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BEST PRACTICES TO SUPPORT AND IMPROVE PAVEMENT MANAGEMENT SYSTEMS FOR LOW-VOLUME PAVED ROADS-PHASE I

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16. Abstract

The Colorado Department of Transportation (CDOT) has been trying to identify the most effective methods for managing low-volume roads (LVRs). These roads are facing multiple challenges including: reductions in maintenance budgets, impact of industrial activities, and potentially not receiving the most cost effective treatments. Considerable savings can be secured by implementing an effective and informed management system for all LVRs engineering issues, including: planning, design, and maintenance. This report documents current national and local practices and investigates treatment policies that are in place on LVRs by summarizing the results of multiple surveys. Four online surveys were sent to the TRB low-volume roads committee, eight state DOTs, local governments in Colorado, and the material advisory committee in the CDOT. Seventy-one transportation agencies and individuals responded to the survey. The findings of this study provide CDOT and transportation agencies nationwide with comprehensive guidelines and state-of-the-practice information for managing LVRs. These guidelines include information about defining low-volume paved roads and types of PMS data recommended on these roads. It also gives insight about the effectiveness of some of treatment strategies applied to LVRs by different states at different management levels. The participants emphasized the need for some innovative maintenance activities for LVRs and integrating optimization techniques. A comprehensive literature review is introduced showing the most commonly applied treatments and new technologies for maintaining LVRs. This report is a useful reference to present key planning, design, and maintenance that are successfully meeting LVRs management needs.

Implementation

The results of this synthesis report are used to inform the second phase of the project studying CDOT maintenance strategies for low-volume roads.

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Executive Summary

The Colorado Department of Transportation (CDOT) has been trying to identify the most effective methods for managing low-volume roads (LVRs). These roads are facing multiple challenges including: reductions in maintenance budgets, impact of industrial activities, and potentially not receiving the most cost effective treatments. Considerable savings can be secured by implementing an effective and informed management system for all LVRs engineering issues, including: planning, design, and maintenance. This report documents current national and local practices and investigates treatment policies that are in place on LVRs by summarizing the results of multiple surveys. Four online surveys were sent to the TRB low-volume roads committee, eight state DOTs, local governments in Colorado, and the material advisory committee in the CDOT. The surveys included questions that focused on the pavement management system (PMS) specifications recommended for only low-volume paved roads. Seventy-one transportation agencies and individuals responded to the survey. The findings of this study provide CDOT and transportation agencies nationwide with comprehensive guidelines and state-of-the-practice information for managing LVRs. These guidelines include information about defining low-volume paved roads and types of PMS data recommended on these roads. It also gives insight about the effectiveness of some of treatment strategies applied to LVRs by different states at different management levels. The participants emphasized the need for some innovative maintenance activities for LVRs and integrating optimization techniques. This report provides an independent review of PMS initiatives for roads at the local level. A comprehensive literature review is introduced showing the most commonly applied treatments and new technologies for maintaining LVRs. This report is a useful reference to present key planning, design, and maintenance that are successfully meeting LVRs management needs.

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List of Abbreviations

The following table describes the various abbreviations and acronyms used throughout the report:

Abbreviation	Description
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Cement
ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic
CBR	California Bearing Ratio
CDOT	Colorado Department of Transportation
CIR	Cold In-Place Recycling
CSU	Colorado State University
DL	Drivability Life
ESAL	Equivalent Single Axle Load
FDR	Full-Depth Reclamation
FHWA	Federal Highway Administration
FWD	Falling Weight Deflectometer
GDOT	Georgia Department of Transportation
HMA	Hot-Mix Asphalt
IDOT	Iowa Department of Transportation
IRI	International Roughness Index
LCCA	Life-cycle Cost Analysis
LVR	Low-Volume Road
M&R	Maintenance and Rehabilitation
MAC	Material Advisory Committee
MNDOT	Minnesota Department of Transportation
MR&R	Maintenance, Rehabilitation, and Reconstruction
MUTCD	Manual on Uniform Traffic Control Device
NCSA	National Crushed Stone Association
PASER	Pavement Surface Evaluation Rating
PCI	Pavement Condition Index
PCI	Pavement Condition Index
PMS	Pavement Management System
PSI	Present Serviceability Index
RSL	Remaining Service life
RUT	Rut Depth
SDDOT	South Dakota Department of Transportation
SSV	Soil Support Value
USACE	United States Army Corps
VSR	Visual Inspection Rating
WYDOT	Wyoming Department of Transportation
WYT^2/LTAP	Wyoming Technology Transfer Center/ Local Technical Assistance Program

Chapter 1: Introduction

Departments of Transportation (DOTs) face the challenge of maintaining the pavement condition of a road network. Although pavement deterioration rates increase over time, the maintenance financial resources are not raised accordingly. This challenge is more critical for low-volume roads (LVRs) which are managed under the supervision of state DOTs and local agencies. Most federal aid supports state highway agencies to improve the condition of national highways (NHS). The *Moving Ahead for Progress in the 21st Century Act* (MAP-21) established performance targets for the NHS which includes Interstates and state highways carrying relatively high traffic volumes. All state DOTs are required to integrate a risk-based Pavement Management System (PMS) for their primary national highways to achieve the desired pavement performance (Title 23 U.S.C. §303 (a), 2011). There is no legal requirement to implement a typical pavement management system on county and local roads since there are no specific performance targets. More flexibility was given to state and local governments in determining their needs, especially considering the modest maintenance budgets allocated for LVRs.

Unlike high volume roads, state and local agencies are interested in developing lower-cost pavement rehabilitation and surface treatments on their LVRs for two reasons. The first reason is that agencies are trying to enhance the overall weighted serviceability of the LVRs network with the available limited resources. The second reason is that most deteriorated low-volume roads usually suffer from non-load-related distresses caused by environmental factors, thus the pavement preservation strategy would have priority compared to the structural enhancement of pavements.

It was recently realized by pavement engineers and researches that considerable savings can be obtained by implementing an effective and informed management system for all LVRs engineering issues, including: planning, design, and maintenance. Several states have been making efforts to research, investigate, and adopt specific polices for their LVRs according to their local objectives. Decision makers and road asset managers need access to the available knowledge on good practice regarding the construction and maintenance of LVRs. This report documents the best practices that have been employed among various U. S. agencies. In 2016, Colorado State University (CSU) and the Wyoming Technology Transfer Center/Local Technical Assistance Program (WYT^2/LTAP) started a research project on evaluating practices applied to build a pavement management system for low-volume roads. As part of this project, multiple surveys were developed, distributed, collected, and then analyzed to investigate the most common and effective practices in managing low-volume paved roads. On average, 26 questions in each survey were disseminated to 73 agencies representing state DOTs, expert engineers, and local governments. The results of the surveys are summarized in this report which focuses only on the management of low-volume paved roads. The pavement management program for LVRs is recommended to integrate the most appropriate pavement treatment techniques resulting in better performance of the network. In addition, a comprehensive literature review is included in this report to highlight and discuss the most commonly applied engineering techniques and new technologies on LVRs. This report should be a useful reference to present key planning, design, and maintenance issues affecting LVRs.

1.1 Objectives

The primary objective of this report is to assist CDOT and other transportation agencies in identifying the best practices and techniques that can enrich their capabilities to manage, maintain, and improve LVRs. This report aims to achieve the following:

1. Provide an independent review of pavement management practice initiatives for LVRs,
2. establish state-of-the-practice information on structural data required for design of LVRs,
3. define common practices of data collection and pavement survey,
4. identify effective polices in various states that are in place on LVRs,
5. evaluate current strategies in optimizing available resources,
6. identify pavement treatments resulting in efficiencies in budgeting and construction efforts, and
7. highlight innovative techniques that are successfully meeting agency needs.

1.2 Background

There are considerable challenges when it comes to managing low-volume roads. Some challenges are related to unpaved surfaces while others are related to low-volume paved roads. There are additional challenges beyond managing the pavement infrastructures such as traffic engineering and safety-related issues.

When managing high volume pavements, there are plenty of experience, training, materials and resources available. However, LVRs have limited resources and lower priority when it comes to allocating funding. Consequently, LVRs fall into poor condition and need reconstruction and improvements around the world (Coghlan, 2000). Some of the major challenges facing LVRs are described below.

