra concept.

The MEPDG contains a dedicated section for LVRs that simplifies the design methodology. Pavement designs are based on the structural requirement for a 20 year design period, with either a 50% or 75% level of reliability. The maximum number of heavy vehicles over the design life for LVRs in the MEPDG is 750,000 ESALs.

Although the MEPDG has been presented as a complete approach pavement design guide, its applicability on LVRs can be problematic. Inputs would have to be further simplified or cataloged for LVR applications. Calibration of the MEPDG for low volume roads is also a major gap and further research is still needed.

4.6 PaveXpress

PAVEXpress is a web-based software created to design flexible and rigid pavements using AASHTO 93/98. The software simplifies the process of using both the 1993 AASHTO design guide for asphalt pavements and 1998 AASHTO supplement for concrete pavements. The software contains quick help buttons to assist the designer with obtaining and properly inputting the necessary information.

PaveXpress also contains a module which can give a simple material cost estimate for the pavement materials. The module is not detailed enough for use by bidders for contract estimation purposes, but can be a tool for agencies and consultants to get a rough idea of pavement material costs.

It also contains a module which can analyze a pavement structure using a more mechanistic type of methodology, which considers the material properties for a given pavement cross section, the anticipated stresses induced by the traffic loading, and the response locations on the pavement surface and at selected points within the pavement structure. The user is allowed to select an analysis regarding the type of transfer functions to be used, which results in an estimate of the number of load cycles to failure.

Finally, the designer needs only to collect the best possible project, traffic, and material information in order to provide reliable results. It is free and easy to use, making it a better tool for those pavement designers without access to larger agency tools and expertise.

4.7 Individual State Approaches

Several states (California, Illinois, Kentucky, Minnesota, Mississippi, New York, Pennsylvania, Texas, Vermont, and Virginia) developed their own design protocols for low-volume roads, incorporating environmental, soil, and traffic factors specific for their state.

A representative example is Minnesota, which has two design procedures: the granular equivalency (GE) method, found in the state aid manual, and the R-value method (i.e., a measure of the response of a compacted sample of soil or aggregate to a vertically applied pressure under specific conditions) (MNDOT 2017). The GE method is more commonly used throughout the state because of its simplicity and less conservative values. Nonetheless, both procedures are more conservative than the AASHTO 1993 method. The GE method has two input variables: traffic load (ADT) and soil strength. The classification of soil, a soil factor, and an assumed R-value are needed as inputs for the soil. With these inputs, a minimum bituminous GE and a total GE for design are obtained. In other words, the thicknesses of bituminous base and surface are determined from a chart. The R-value procedure uses two inputs: traffic loads and soil strength. Traffic loads are related to a standard 18-kip single-axle load representing the effect of heavy vehicles over the design life, and strength is the R-value determined from a stabilometer (MNDOT 2017). The pavement structure is sensitive to small changes in this value.

Another example is Virginia's design procedure for low-volume roads. This procedure requires traffic and soil inputs. The design ADT is calculated by multiplying the current ADT by a growth factor, and a soil support value (SSV) is used to represent soil strength.

Mississippi also uses an SSV for soil strength based on CBR and a resiliency factor based on the soil classification that accounts for the soil's elastic deformation characteristics and its ability to withstand repeated loading. Multiplying the design CBR by the growth factor gives the SSV. Each county has cataloged SSV values in design tables. The required thickness index is determined from the SSV and the design ADT. This design procedure is less conservative than the 1993 AASHTO method, but it provides similar design values. Features of LVR pavement design procedures adopted by other state DOTs are summarized in Table 6.

Table 6. Summary of LVR Pavement Design Procedures in Select State DOTs (Lee et al. 2010)

State	Key Features of Pavement Design Procedures
Illinois	▪ Road with less than 400 ADT. ▪ Required inputs: traffic (% heavy vehicles) and subgrade modulus. ▪ Design period of 15 or 20 years. ▪ Estimated using the ADT for the year representing one-half of the design period.
Mississippi	▪ Required inputs: soil strength (soil support value based on CBR), design life (5-8 years), traffic loads (ADT and ADL) ▪ Soil support value = 30289 log base 10 * (CBR) + 1.421 ▪ 4-inch minimum base required for all full-depth asphalt construction.
Pennsylvania	▪ Required inputs: traffic (18-kip ESALs), soil strength (CBR),and the effects of freeze-thaw action (Design Freezing Index, DFI). ▪ No traffic data necessary for each type of truck.
Texas	▪ Required inputs: traffic (18-kip ESALs) and soil strength. ▪ Design period of 20 years. ▪ Layer moduli values back-calculated from FWD data or estimated based on soil support value (CBR).

Kentucky, Oklahoma and South Carolina have pavement design guidelines for parking lots and low-volume roads. The Kentucky guideline considers traffic up to 120,000 ESALs (PAIKY 2013), while the Oklahoma guide indicates a maximum traffic of 500,000 ESALs (OAPA 2013). The South Carolina guideline also considers pavement condition and quality of the subgrade based on CBR values and Atterberg limits (SCAPA 2016).

Overall, these individual state approaches rely on simple material properties such as CBR or R-value, and basic traffic characterization (e.g. ADT and percentage of trucks). These pavement design catalogs avoid detailed inputs, complex algorithms or software and provide statewide uniformity for practitioners.

4.8 Relevant Pavement Design Studies

This section reviews recent research studies that evaluated flexible pavement design methodologies for LVRs and includes lessons learned that could be used to help establish a more unified pavement design methodology for LVR applications.

Study 1. Abdel et al. (2015) proposed a simple empirical guide to pavement design of low-volume roads in Indiana. This guide uses inputs from readily available information that accounts for specific weather and subgrade conditions. The proposed design guide is presented as a simple flow chart and is based on the NCSA and USACE methods for pavement design. The proposed guide requires three basic inputs: traffic count and truck percentage, subgrade strength, and affirmation of the road being in a frost zone or not. Considerations used to develop the guide are as follows:

- The lifetime expectancy of low-volume roads is 15 to 20 years, with regular maintenance needed to ensure such service life.
- Traffic is divided into three categories: low (less than 70 vpd), medium (70 to 200 vpd), and heavy (201 to 1,000 vpd).
- All trucks are assumed to have three or more axles (all axles are expected to be tandem axles, except the steering axle). Pickup trucks and light-duty vehicles not considered trucks; they are considered part of the general traffic.
- Freeze depths in Indiana are approximated from the USACE frost zone map.
- Soil subgrade strength is based on CBR or dynamic cone penetrometer (DCP) values. A relationship to convert DCP to CBR was adopted from ASTM D6951.