1.2.1 Funding Levels

Funds are considered the most important issue associated with managing and maintaining LVRs. According to data from the U.S. Office of Management and Budget and the U.S. Census Bureau, the investment for maintaining transportation surfaces is declining in recent years. Figure 1.1 shows the amount of decline in spending for state, local, and federal surface transportation from 2002 to 2011.

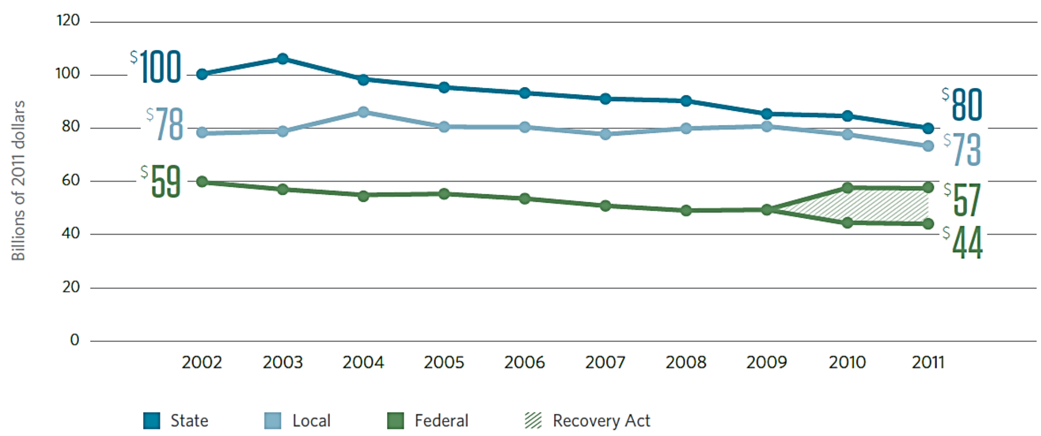


Figure 1.1: 2002-11 Highway and Transit Spending by Level of Government (The Pew Charitable Trusts, 2014)

Local spending fell by 7 percent adjusted for inflation (The Pew Charitable Trusts, 2014). In addition, the amount of spending by localities (e.g., municipalities, counties, and local transportation authority) comprises 36 percent of the total spending on surface transportation. This funding should be invested so that higher return can be achieved. Most federal aid and support focuses mainly on Interstate roads and national highways. LVRs have low-effective returns. They cannot compete with the return of higher-speed roadways and higher traffic volume transportation facilities. Therefore, the limited funding for low-volume roads affects the sufficiency of appropriate construction and maintenance. As a consequence, the LVRs continue to deteriorate annually, resulting in overall poor conditions and lower-performance levels.

1.2.2 Data Availability

LVRs have significant shortage of inventory, traffic, condition, structural, and performance data. Local governments and municipalities suffer from difficulty in allocating the funds required for building a management system in addition to a lack of expertise. In many cases, the construction data history and drawings of LVRs have been lost or never existed. As a result, low-volume road networks have incomplete data. The roadway management officials don't have a clear strategy of maintaining and enhancing the LVRs networks. They cannot demonstrate priorities, quantify disinvestment, or support maintenance needs to the state legislatures. Therefore, investments and funding justifications are inherently weak for LVRs. However, most state DOTs do not have these issues and they include LVRs data in their pavement management databases.

1.2.3 Safety-Related Issues

LVRs experience safety-related issues for traffic. Along LVRs, some crash frequencies and severities are strongly related to traffic volume. A study in the State of Iowa has shown that low-volume local roads exhibit a high frequency of injury crashes compared to the primary roads (Souleyrette et al., 2010). LVRs experience frequent crashes of fixed objects, rollover, and other run-off-road crashes.

1.3 Summary

Although state DOTs are supported with federal aid for managing their national highways, limited resources and funding are allocated for managing low-volume roads. This challenge is more critical to local governments and municipalities which suffer from limited expertise, budgets, and knowledge. In recent years, state and local agencies have dealt with considerable challenges for managing LVRs, including: low funding levels, data shortage, and increasing crash rates. As a result, good and informed management practices are highly required. This report documents the best management practices that have been employed by summarizing the results of multiple surveys sent to state DOTs, expert engineers, and local governments in Colorado. These surveys provide evaluation of management techniques commonly applied on LVRs. Also, they highlight recent and innovative technologies adopted to maintain pavement surfaces cost-effectively. Further, a comprehensive literature review is included in this report showing main LVRs engineering issues. This report should be a useful reference for Colorado DOT and other transportation agencies to present key planning, design, and maintenance issues applicable to LVRs.

Chapter 2: Literature Review

This chapter provides a comprehensive literature review about the definition of low-volume roads and key points of LVRs design, maintenance, and rehabilitation. Surface treatments and low-cost pavement rehabilitation are also introduced showing the most recent technologies applied for surfacing and recycling. In addition, several PMS programs and studies were reviewed to provide information on what other states have been doing to face LVRs management challenges.

2.1 Low-Volume Roads Definition

Low-volume roads have relatively lower usage and occur in regions connecting remote areas with local access and collector roads. Some agencies differentiate between urban low-volume roads and from-farm-to-market rural low-volume roads. In rural areas, the roadways are generally classified into four functional systems as follows (Male, 2014):

- **Principal arterials –** which are interstate roads, major federal and state highways linking states and major population centers.
- **Minor arterials –** comprised of less traveled state and county highways linking smaller cities and major towns.
- **Rural collectors –** which are major and minor collectors linking the smaller population centers with the rural areas.
- **Local roads –** which are residential roads connecting the smaller communities and the individual homes. They also connect business and farm roads to the surrounding communities. Table 2.1 lists the typical distribution of traffic volumes on the different

functional systems in addition to the percentage of road miles compared to the total length of network. It is obvious that local road systems account for a small percentage of the total traffic volume. Yet, local roads represent the majority of road miles with a percentage ranging from 65 to 80 percent.

Table 2.1: Typical Distribution of Functional Systems

Functional System	Range	
	Traffic Volume (%)	**Length (%)**
Principal arterial system	40-65	5-10
Principal arterial plus minor arterial street system	65-80	15-25
Collector road	5-10	5-10
Local road system	10-30	65-80

Source: A Policy on Geometric Design of Highways and Streets,
American Association of State Highways and Transportation Officials, 2001

Based on traffic volumes, roads can be also classified into three categories: High-volume; medium-volume; and low-volume roads. According to the Manual on Uniform Traffic Control Devices (MUTCD), a low-volume road (LVR) is defined as a road carrying an Annual Average Daily Traffic (AADT) less than 400 vehicles per day (MUTCD, 2009). LVRs cannot be any of the following roadway facilities (MUTCD, 2009):

- A freeway
- An expressway
- An interchange ramp
- A freeway service road
- A road on a designated State highway system
- A residential street in a neighborhood

Low-volume roads constitute the vast majority of the United States road network. There are about 73 percent of the public roads located in rural areas with populations less than 5,000

(Mozaffarian et al., 2015), and the total miles of low-volume roads represent approximately 70 percent of federal-aid road miles nationwide (Muench et al., 2004). Most of these roads are owned by the local governments. The 2015 status of the nation's highways shows that about 77% of highway mileage nationwide are owned by the local governments, see Figure 2.1.

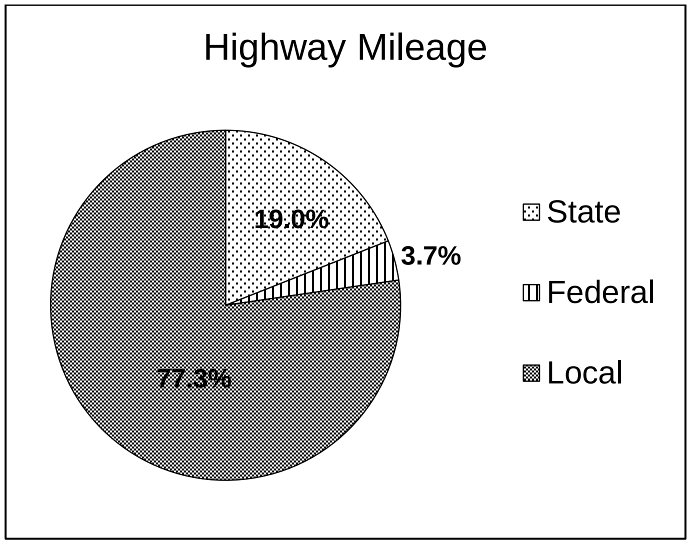


Figure 2.1: Highway Ownership by Level of Government (Mozaffarian et al., 2015)

Suitable LVRs classifications are important to provide the appropriate framework for designing, managing, and maintaining these roads. In many countries, rural roads are classified based on administrative or political criteria and not on the traffic volumes (Cook et al., 2013). However, from an engineering viewpoint, a low-volume road should be designed to accommodate not only the amount of traffic volume but also the types of vehicles travelling on the road. There are questions about including more parameters in defining LVRs. For example, oil and natural gas production involves heavy trucks which might have a greater effect on the performance of pavements on LVRs. Industrial activities generate higher volumes of trucks. Hence, LVRs should be defined with a limitation of truck volumes. Other parameters such as design speeds and corresponding road geometry are also recommended to be considered.