The design process involves the following steps: (a) acquiring a Design Index (DI), (b) determining the frost zone for the project location, (c) selecting the proper subgrade strength–quality category, and (d) choosing the desired structural design from the available options.

The pavement DI, based on the traffic volume and truck percentage, is assigned a value from 1 to 4, as shown in Table 7.

Table 7. Design Index (Abdel et al. 2015)

Traffic Volume (vpd)	Truck Percentage		
	<1%	**1%–10%**	**>10%**
<70	1	1	1
70–200	1	2	3
201–1,000	2	3	4

The second step is to identify the frost zone for the project from a frost map. Third, the subgrade strength–quality category (i.e., weak, medium, or strong) of the soil is identified in regards to CBR, DCP, or descriptive soil type (Figure 1).

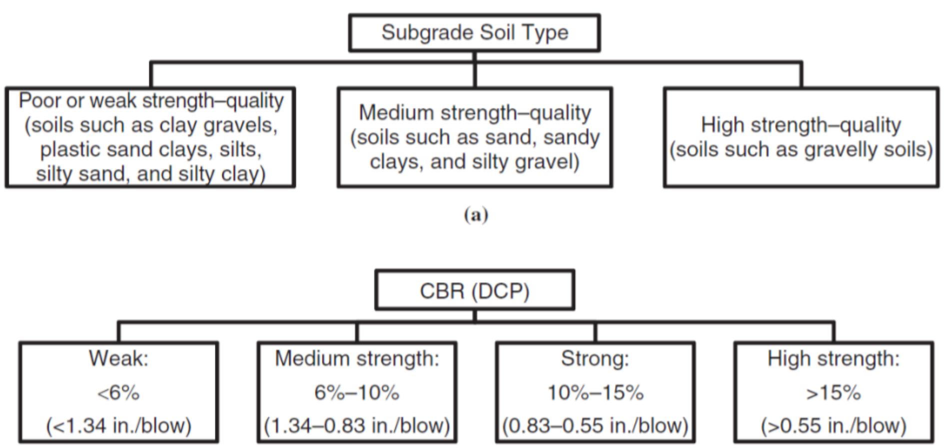

Figure 1. Categorizations of Subgrades by (a) Descriptive Soil Types and (b) CBR Strength Categories and, in Parentheses, DCP (Abdel et al. 2015)

The proposed design guide offers two pavement design options for a given set of inputs: an aggregate-road option and a flexible-pavement option. Figure 2 shows an example of the pavement design catalog for DI = 1. For this lowest traffic category, it can be seen that all pavement designs have only a one-inch asphalt surface course.

The proposed guide for Indiana is very simple. The authors recommend development of a similar guide for tropical climates and cold regions.

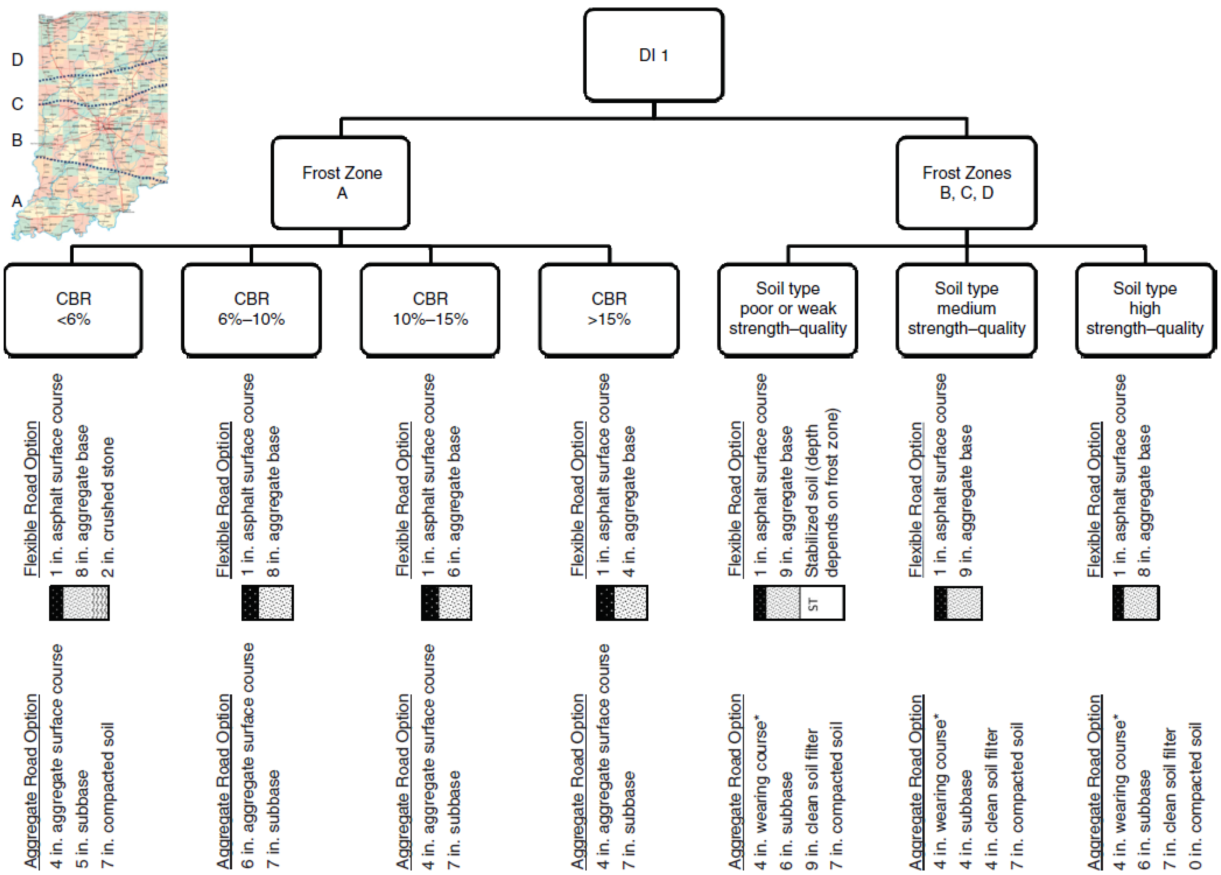

Figure 2. Proposed Sections for Pavements with DI 1 (Abdel et al. 2015)

Study 2. Timm et al. (2006) proposed a simplified perpetual pavement design guide for lower trafficked roads. The authors suggested that LVRs could benefit from the application of the perpetual pavement design approach. With perpetual pavements, pavement reconstruction is avoided, causing less inconvenience to local businesses and residents since rehabilitation would be confined to the pavement surface.

The guide was based on analysis of results from 486 perpetual pavement designs for rural and urban collector roadways using PerRoad software version 3.01. PerRoad is a mechanistic-based pavement design program that utilizes layered elastic analysis and Monte Carlo simulation to develop probability-based flexible pavement designs. The range of inputs used in the analyses are shown in Table 8.

Table 8. Matrix of Pavement Designs (Timm et al. 2006)

Parameter	Range
Soil stiffness	10,000 – 30,000 psi
Asphalt Mixture stiffness	400,000 – 1,000,000 psi
Volume	500 – 5,000 AADT
Growth	0% – 3%
Percent Trucks	5% – 20%
Directional Distribution	50%

For each set of conditions, the HMA thickness was iterated to obtain a 30-year pavement performance period. From these simulations, simple design equations were developed for the rural and urban collectors with the following format:

$$HMA = C_0 + C_1{*}AADT + C_2{*}\%Trucks + C_3{*}\%Growth + C_4{*}Soil\ Stiffness + C_5{*}HMA\ Stiffness$$

where:

HMA = required thickness of the asphalt layer, in
AADT = two-way average annual daily traffic
%Trucks = percentage of trucks in AADT
%Growth = growth rate of trucks over a 30-year period
Soil Stiffness = subgrade soil stiffness, psi
HMA Stiffness = stiffness of the asphalt layer, psi
C_0, C_1, C_2, C_3, C_4, C_5 = regression constants (Table 9)

Table 9. Design Equation Regression Constants (Timm et al. 2006)

Coefficient	Urban Collector	Rural Local Collector
C_0	10.963	11.963
C_1	6.661E-4	6.753E-4
C_2	0.120	0.124
C_3	0.258	0.234
C_4	-1.150E-4	-1.276E-4
C_5	-5.071E-6	-5.486E-6
R^2	0.942	0.938

A low-volume road version of PerRoad was developed following this study: PerRoadXpress 1.0. This software is an easy-to-use, one-screen program for designing perpetual pavements for low- and medium-volume roads and parking lots. PerRoadXpress allows the designer to use defaults for traffic and soil, or to input the actual values if they are known. Granular base thicknesses from 0.0 to 10 inches were included and new coefficients were obtained based on almost 2,000 designs (Table 10). The software quickly provides the user with a recommendation for the total thickness of asphalt pavement needed for a particular situation.

Table 10. PerRoadXpress 1.0 Design Equation Regression Constants (Timm et al. 2006)

Coefficient	Urban Collector	Rural Local Collector
C_0	10.1587	10.8162
C_1	6.281E-04	6.396E-04
C_2	0.1817	0.1861
C_3	0.2264	0.2222
C_4	-9.437E-05	-9.915E-05
C_5	-0.0780	-0.0743
C_6	-5.098E-06	5.365E-06
R^2	0.90	0.90

Study 3. Buss et al. (2015) developed the user-friendly *I-PAVE Low Volume Road Design Guide* software for the Asphalt Paving Association of Iowa. Based on the 1993 AASHTO Design Guide, the I-Pave software can be used to determine pavement thicknesses for pavements with less than three million ESALs. The software can also evaluate the life cycle cost of three pavement alternatives. As shown in Figure 3, the inputs required include project information, traffic information, and design parameters.

Darter et al (2015) examined I-PAVE inputs and program default values for new and rehabilitation design for both flexible and rigid pavements. This study also examined the equations used for calculating ESALs, design thickness and life-cycle costs. For flexible pavements, this study found that thicknesses from I-PAVE were identical to that from the 1993 AASHTO design equation. Final design thicknesses from I-PAVE are rounded up to the nearest 0.5 inches and the minimum design thickness for the asphalt layers is 3 inches. The authors noted that the rehabilitation functionality of I-PAVE was not verified, had several flaws, did not provide some equations, and did not provide default values for some inputs.