2.2 Types of Low-Volume Road Surfaces

As shown in Figure 2.2, low-volume roads surfaces are either paved roads using asphalt or unpaved roads using gravel or stone surfaces. Each surface requires specific maintenance and materials to keep the road serviceable. The agency's available resources are the most significant parameters on the decision of paving or un-paving the low-volume road surface.

(a) (b)

Figure 2.2: Types of Road Surface; (a) Paved "Asphalt" Road; (b) Unpaved "Gravel" Road

In rural areas, some LVRs have nonmotorized trips. Other LVRs have heavy loads from heavy farm equipment and trucks. The decision to select a type of surface does not depend only on the type of loads. There are numerous parameters that should be considered. Most low-income countries have agricultural-based economies and they have very limited resources to construct, preserve, and maintain paved roads in rural zones. Table 2.2 shows that most LVRs in the rural societies of these countries remain unpaved.

Previous research studies were conducted by agencies to find the appropriate decision as to whether a road should be paved or unpaved. The decision-making process depends on a variety of factors. Some of these factors were minutely discussed and others still need more investigation. The following section provides a brief review of these considerations for the appropriate surface type of LVRs.

Table 2.2: Rural Roads Status in Developing Countries (Cook et al., 2013)

Country/Region	Rural Roads (mile)	%Unsealed
Indonesia	180,819	46
Philippines	104,825	80
Cambodia	13,484	96
Lao PDR	13,484	85
Vietnam	80,778	82
Bangladesh	127,443	86
Mongolia	23,550	97
Kenya	23,220	94
SADC	254,762	95

2.2.1 A Framework for Selecting the Appropriate Road Surface

Any road should fulfill the objective of maximizing the benefits from applying a particular surface type. The costs and benefits of the alternative surfaces are strongly influenced by the maintenance practices which in fact vary significantly among agencies. Several documents provide information on recommended maintenance practices for gravel roads (FHWA, 2015; Bloser et al., 2012; Huntington and Ksaibati, 2010; AASHTO, 2007; Skorseth and Selim, 2005) and paved roads (AASHTO 2007; Smith, 2006). It is commonly known that engineers rely on the use of unsealed gravel roads as the default low-volume rural road (Cook et al., 2013) due to its low initial cost and simplicity of construction. Then, different issues are studied on the maintenance and sustainability of these roads. The decision of upgrading the default road depends on three general terms: 1) Engineering factors, 2) Costs, and 3) Public opinion. These terms are explained below.

2.2.1.1 Engineering Factors

Gravel and paved roads differ in many aspects, including construction, maintenance, drainage systems, smoothness, and types of vehicles that can be accommodated (Kentucky Transportation Center, 1988). The simplicity of constructing and maintaining gravel roads make the costs of building unpaved roads low. However, gravel roads have more dust problems, lower operational speed, and higher user costs. On the other hand, paved roads provide smoother surfaces, better protection for both the subgrade and base layers, and more durable surfaces against adverse weather and environmental conditions. However, paved roads require a comprehensive management system and higher-quality materials to preserve the pavements in serviceable conditions. Therefore, low-volume unpaved roads should be considered where the following engineering characteristics are achieved:

1. The gravel quantities are available and the quality is adequate.
2. The road does not have steep gradients.
3. Low-traffic levels are expected on the road with lower speeds.
4. A practice for controlling dust and maintaining roads is guaranteed.
5. The surrounding environment is suitable where the rainfall rate is low to moderate.

It is to be noted that unpaved roads should not only be a gravel road. There are other surfacing types for unpaved roads, including dirt roads, earth or native soil roads, chemically treated roads, and gravel roads (Huntington and Ksaibati, 2010). However, unpaved roads are often referred to with the general term of a 'gravel road' which comprises appropriate and sustainable granular aggregates in unsealed conditions. When the unpaved roads have engineering problems, specific stabilization treatments are applied in which case the road is called a 'treated road'. The decision of paving the gravel road is taken by the officials to acquire many objectives which include:

1. Accommodate heavier trucks and higher traffic volume
2. Eliminate summer dust and spring mud
3. Drain most of the water off the surface into ditches
4. Provide a smoother and safer ride
5. Improve vehicle and driver efficiency

2.2.1.2 Costs

Agencies should conduct Life-Cycle Cost Analysis (LCCA) on their roads since the available funds, spent on the roadways, are decreasing in recent years (Figueroa et al., 2013). Many local agencies cannot effectively make the decision of paving a gravel road because they do not have enough information about the initial and maintenance costs of the different alternatives. Applying an asphalt overlay is expensive. However, it does not require any expensive repairs as long as the pavement is not highly deteriorated. On the other hand, the initial costs of gravel roads are very low for a low-volume road. It may provide a cost-effective solution in an appropriate rural environment. However, the costs of maintaining these roads should be analyzed. Gravel can be lost from the road surface at more than 1.2 inch per year (Cook et al., 2013) so there is a need to re-gravel the road frequently. Also, there are other costs required for the regular maintenance of these roads, including grading, shaping, and dust control. These costs increase significantly when the traffic volumes are relatively higher (MaineDOT, 2013).

Therefore, the costs associated with gravel and paved roads vary significantly. There is a need to identify methods and costs of maintaining and upgrading gravel roads. However, many state and local agencies do not track these costs. They found difficulties in estimating the life cycle costs of the different maintenance practices. As noted in *When to Pave a Gravel Road?* (Kentucky Transportation Center, 1988), agencies must determine the costs of maintenance for all options before making the decision of paving the gravel road. These estimates enable the agencies not only to compare between the different surfacing types, but also to determine the appropriate time to change the surface type of the low-volume unpaved road. As shown in Figure 2.3, cost estimates for the routine maintenance of unpaved roads indicate that, at a specific time, it is more cost-effective to apply asphalt rehabilitation on the surface. The cost of the rehabilitation is significant, however, less money will be spent on the road in the future.

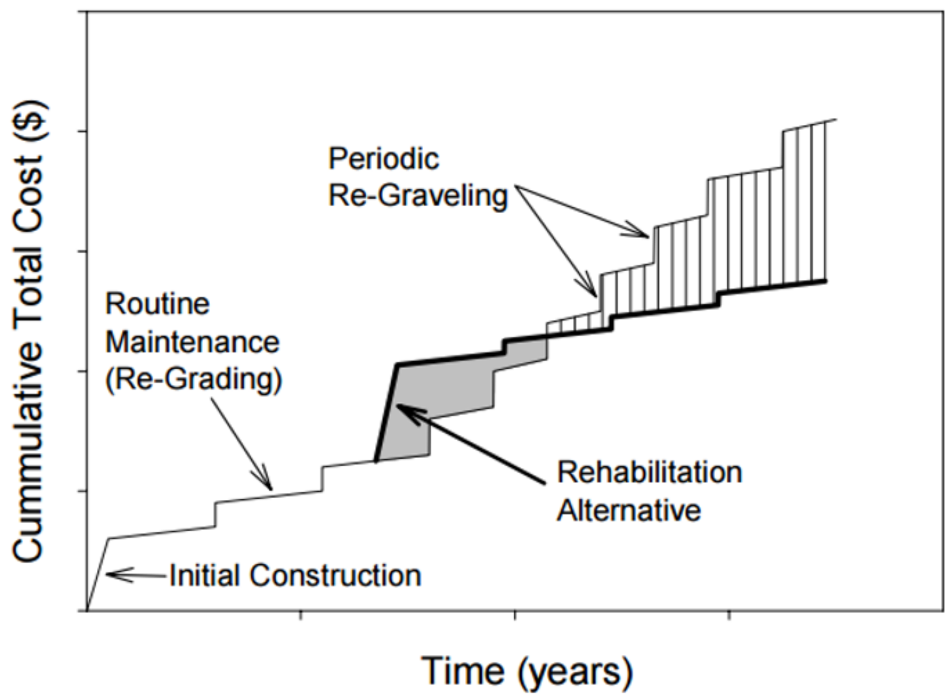


Figure 2.3: Road Cumulative Maintenance Costs of Different Surface Types (Rukashaza-Mukome et al., 2003)