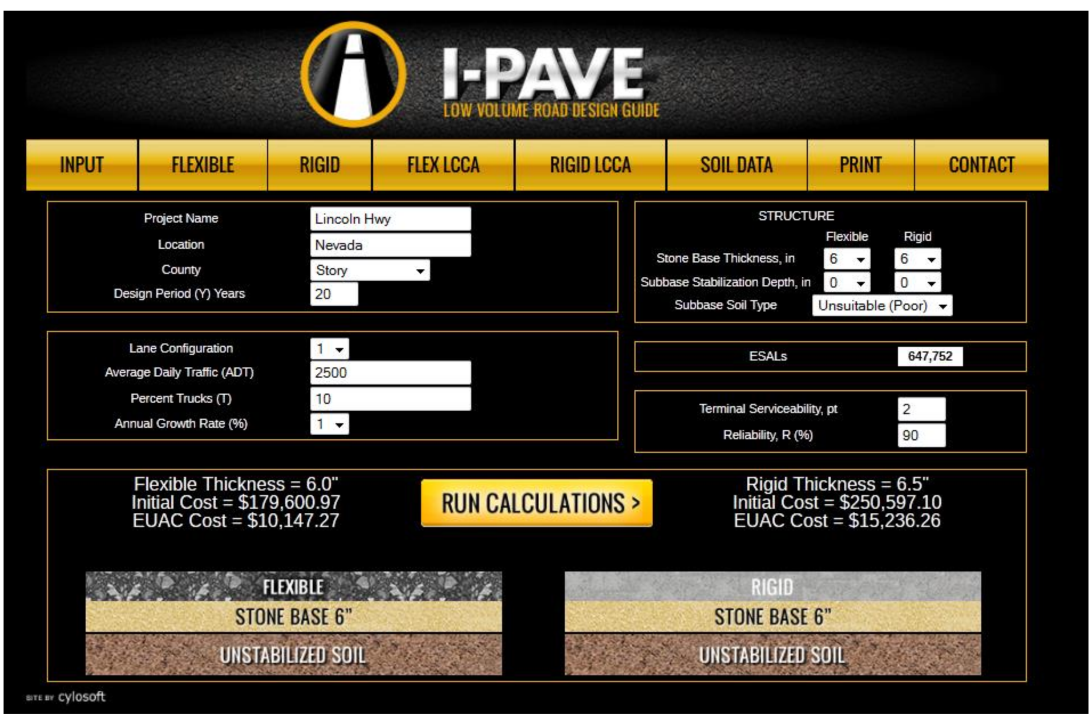

Figure 3. Screenshot of I-PAVE Low Volume Road Design Guide

4.8.1 Summary of Recent Pavement Design Studies for LVRs

Each of the three recent efforts aimed at developing structural pavement design guides for LVRs focused on providing simple to use methods. Although Study 1 was developed specifically for Indiana, the approach could be replicated in other states after conducting research to prove its general applicability. PerRoadXpress, developed in Study 2, is applicable to any location. This perpetual pavement program would logically produce more conservative pavement structures based on its approach to completely eliminate failures originating in lower layers of the structure. The I-PAVE program, based on the AASHTO 1993 design guide, is also applicable to any location. It can be used for designing new pavements and determining overlay thicknesses for rehabilitating existing pavements.

5. STATE-OF-THE-PRACTICE

Persons responsible for LVRs need information related to appropriate pavement materials, pavement layer thicknesses, and suitable methods to preserve, rehabilitate, and rebuild those roadways. In order to understand the current state of practice and knowledge on these need, a web-based survey was conducted in September 2017 to obtain information from state DOTs and SAPAs. Survey questions were organized into two areas: (1) current practices for LVR mix design, and (2) practices related to LVR pavement structural designs. Survey questions are provided in Appendix A.

5.1 Survey of State DOTs and State Asphalt Pavement Associations

Responses were received from 35 states as shown in Figure 4. Of the 35 states, some responses were received from the state DOT, some were from the SAPA, and in a few cases, both submitted responses. A few email responses were also received that referred to the state's existing design catalog or pavement design manual. Details of the responses can be found in Appendix B.

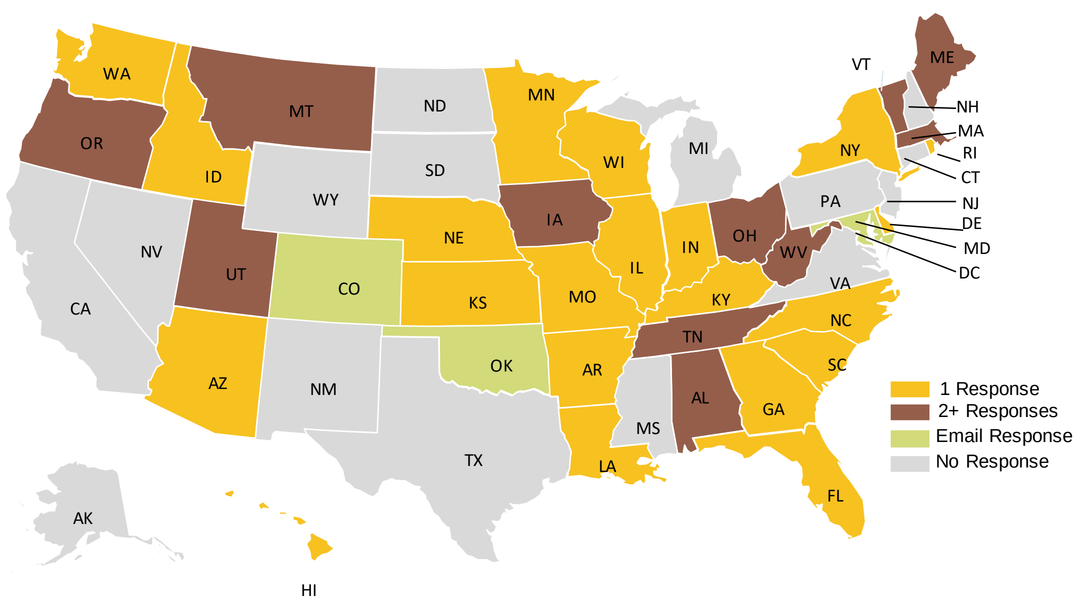

Figure 4. Map of U.S. State DOT Survey Responses

Responders were asked to provide their definition of low-volume roads. Four options were given based on asphalt mixture and pavement design methods. As shown in Figure 5, the majority of the responders use a different definition than the options provided. Responders defined LVRs in many different ways, including:

- Maximum 1000 average daily traffic (ADT),
- less than 500 vehicles per day (vpd),
- less than 750 vpd rural; 1500 vpd urban,
- less than 3000 ADT,
- less than 150 ADT or 100,000 ESALs,
- less than 2500 AADT and less than 250 trucks/day.

The most common definition of LVRs includes less than 400 vehicles per day.

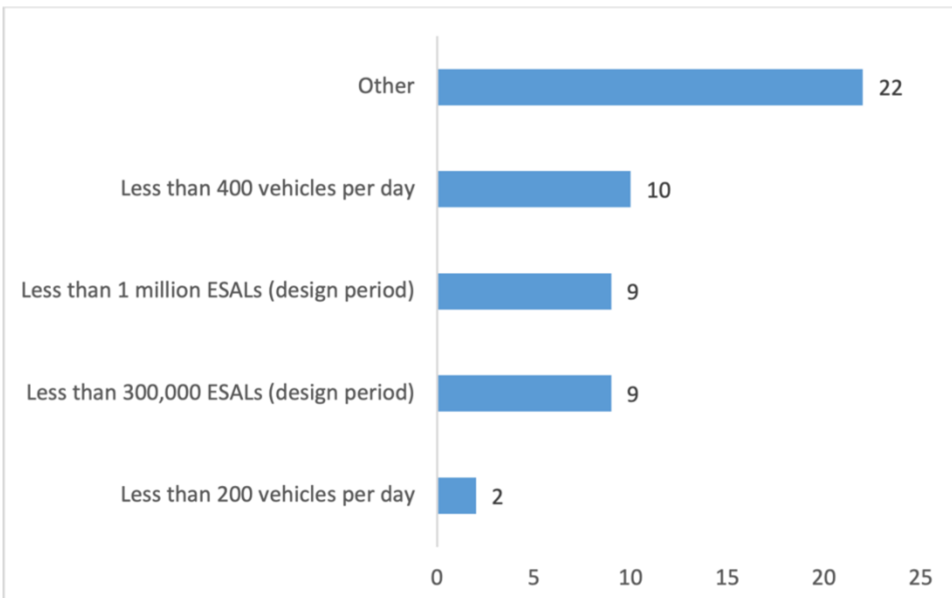

Figure 5. Agency Definition of Low-Volume Roads

State DOTs and SAPAS were asked to share their experience regarding mixture type selection for LVRs (i.e. dense-graded, SMA, OGFC, etc.). Figure 6 shows that the majority of responders select the asphalt mixture based on traffic volume or functional classification. Several responders made reference to a dense graded mixture specified in their local standard specification manual. In second place, economic conditions are used for the selection of the mixture. In the "Other" category, responses include: based on traffic and existing pavement conditions, pavement age, posted speed, existing structural capacity, and some responders specified that only dense graded mixtures were used on LVRs. Finally, seven responders indicated that mixture selection was based on thickness/NMAS ratios.