In order to identify the appropriate surfacing decision, many research studies were conducted to provide numerical analyses of the costs based on the spending history on low-volume roads. South Dakota Department of Transportation (SDDOT) developed a software tool that enables local officials to make a surfacing decision using an Excel-based program. The decision can be made by comparing the costs associated with different surface types and the available funding (Zimmerman and Wolters, 2004). In this software, cost analysis models were developed for different surface types, including hot-mix asphalt (HMA), blotter, gravel, or stabilized gravel. The total cost for each surface type derives from three main components which are:

1. Initial costs
2. Annual maintenance costs

3. User costs

The models were developed using regression analysis of 95 roadway sections in South Dakota and based on a 20-year analysis period. Local agencies can calculate all the associated costs automatically, even though SDDOT provides a guideline to calculate the costs manually using a technical brief provided with the report (Zimmerman and Wolters, 2004). Table 2.3 lists the construction and maintenance costs determined for the HMA roadways. The costs are dependent on the traffic volumes because it was found that ADT is a significant predictor in the regression models. The estimated costs were based upon average costs of the roadway sections collected during the study. It should be noted that all the costs were determined in 2003. Therefore, all costs need to be adjusted by inflation when using those estimates. For unpaved roads, the costs and frequencies of applying maintenance practices differ depending on whether the road is a gravel or stabilized gravel road. Table 2.4 shows the costs for gravel roads that derive from the initial construction or major rehabilitation, blading, and regravelling. For stabilized gravel roads, application of dust control is applied which reduces the frequency of both blading and regravelling practices compared to the non-stabilized gravel road. Table 2.5 and Table 2.6 summarize the costs related to the stabilized gravel roads and blotter roads, respectively.

Table 2.3: Construction and Maintenance Costs for HMA Roadways (Zimmerman and Wolters, 2004)

ADT	Initial Const. or Major Rehab. Cost ($/mile)	Crack Seal		Seal coat		Overlay		Stripping and Marking		Patching/Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/mile)	Years between app.	Cost ($/mile)	Years between app.	Cost ($/mile)	Years between app.	Cost ($/mile)	
0-99	35,000	3	900	5	6,500	21	35,000	5	210	500
100-199	35,000	3	900	5	6,500	17	35,000	4	250	500
200-299	37,000	3	1,200	4	7,000	20	37,000	4	280	500
300-399	37,000	3	1,200	4	7,000	20	37,000	4	280	500
400-499	39,000	5	1,600	4	7,300	20	39,000	4	310	500
500-599	40,000	6	1,600	4	7,300	20	40,000	4	320	500
600-699	43,000	6	1,600	4	7,300	20	50,000	4	360	500
>700	43,000	6	1,600	4	7,300	20	50,000	4	360	500

NOTE: All costs were determined using 2003 dollars

Table 2.4: Construction and Maintenance Costs for Gravel Roadways (Zimmerman and Wolters, 2004)

ADT	Initial Const. or Major Rehab. Cost ($/mile)	Blading		Regravel		Spot Gravel/Annual Maint. Cost ($/mile)
		Times per year	Cost ($/mile)	Years between app.	Cost ($/mile)	
0-99	3,700	17	45	8	3,700	350
100-199	3,700	20	45	8	3,700	800
200-299	4,500	30	50	6	4,500	1,070
>300	7,036	50	65	6	7,036	2,420

NOTE: All costs were determined using 2003 dollars

Table 2.5: Construction and Maintenance Costs for Stabilized Gravel Roadways (Zimmerman and Wolters, 2004)

ADT	Initial Const. or Major Rehab. Cost ($/mile)	Dust Control		Blading		Regravel		Reshape Cross Section		Spot Gravel/Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/mile)	Times per year	Cost ($/mile)	Years between app.	Cost ($/mile)	Years between app.	Cost ($/mile)	
0-99	5,000	1	2,700	4	40	12	2,300	--	--	500
100-199	8,154	1	3,300	4	40	5	4,854	--	--	333
200-299	8,154	1	3,300	4	40	5	4,854	--	--	333
>300	19,716	1	2,300	6	380	10	17,416	10	3,400	3,635

NOTE: All costs were determined using 2003 dollars

Table 2.6: Construction and Maintenance Costs for Blotter Roadways (Zimmerman and Wolters, 2004)

ADT	Initial Const. or Major Rehab. Cost ($/mile)	Seal Coat		Striping and Marking		Patching/Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/mile)	Years between app.	Cost ($/mile)	
0-99	7,000	5	7,000	5	250	530
100-199	7,000	5	7,000	5	250	920
200-299	7,170	4	7,170	4	280	1,250
300-399	7,850	4	7,850	4	370	1,260
400-499	9,180	5	9,180	5	440	1,430
>500	9,540	4	9,540	3	450	3,150

NOTE: All costs were determined using 2003 dollars

User costs are calculated from the crash costs and vehicle operating costs which are estimated based on the crash data and ADT of the road sections respectively. The crash costs are calculated using the standard crash costs estimated by FHWA (FHWA, 1999). The standard costs used for each of the three crash types (fatality, injury, and property damage only) are shown in Table 2.7. In the SDDOT software, all roadway sections are identified to be rural highway segments. For the operating (running) costs, the associated costs were determined from fuel consumption, tires, engine oil, and maintenance and depreciation of the vehicles. These costs were found to be significantly affected by the longitudinal grade and operating speed on the roads (Winfrey, 1969). Based on Winfrey's methodology, the operating costs were determined by SDDOT for different vehicle types on HMA surfaced pavement. Tables were also provided in the technical brief of the software showing the costs based on the longitudinal grade and speed (Zimmerman and Wolters, 2004). Then the SDDOT developed a graph, shown in Figure 2.4, to convert the determined running costs on HMA surfaces to running cost values on gravel roads. The conversion factors are dependent on the speed limit and the type of vehicle.

Table 2.7: Standard Crash Costs (1990 dollars) (FHWA, 1999)

Intersection or Facility Type	Fatality		Nonfatal Injury		Property Damage Only (PDO)	
	Rural	Urban	Rural	Urban	Rural	Urban
RR Grade Crossing	$1,008,000	$994,000	$252,000	$133,000	$159,000	$309,000
Intersection/Interchange	$1,059,000	$932,000	$219,000	$143,000	$198,000	$135,000
Bridge	$1,111,000	$978,000	$249,000	$143,000	$214,000	$127,000
Highway Segment	$1,111,000	$978,000	$249,000	$143,000	$214,000	$127,000