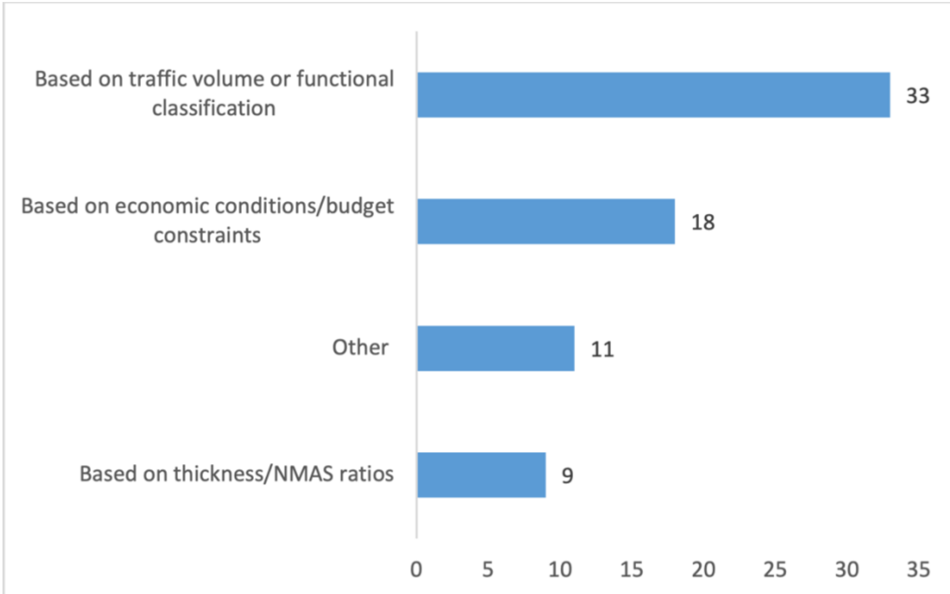

Figure 6. Agency Mix Type Selection

Out of 44 responders, only 20 indicated that they follow a specific mixture or mix design procedure for LVRs. Several responders made reference to a dense graded mixture in their standard specifications, and for mixture design procedure, the majority indicated Marshall design method. When asked if it is necessary to have an asphalt mixture design procedure for low-volume roads in their state, 18 out of 42 responded “yes” and 24 responded “no”. One common argument was that most local agencies would prefer a recipe mix or they already have one.

State DOTs and SAPAs were asked the air void target (or range of air voids) used to determine optimum asphalt content. The majority of responses were 4.0% air voids; however, a significant number of responses identified 3.5% air voids, and in a few cases, 3.0% was specified as the target. The use of a lower air void target may help increase mixture durability due to the higher optimum asphalt content.

When asked if the aggregate requirements were reduced for LVRs relative to medium-high-volume roads, 33 out of 44 indicated that requirements are reduced or relaxed. Requirements that are commonly relaxed or eliminated include fractured faces percentages, fine aggregate angularity, LA abrasion wear, friction requirements, freeze thaw requirements, more liberal use of natural sands and uncrushed gravel.

When asked if there were any modifications to the mix requirements for field production such as air voids requirements or VMA requirements, the majority (31 of 41) indicated that this was not the case. Of those that responded “yes”, a reduction in air voids content, lower level of compaction, and increase in VMA were the common elements.

The survey asked if the same asphalt binder grade is used for low-volume and higher volume roads, and if polymers are used in mixtures for LVRs. 24 out of 40 responses indicated that a different asphalt grade is used for LVRs and 52% of the 40 indicated that polymers are being used in LVRs. Some of the reasons why polymers are used included: overlay applications to address durability, used in thinlays or wearing courses, used for zones with lower traffic speed and high truck traffic / heavy load zones, and to extend the life of their pavements (towards a long lasting/perpetual pavement). Responses also indicated that, in most cases (27 of 42), no minimum asphalt content is specified based. For those states that do specify minimum asphalt contents (15 of 42), those minimums ranged from 4.3% to 5.8%.

The survey also asked about the amount of RAP and/or RAS allowed in mixtures for LVRs. Figure 7 shows that only one response indicated that RAP/RAS is not allowed. However, eleven responses noted that RAP/RAS usage is limited based on the total binder content. The majority provided "other" responses which typically included limits on the combination of RAP and RAS based on the layer type (surface, intermediate, and bottom).

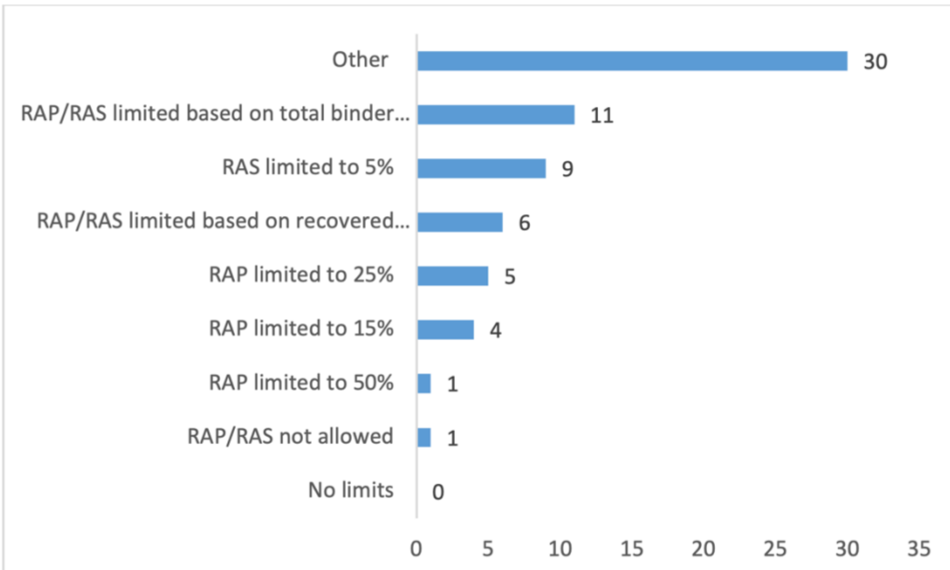

Figure 7. Use of Recycled Asphalt

On the method to determine the binder content of RAP/RAS samples, responses indicated that ignition oven and solvent extraction were equally preferred (15 of 42), as shown in Figure 8. In third place and as part of the "other" category, the nuclear gauge was specified.

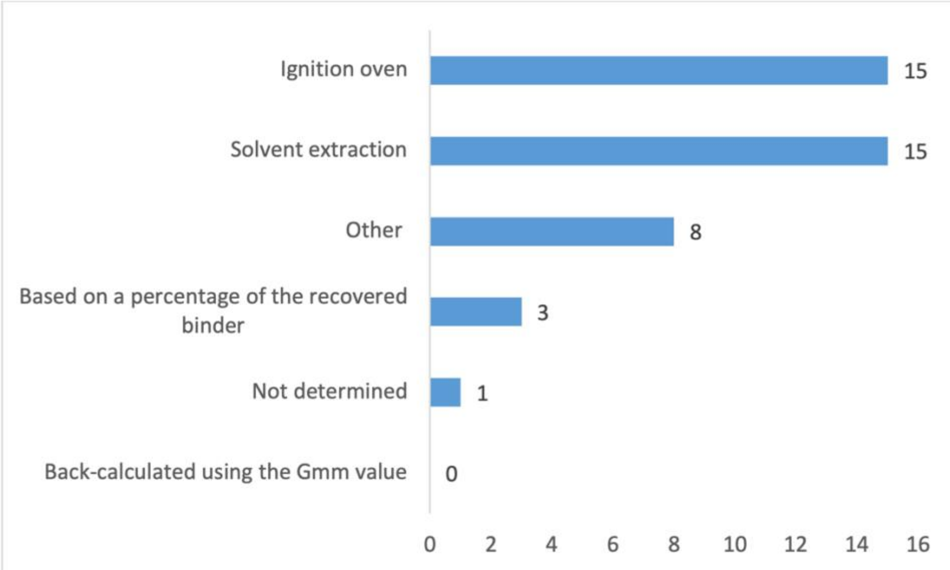

Figure 8. Determination of Recycled Binder Contribution

The survey asked if local agencies (cities/counties) would benefit from a national standard for LVR mix design. 22 of the 39 responses agreed. Similarly, the survey asked if local agencies (cities/counties) would benefit from a national standard for acceptance criteria for LVRs. 24 of 40 responses agreed.

The majority of responses (25 of 41) indicated that a pavement structural design guide for LVRs was not available in their state. Among those responses that do have a design guide for LVRs, most indicated that their guides were based on the AASHTO 93 or AASHTO 98 method. When asked if there is a minimum asphalt pavement thickness for LVRs, 26 out of 45 responses provided a positive response with minimum thicknesses ranging from 0.75 to 3.0 inches. As shown in Figure 9, the selection of the asphalt layer thickness is mostly based on the 3xNMAS rule (18 of 43 responses). However, 16 of 43 responses indicated that the selection of the asphalt layer thickness is independent of mixture NMAS.

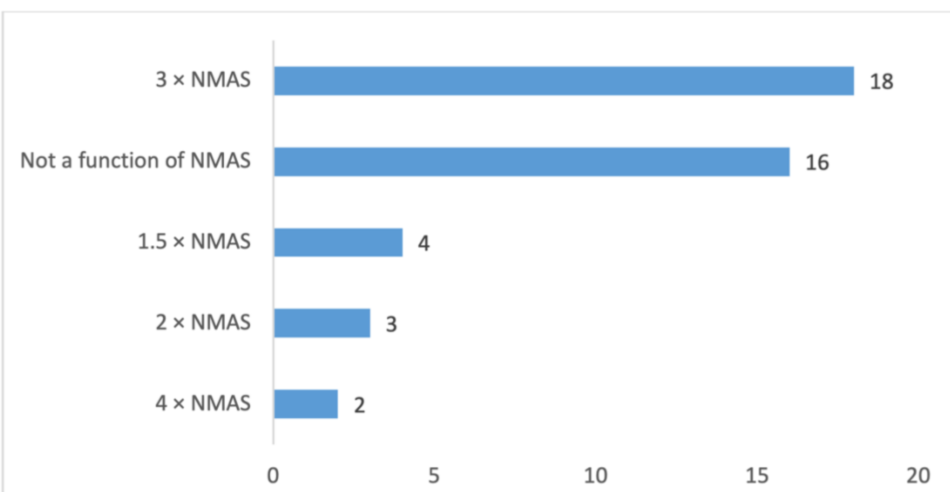

Figure 9. Asphalt Layer Thickness as a Function of NMAS

The survey also asked which mixture/pavement properties are used for acceptance. As shown in Figure 10, field density was the most popular property used for acceptance, followed by asphalt content and gradation parameters. A considerable amount of responses (17) included smoothness as an acceptance criteria for LVRs. In the “others” category, asphalt film thickness, D/A ratio, and VFA were also specified.

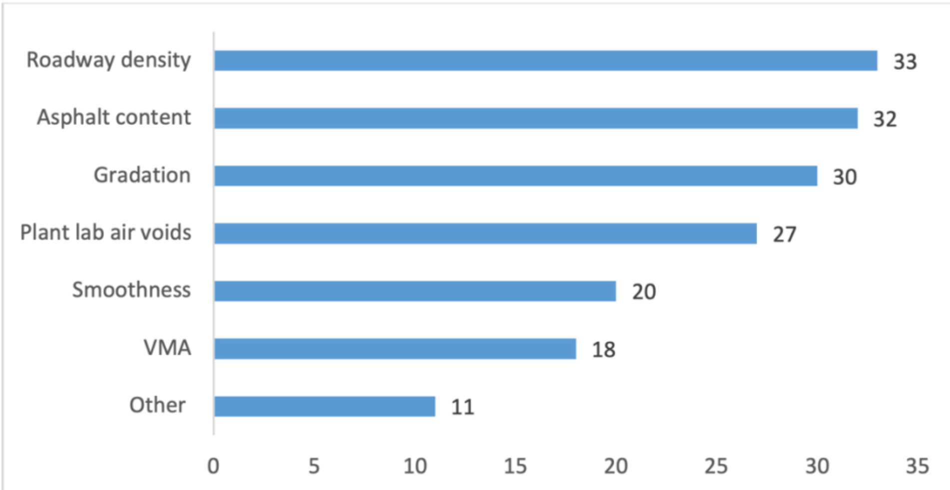

Figure 10. Mixture/Pavement Properties Used for Acceptance

In the pavement design section of the survey, a question was about the method used evaluating pavement condition. Figure 11 shows that the majority of the responses were given in the “other” category. These responses (20 of 44) included the use of automated distress survey equipment as a common method. In second place, responses identified manual condition surveys (12 of 44).