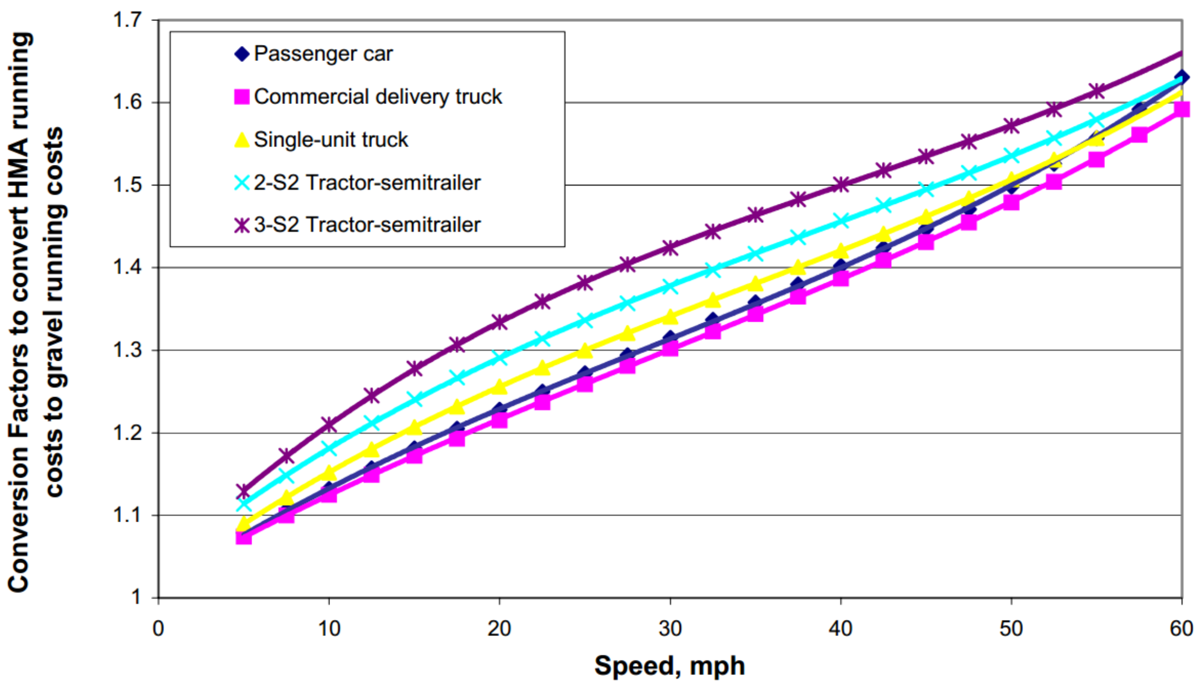


Figure 2.4: Factors for Converting Vehicle Operating Costs from HMA sections to Gravel Roads (Zimmerman and Wolters, 2004)

Based on the cost data, a comparison between the different surfaces can be conducted to make the appropriate surfacing decision. The SDDOT software allows the user to compare any combination of the four surface types: HMA, blotter, gravel, and stabilized gravel. The LCCA is conducted in the software using the default values shown before. However, the user has the ability to alter the inputs to be consistent with the agency's needs. The decision is based on the present value (PV) which can be calculated using Eq. 1. It is to be noted that most of the associated costs for the different types of road surfaces have different economic impacts. Agencies may have to alter evaluation practices for some of the costs, especially the operating cost, because they, most of the time, overwhelm the agency costs. The software allows the user to decide to exclude user costs or reduce the impact of associated costs using weighting factors. These factors are available in the technical brief for all sources of costs and for each surface type (Zimmerman and Wolters, 2004).

$$PV = A * \frac{(1+i)^N - 1}{i * (1+i)^N} \qquad \text{Eq. (1)}$$

where,

PV: is the present value

A: is the annual value

i: is a discount rate

N: is the study years

2.2.1.3 Public Opinion

After studying all the previous considerations in deciding the appropriate surface type for a low-volume road, public opinion is an important factor to be considered. Every agency has different circumstances about the public acceptance of gravel roads. In most cases, public opinion favors paved roads. However, gravel roads are more applicable in agricultural and low-income societies because of the low maintenance costs. In some cases, residents may prefer gravel roads for the local roads more than the paved roads. They believe that gravel roads reduce the speed and volume of traffic which is desirable from the perspective of local walkers, equestrians, and cyclists (Kimley-Horn and Associates, Inc., 2009). In general, poorly maintained roads generate negative public opinion. State and local agencies should consider the potential reactions from public users of low-volume roads before making the decision of selecting the type of road surface.

2.3 Low-Volume Roads Pavement Design Methods

Throughout the world, safe roads and sustainable pavement sections are the ultimate goals of designing roads. Transportation agencies apply different standards of road alignments and geometric designs in order to enhance sight and safety on roads. Another important aspect of designing roads is to select the thickness and material characteristics of pavement layers to accommodate the expected traffic loading over the pavement service-life. Most research efforts for infrastructure investments are geared toward high volume roads. When it comes to designing LVRs, it is challenging to define the appropriate pavement structure in an economic manner using inexpensive materials and techniques. Although traffic volumes on LVRs are relatively low, pavements are still subjected to environmental effects over time. When the pavement deteriorates to a poor level, it becomes hard to sufficiently maintain or rehabilitate the road because of the limited resources allocated on LVRs. Thus, it is important to document the efforts used to improve the ability to sustain LVRs in an economic manner and within the local needs.

The methodology to design LVRs pavement structure should focus on eliminating the main types of pavement distresses. Pavements in LVRs have similar structure to high volume and national highways. However, LVRs have unbound granular layers covered with a thin layer of asphaltic seal and chips, see Figure 2.5.

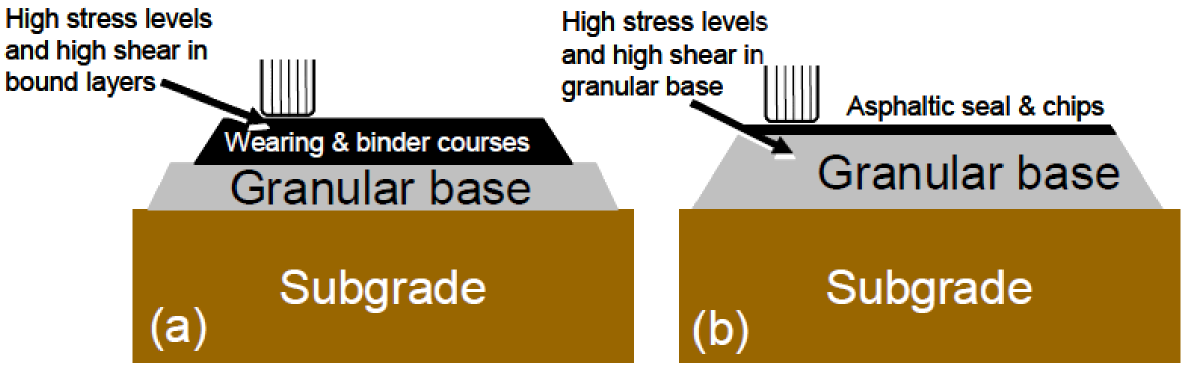


Figure 2.5: Schematic Profile of (a) High-Volume Road; (b) Low-Volume Road Pavement (Brito, 2011)

Since rutting is the main distress mode in unsealed and thin sealed pavement, LVRs should be designed to limit the vertical permanent deformation in the base and subgrade layers. Coghlan (1999), Visser and Hall (2003), and El abd *et al.* (2004) emphasized that LVRs may not be designed with the traditional highway engineering standards. The reason is that most of the design methods are based on linear elastic calculations. The unbound properties of LVRs layers make applying many traditional design methods inapplicable. As a result, research was conducted to investigate the appropriate design procedures for low-volume roads. Many states have developed or adopted other design methods for lower-volume pavements. Some of them are empirical by designing the layer thicknesses on the basis of experience. Others are semi-analytical and mechanistic-empirical procedures. In general, the objective from any pavement design guide is to select the most economic pavement structure providing a satisfactory level of service for the expected traffic. There are several input variables for a pavement design procedure. They should comprise the following (Brito, 2011):

- Design Traffic
- Subgrade and pavement materials
- Environment

- Construction and maintenance
- Road geometry
- Equipment availability
- Social concerns
- Sustainability

The existing pavement condition is also an important input when designing an overlay, or re-gravelling in case of unsurfaced roads. The following subsections compile the effort by pavement agencies to develop specific low-volume design methods.

2.3.1 AASHTO Design Procedure

The *American Association of State Highway and Transportation Officials* (AASHTO) developed design methods for flexible pavements based on the AASHO road test in the 1950's (AASHTO, 1993). The methods include design catalog and empirical methods. The design principle of this method is that the overall pavement strength should endure the total applied traffic loads, where the serviceability loss is acceptable over the pavement serviceable age. The outputs from this methodology depend mainly on the subgrade soil strength in terms of resilient modulus (M_r), reliability in terms of desired design reliability, traffic, and material properties. For traffic data, there are different vehicle configurations travelling on roads. The mixed types of traffic cause different magnitudes and repetitions of wheel loads. All of these loads can be converted into a single value called the Equivalent Single Axel Load (ESAL), commonly 18,000 lbs (e.g., 18 kips). The general equation of the design method is shown in Eq. (2).

$$\log_{10}(W_{18}) = Z_r\, s_o + 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \left[\frac{1094}{(SN+1)^{5.19}}\right]}$$

$$+2.32\log_{10}(M_r) - 8.07 \qquad \text{Eq. (2)}$$

where,

W_{18}: is the estimated traffic (ESAL)

Z_r: is standard normal deviate determined from the reliability

s_o: is the overall standard deviation of the input data

SN: is the structural number (inches)

ΔPSI: is the loss in serviceability over the life of the road

M_r: is the resilient modulus of the subgrade (lb/in^2)

Nomographs were developed to solve the previous equation graphically as shown in Figure 2.6. The output from these graphs is the structural number (SN) which is an indication of the pavement strength. SN is then represented by the compound properties of the pavement layers as shown in Eq. (3).

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3 \qquad \text{Eq. (3)}$$

where,

a_1, a_2, and a_3 are layer coefficients for the surface, base, and subbase layers, respectively, reflecting their material strengths

D_1, D_2, and D_3 are the thicknesses of the surface, base, and subbase layers, respectively.

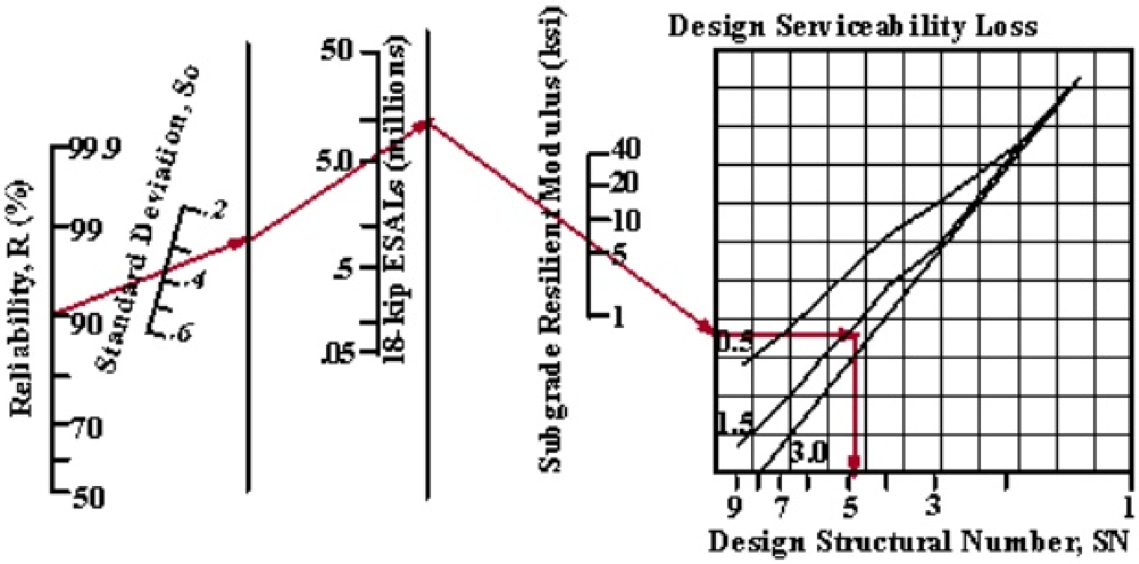


Figure 2.6: AASHTO Design Nomograph (AASHTO, 1993)

The *AASHTO Guide for Design of Pavement Structures* (AASHTO, 1993) provides specific design standards for low-volume roads. The design guide states that a low-volume road should have ESAL values ranging from 50,000 up to 1,000,000. The design charts for flexible pavement in low-volume roads are similar to those for highway pavement design. However, the inputs are simplified to allow state and local agencies the option of using some default and standard inputs. Hall and Bettis (2000) indicated that AASHTO design procedure is relatively complex and includes many input variables. Most of the inputs need to be determined in a way that is beyond the local agency's needs and capabilities. Although the design procedure for LVRs is a simplified version of the high volume roads, the resilient modulus (M_r) of the subgrade, traffic ESAL, and the structural layer coefficients (a_i) still need to be determined. Therefore, the AASHTO design method may be an inapplicable procedure for LVRs given the limited resources available to local agency engineers.

2.3.2 *United States Army Corps of Engineers (USACE) Procedure*

The USACE's airport pavement design method has been also simplified into a version that is suitable for low-volume roads and local streets (USACE, 1992). Two major inputs are considered in the design method. The first input is the soil strength in terms of CBR (e.g., California Bearing Ratio) value. This value can be determined by applying a penetration test in the lab on a soil sample of the subgrade. The second input is the traffic load in terms of 18-kips ESALs. The design method is classified by the design index which is obtained by the traffic category, as shown in Table 2.8 . Then the pavement thickness of each layer is determined using design charts depicted in Figure 2.7. The design method also gives recommendations about the minimum thicknesses of pavement layers and provides equivalency factors for stabilized soil layers. These factors enable designers to reduce the base or subbase thicknesses depending on the material properties of each layer.

Table 2.8: Pavement Design Index Versus Traffic load (USACE, 1992)

Traffic Category	Pavement Design Index for Road or Street Classification					
	A	B	C	D	E	F
I	2	2	2	1	1	1
II	3	2	2	2	2	1
III	4	4	4	3	3	2
IV	5	5	5	4	4	3
IVA	6	6	6	5	5	4
V (60-kilopound (kip) track-laying vehicles or 15 kip forklifts)	7	7	7	7	7	(*)
500/day	6	6	6	6	6	(*)
200/day	6	6	6	6	6	(*)
100/day	6	6	6	6	6	6
40/day	6	6	6	5	5	5
10/day	5	5	5	5	5	5
4/day	5	5	5	5	4	4
1/day	5	5	5	4	4	4
VI (90-kip track-laying vehicles or 25 kip forklifts)						
200/day	9	9	9	9	9	(*)
100/day	8	8	8	8	8	8
40/day	7	7	7	7	7	7
10/day	6	6	6	6	6	6
4/day	6	6	6	6	6	6
1/day	5	5	5	5	5	5
1/week	5	5	5	4	4	4
VII (120-kip track laying vehicles):						
100/day	10	10	10	10	10	10
40/day	9	9	9	9	9	9
10/day	8	8	8	8	8	8
4/day	7	7	7	7	7	7
1/day	6	6	6	6	6	6
1/week	5	5	5	5	5	5

* Traffic limited to 100 vehicles per day.

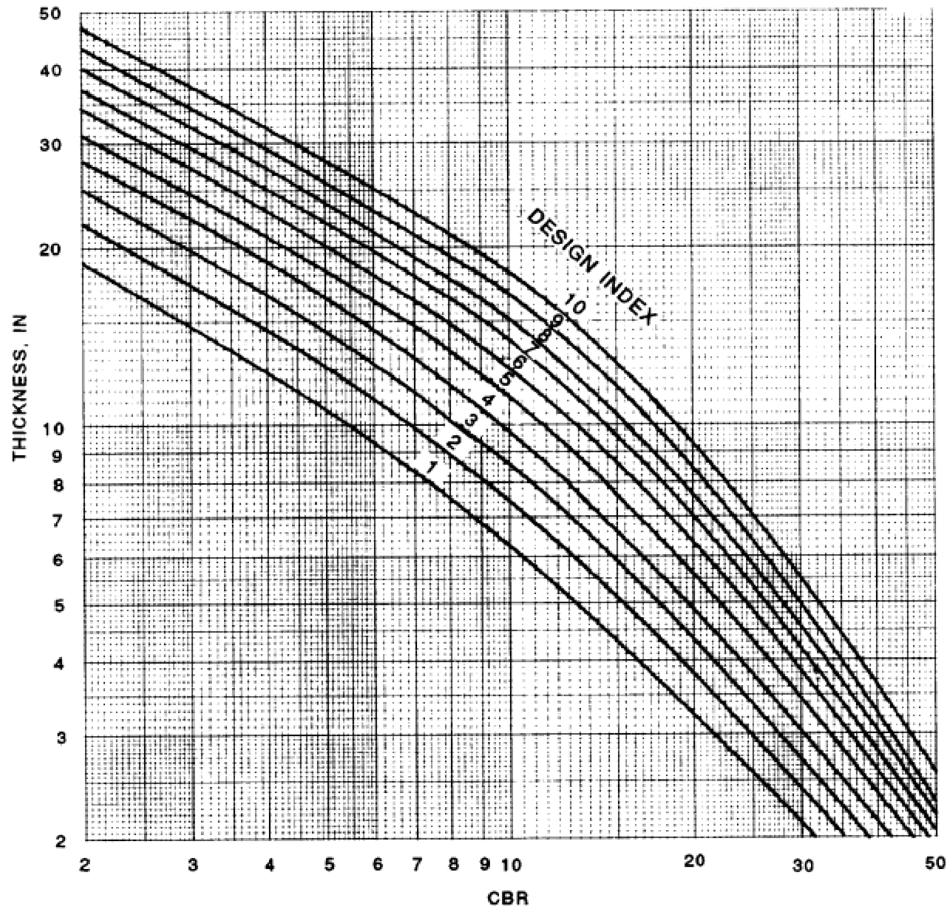


Figure 2.7: Flexible Pavement Design Curve for Roads and Streets (USACE, 1992)

The USACE's design method is simple to use. However, it has limitations in some respects. With only two input factors, many environmental effects and uncertainties are not adequately covered. The thickness of overlays are also determined using complex equations.