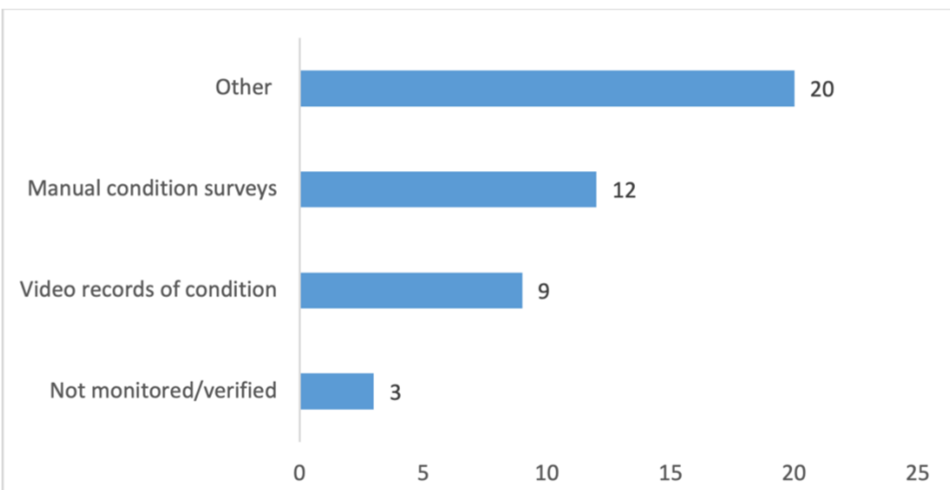

Figure 11. Pavement Condition Evaluation

The survey also asked how timing of preservation/rehabilitation of LVRs is determined. 16 of 39 responses indicated that pavement condition threshold values are used to determine when action is needed; 9 of 39 use deterioration curves, and the remaining responses indicated that a combination of thresholds and predefined times (5 to 10 years) are typically used.

The majority of responses indicated that warranties are not required for LVRs (35 of 42). The few that do require a warranty indicated that it was for at least one year with a maximum of five years.

When asked which type of pavement design would be useful for LVRs in their state, most preferred an empirical design approach, followed by an M-E approach for both rehabilitation designs and new construction (Figure 12). For overlays, the preferred option is an empirical design method.

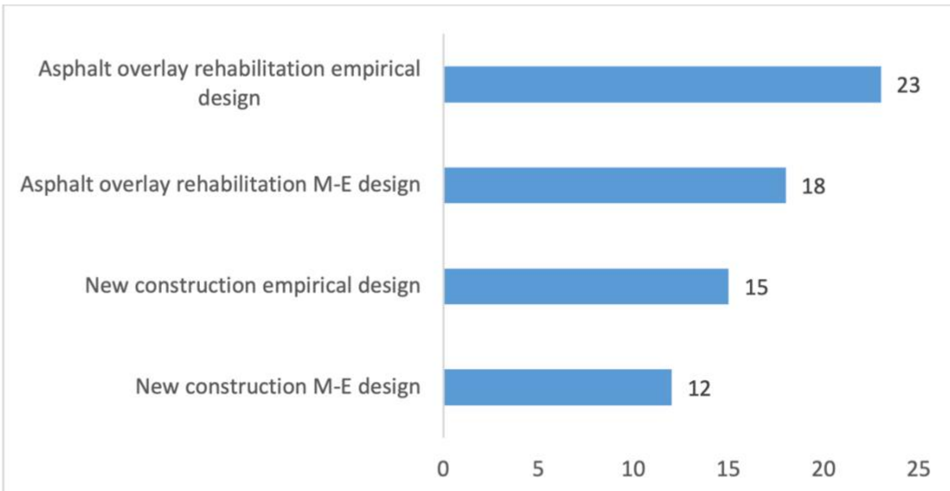

Figure 12. Potential Pavement Design Guides for LVRs

The survey asked responders to identify the biggest barriers to design, build, and maintain LVRs. The most common response was budget constraints. Lack of historical data, lack of contractor experience, lack of inspector experience, and lack of standard specifications applicable to LVRs were other common responses.

Critical areas that responders recommended be given more attention during LVR pavement design are shown below. Overall, responders were most concerned about the method used to obtain an adequate pavement structure.

- Adequate structure/thickness
- Drainage
- Traffic data
- Condition survey
- Proper mixture/binder
- Improve subgrade/subbase condition
- Proper pavement preservation
- Serviceability
- Recycled materials
- Construction techniques

Finally, critical areas for designing asphalt mixtures for LVRs were identified. Overall, responders were most concerned about the selection of proper asphalt content, followed by cracking and rutting susceptibility.

- Asphalt content
- Cracking resistance
- Rutting resistance
- Proper binder grade
- Aggregate quality
- Mixture durability or susceptibility
- Decrease air voids
- Recycled materials
- Mixture service life

5.2 Summary of Issues and Needs

Insufficient funding is a critical constraint associated with LVRs. It affects the sufficiency of construction and maintenance and the amount of engineering invested in roadway planning and design. As a consequence, LVRs are generally in poorer condition than higher-traveled highways and deterioration occurs at faster rate, creating a growing backlog of improvement needs.

In addition, many agencies lack sufficient data on their roadway inventory, traffic, and pavement condition to support better decision making for prioritizing maintenance and utilizing limited funding to achieve the best return on investment. Many agencies also often struggle with replacing experienced staff and developing their technical workforce. Considering the limited resources to most agencies responsible for LVRs, guidance for pavement structural design, materials specifications, and construction quality assurance must be based on sound pavement engineering principles and experience, yet practical, easy to use and understand with basic training.