2.3.3 National Crushed Stone Association (NCSA) Procedure

The National Crushed Stone Association (NCSA) modified parts of the USACE method to consider some environmental and drainage issues. The soil strength is represented by CBR, but it is classified into four categories: excellent, good, fair, and poor. The design index is determined based on the traffic conditions. However, design tables provide values for the total thickness of crushed stone or bituminous surface. Then, the design procedure allows engineers to adjust the design thickness if severe conditions are applicable, such as frost damage or drainage issues (Abdel Warith et al., 2015).

2.3.4 Asphalt Institute Procedure

This method was developed using a mechanistic-empirical approach. The analysis of pavement layers is conducted using two main inputs: 1) the design subgrade resilient modulus; 2) traffic in terms of 18-kips ESALs. The method was simplified to the local needs so that the number of 18-kips ESALs can be determined. Also, there are simplified methods to calculate the resilient modulus of the subgrade. This design procedure is relatively simple to use. However, it is limited by specific application of stabilized layers or subbase layers (Asphalt Institute, 1991).

2.3.5 States Design Procedure

Many states have developed specific low-volume pavement design procedures. These procedures are considered as 'non-AASHTO' design protocols and they have various complexity levels. Some of these methods incorporate the soil and environmental effects for the states' regions. Relatively recently, California, Illinois, Kentucky, Mississippi, New York, Pennsylvania, Texas, Vermont, Virginia, and Minnesota have developed their own design procedures. In this section, a brief description is introduced about each method developed at the previously mentioned states. Then, a comparison among all methods is presented to show the common data inputs required for designing LVRs.

2.3.5.1 California Procedure

The California design procedure was developed based on studies and tests from various agencies. Three major parameters are required in this procedure which are (Caltrans, 2017):

- Traffic – The traffic data is represented by a traffic index (TI) based on 18-kips ESALs. TI can be determined through a standard method. Traffic counts are first obtained and then they are converted into the equivalent loads using truck constants. Another simplified method is obtaining TI directly from ADT, percentage of trucks, and a design-life period of 10 years.

- Soil Resistance Value (R-Value) – This value can be determined using a stabilometer test (Chua and Tenison, 2003). The R-value of the subgrade refers to the ability of a material to resist lateral deformation when acted upon by a vertical load. The R-value ranges from 0 (water) to 100 (steel). Typically, the R-value of subgrade ranges from less than 5 up to 85. When testing subgrade, the soil specimen is compacted to conditions that approximate those in the field. Then, it is tested at full moisture saturation as to represent the worst case the soil can be in at any given time. If the local agency cannot perform a stabilometer test on the soil, the R-value may be estimated by using some simple soil classification tests in conjunction with the sand equivalent (SE) test (Caltrans, 2017).

- Gravel Equivalent Factor (G_f) – This is an empirical factor developed through research and field experience. G_f represents the strength of the pavement structure, and it relates the relative strength of a unit thickness of the pavement materials in terms of an equivalent thickness of gravel. The G_f is easily taken from a chart included in the design procedure.

The California design method is relatively simple. A design chart is used to determine the required thickness of each layer of the pavement structure after obtaining the three inputs.

2.3.5.2 Minnesota Procedure

Two pavement design methods are available to local agencies when designing LVRs in Minnesota (MNDOT, 2017). The first method depends on obtaining the R-value of the subgrade. The second method is based on gravel equivalency (GE) found in Minnesota's State Aid Manual. This method is more preferable to the local agencies since it depends on a less conservative procedure. The designer simply uses a design table to obtain a soil factor and an estimated R-value based on the soil classification of the subgrade. This information is then combined with the ADT of the road to obtain a Minimum Bituminous GE and Total GE for the design. These values represent the bituminous and base layer thicknesses in inches. In the R-value procedure, two additional inputs are considered. The traffic load is determined in terms of Sigma N-18 value (e.g., the standard 18-kip ESAL). The second input is the actual R-value of the soil determined from the stabilometer test. The design outputs are very sensitive to the R value.

2.3.5.3 Mississippi Procedure

The updated Mississippi design procedure combines several inputs. The thickness of each layer is determined using a design chart requiring the following inputs:

- Soil Strength – The Soil Support Value (SSV) represents the soil strength with a scale ranging from 1 to 10 (George, 2004). The natural soil at the road commonly has an SSV of 3. Although the AASHTO design guide replaced the SSV with the resilient modules, local agencies still use SSV because it is relatively simple to estimate. Through research performed on soils in Mississippi, Eq. (4) was developed to determine SSV. A correlation was found between the SSV and the CBR of the soil.

$$SSV = 30289\ log_{10}(CBR) + 1.421 \qquad \text{Eq. (4)}$$

- Design Life – The design life, in years, is not the same. It is estimated depending on the amount of Design Heavy Vehicles (DHVs).

- Traffic Loads – Two parameters are determined for traffic loads: the percent 18-kip load and the average 18-kip daily load (ADL).

Also, the ADT for the road is used in the design chart to obtain the design index (DI). DI is used to determine the design thickness of subbase and the combined base and surface thickness. Although this design procedure has empirical equations and charts, it gives similar design values as AASHTO's (Abdel Warith et al., 2015).

2.3.5.4 New York Procedure

This procedure is based on the AASHTO design equation for flexible pavements (NYSDOT, 1994). However, it takes into account the frost susceptibility in the determination of the layer coefficients (a_i) and the Drainage coefficients (m_i). This is because various frost susceptible soils are encountered in the upper Northeast of the United States. The frost susceptible soils affects the design charts when determining the subgrade modulus.

2.3.5.5 Virginia Procedure

The Virginia design procedure for low-volume roads differs from the other procedures. This method appears to be applicable for many states and local agencies since it has simple inputs. First, the design traffic amounts are determined based on the present ADT and an estimated Growth Factor (GF). These factors can be found from historical traffic data or empirically estimated by a traffic engineer. Second, the soil strength is represented by SSV. It is calculated by the Design CBR and a Resiliency Factor (RF) (VDOT, 2000). The RF represents the soil's elastic deformation characteristics and its ability to withstand repeated loading. Typical values are extracted for RF from design tables based on soil classification. The required thicknesses can be determined by the design index (D_R) (obtained from a design nomograph using SSV and design ADT).

From all the previously discussed procedures, it was found that traffic data and soil strength of the subgrade are the most common inputs when designing low-volume roads. Each state has its own methodology to represent these inputs with different sophistication levels. However, all states tried to customize their procedure to the available local needs and resources. In summary, Table 2.9 lists the different input parameters required for each design procedure. Abdel Warith *et al.* (2015) also displayed the complexity of each design procedure. Table 2.10 shows the level of complexity and the availability of the design inputs. Most of the local agencies are obviously struggle to obtain the input data for designing the pavement of LVRs. According to Abdel Warith *et al.* (2015), only the USACE and the NCSA design procedures are simple enough for many local agencies.