Quality assurance programs that are commonly used on state paving projects can be scaled-back for LVRs. While most agencies responsible for LVRs lack the manpower and facilities to perform quality assurance checks, most paving contractors can provide the agency with quality control test results to demonstrate whether or not the materials meet the project specifications. At a minimum, agencies should invest in training for their project level technical staff so that they can understand the key items to check and inspect prior to and during construction to verify that the appropriate materials and construction methods are used to assure good performing LVR pavements.

6. RECOMMENDED ACTIONS

Although numerous advancements and refinements have been made in asphalt materials specifications and pavement engineering over the past few decades, relatively little attention has been given to the application representing the largest segment of the nation’s road network, low volume roads.

Based on the literature review and the survey of experts, technical information is needed in four areas to help improve the management of LVR pavements: (1) practical guidance on determining appropriate methods for maintaining and rehabilitating existing LVRs needing repair, (2) a reliable and simple LVR pavement design procedure that is applicable throughout the USA, (3) national standards for LVR pavement materials including compacted subgrades, bound and unbound base layers, and asphalt mix designs, and (4) appropriate construction specifications for LVRs.

Therefore, development of simple guides for agencies responsible for local roads is the recommended next step. Considerable effort will be needed to develop these guides. One of the biggest challenges of this type of work is getting all stakeholders to agree on technical items. This often requires several iterations of the draft documents following reviews.

Another key decision is the media/format for the guides (e.g. print &/or on-line). On-line content is easier to update, enables video, is more accessible as our culture embraces mobile devices as the primary portal for information, and allows for usage feedback.

Task 1. Develop an LVR Materials Guide

This guide would include recommended specifications and explanatory information for asphalt mixtures as well as for base layers and compacted subgrades. Given that existing underlying materials and conditions may be more variable for LVRs, it is desirable to provide mix design criteria that will result in more crack resistant pavement surfaces. Some unique aspects of mix designs for LVRs may include:

1. Aggregate requirements (mostly shape and angularity) should be less restrictive for LVR asphalt mixtures. In some areas, higher percentages of natural sands may be suitable and permit more economical and more workable mixes. Aggregate gradation ranges should be limited to smaller NMAS (i.e. 4.75, 9.5, and 12.5 mm) to aid compaction and improve resistance to water intrusion.
2. Binder grade selection should be based on environment and not influenced by traffic. A climate based map of PG grades would be included in the guide.
3. The guide should recommend practical limits on RAP and RAS contents based on a general consensus of the industry.
4. Mixture compaction should be based only on the Superpave gyratory compactor to simplify the guide, to streamline training, and to avoid laboratories having to maintain equipment for multiple methods.
5. Volumetric criteria may be adjusted from current AASHTO Superpave criteria to achieve higher asphalt binder contents for improved compactability, lower permeability, and improved cracking resistance.
6. Warm mix asphalt technologies should be mentioned. The “drop in” approach would be recommended.
7. To protect against moisture damage, it should be recommended that all mixtures contain an antistrip additive approved by the state at the supplier’s recommended dosage. This would streamline the mix design effort rather than recommending a TSR or Hamburg test. In states where no moisture damage has been observed and no antistrip additives are used, the requirement for antistrip additive could be omitted.

8. In the future, performance tests may become an integral part of mix designs (i.e. balanced mix design). Although criteria for the performance tests are in development, very little attention has been given to the potential use of performance tests for LVR mixes. This topic should be mentioned in the guide to let readers know that performance tests are coming, but until appropriate LVR criteria can be established, the LVR mix design procedure should be based on volumetric criteria.

The LVR Materials Guide should also include information to help users understand and specify common base layer materials including cold recycled layers, aggregate base, and stabilized soil treatments that are used by state highway agencies. Similarly, the guide should also provide information on soil classifications, drainage characteristics, field testing methods (e.g. Dynamic Cone Penetrometer and Standard Penetration Test), and references for chemical and mechanical treatments.

Task 2. Develop an LVR Pavement Design Guide

The current state-of-the-practice for pavement design for most state highway agencies is based on empirical methods such as the AASHTO 1993 design guide. Although a given state highway agency may eventually change to mechanistic-empirical (M-E) pavement design procedures, there are some challenges in getting project level input data and the some of the existing distress damage models may not be reliable, especially for LVRs. Therefore, at this time, the recommended path forward is to either enhance PAVEXpress or I-PAVE as the primary structural pavement design tool for LVR pavements. Both options require the same inputs since they are based off the AASHTO 1993 design guide; however, some inputs could be streamlined for LVR applications. For instance, suggested traffic levels and CBR values for LVRs could be incorporated into a simplified module. At this point, PaveXpress can be utilized on tablets or smartphones which can be a more useful tool for the field practitioner.

Task 3. Develop an LVR Construction Guide

Construction specifications must be clear in their communication of an owner agency's expectations and requirements. This guide would include information for construction of new LVRs and rehabilitation of existing LVRs. Topics should include preconstruction meetings (safety plans, schedules, materials approvals, inspections, traffic control plans, and quality assurance plans), milling, patching, leveling, weather limitations, surface preparation (e.g. prime coat, cleaning of surfaces, tack coats), mixture production (temperature ranges, coating), sampling and testing for quality assurance, mixture placement (e.g. grade control, segregation, temperature uniformity, thickness, turn outs, drop offs), and compaction (density control, joints, smoothness).

Existing guides and specifications will be helpful such as the Hot Mix Asphalt Paving Handbook (2000), the Asphalt Institute's MS-22 Construction of Hot Mix Asphalt Pavements, state DOT specifications, and the American Public Works Association's Greenbook Field Edition.

Task 4. Develop an LVR Maintenance and Rehabilitation Guide

Agencies responsible for LVRs also need guidance on maintaining and rehabilitating the pavements. This guide would include basic pavement management principles, how to evaluate existing pavement conditions using simple tools such as MicroPaver, and likely causes of observed pavement distresses. The guide should include information on repairing localized areas due to advanced distresses or utility cuts, as well as recommended methods of rehabilitating deteriorated pavements. As suggested previously, this guide would ideally be designed for use with mobile devices and include easy to follow visual prompts, photos, videos, and illustrations.

Task 5. Training

Local agencies are encouraged to create or update their training program based on the outcomes from tasks 1 to 4. New staff at local agencies (and/or the consultant working along with the agency) are encouraged to register with the state DOT and take their training program. Training is recommended to be recorded and made available online for local agencies to view as many times as they need. Finally, training could be provided in smaller training sessions that target local agency programs in smaller components (e.g., materials, inspection, etc.) and get more specific and in-depth.

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