Table 2.9: Inputs Summary of Traffic and Soil Strength Criteria by Design Procedure for Low-Volume Roads

Procedure	(a) Traffic Input Criteria				
	ESAL	ADT	Index	Design Period	GF
AASHTO	•	•			
USACE	•				
NCSA	•		•		
Asphalt Institution	•				
California	•		•		
Minnesota (GE)		•			
Minnesota (R-Value)	•				
Mississippi	•			•	
New York	•				
Pennsylvania	•				
Vermont	•				
Virginia		•			•

Procedure	(b) Subgrade Strength Criteria					
	MR	CBR	Soil Type	R-value	Frost	Drainage
AASHTO	•					
USACE		•				
NCSA		•	•		•	•
Asphalt Institution	•					
California				•		
Minnesota (GE)			•			
Minnesota (R-Value)				•	•	
Mississippi		•				
New York	•				•	•
Pennsylvania		•			•	
Vermont	•				•	
Virginia		•				

NOTE: GF = growth factor; blank cells = no input required

Table 2.10: Complexity of Low-Volume Road Design Procedures (Abdel Warith et al., 2015)

Procedure	Availability of Design Inputs		
	Traffic	Subgrade Strength	Complexity of Procedure
AASHTO	Not readily available	Not readily available	Complex
USACE	Available	Available	Simple
NCSA	Available	Available	Simple
AI	Not readily available	Not readily available	Simple
California	Available	Not readily available	Moderate
Minnesota (GE)	Not readily available	Not readily available	Simple
Minnesota (R-Value)	Not readily available	Not readily available	Moderate
Mississippi	Not readily available	Available	Simple
New York	Not readily available	Not readily available	Complex
Pennsylvania	Not readily available	Available	Moderate
Vermont	Not readily available	Not readily available	Complex
Virginia	Not readily available	Available	Moderate

2.4 Pavement Maintenance and Preservation on Low-Volume Roads

2.4.1 Introduction

All pavements deteriorate over time due to traffic loads and environmental effects (Bandara and Gunaratne, 2001). The pavement performance and the quality of road surfaces have different behaviors depending on the pavement materials, soil characteristics, traffic loads, and environmental conditions. However, as displayed in Figure 2.8, the conceptual performance curves of pavements always have the same trend: older pavement sections deteriorate faster and they cost more money to fix.

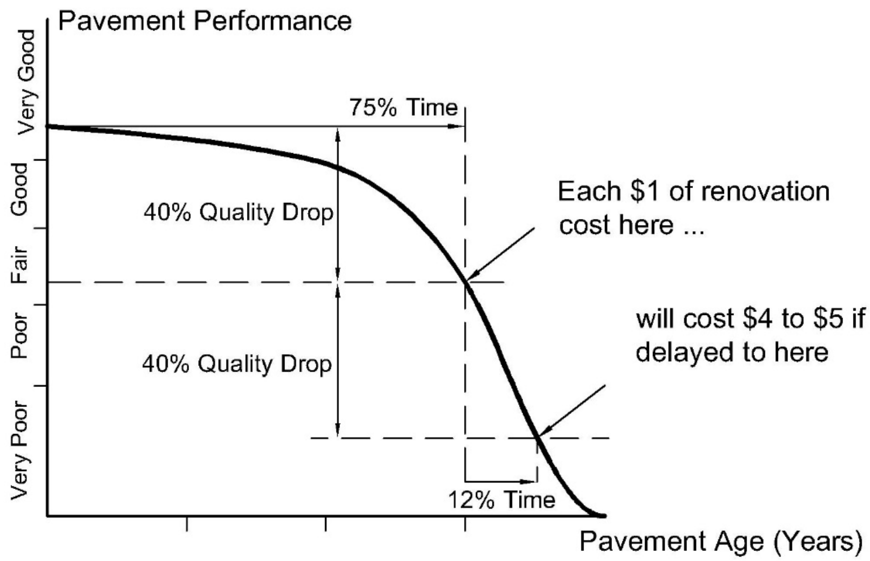


Figure 2.8: Relationship between Pavement Performance and Repair Costs (Shahin and Walter, 1990)

There are multiple treatment options applied on paved roads. They have different effects on the roads depending on present pavement conditions and the targeted serviceability. All pavement treatments can be categorized into four main types:

1. Routine or Preventive Maintenance
2. Light to Moderate or Minor Rehabilitation
3. Heavy or Major Rehabilitation
4. Reconstruction

Figure 2.9 shows an example of identifying the type of treatment recommended for a road based on the Pavement Condition Index (PCI) of the segment. It is not prudent to include only the roads requiring reconstruction in the maintenance strategy of the road network. This is not only an expensive strategy, but good and fair pavements will also continue to deteriorate to very poor levels. Therefore, the process of only repairing the worst roadways when they fall into very poor condition is not a cost-effective strategy.

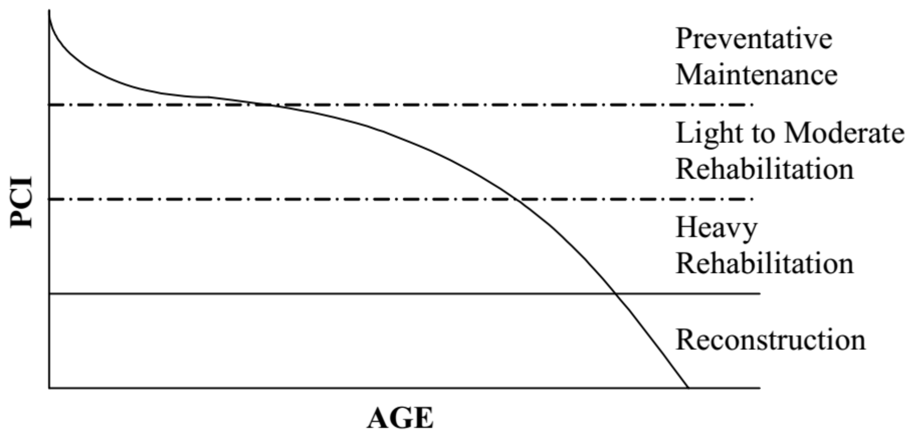


Figure 2.9: Performance Models vs. Trigger Values for Treatments (Smith, 2002)

2.4.2 Pavement Preservation

The concept of pavement preservation has become an important treatment strategy especially with the limited resources available for agencies. Pavement preservation has the ability to keep the overall condition of pavement in higher levels by applying early, frequent routine maintenance and minor rehabilitation.

Figure 2.10 shows how the pavement preservation process maintains roads in good condition over the pavement age compared to the major rehabilitation and reconstruction practices. It should be noted that most pavement preservation programs do not enhance the structural capacity of pavements. Pavement preservation only extends the remaining service life of good pavements by applying surface treatments which can be labeled as 'preventive' or 'corrective' maintenance (Peshkin and Hoerner, 2005). The advantage of applying surface low-cost treatments is that most agencies can afford these treatments in the maintenance strategies compared to the 'worst first' approach. As a result, maintenance budgets can cover more miles of road and the overall weighted condition of the network can be enhanced. Therefore, pavement preservation appears more applicable to the agencies.

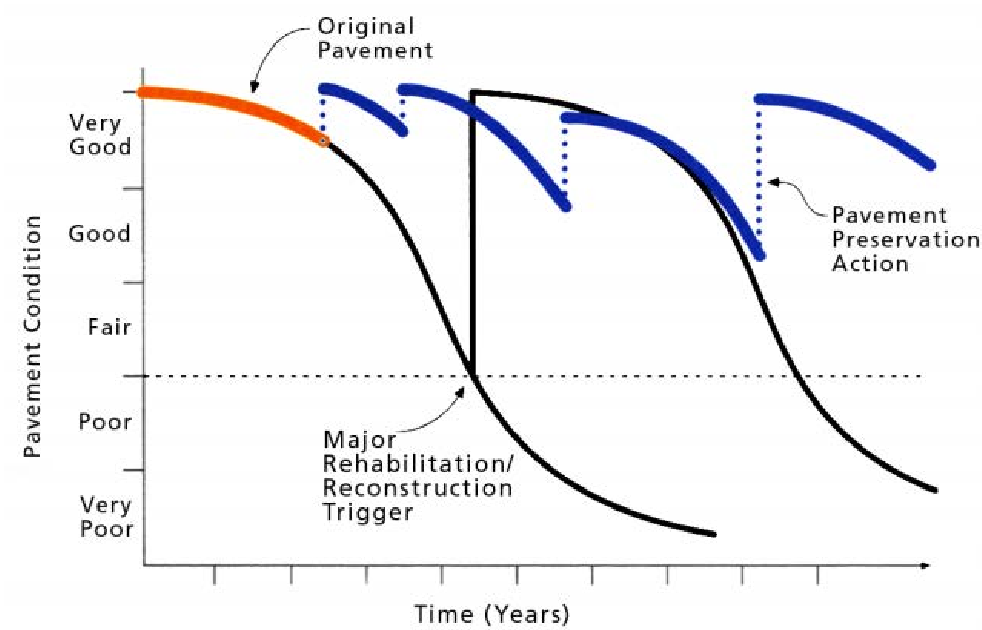


Figure 2.10: Pavement Preservation Concept (NPS, 2014)

2.4.3 Types of Preventive Maintenance

Several types of preventive maintenance are used in the pavement preservation strategy. This section focuses on treatments commonly applied on low-volume paved roads. Some of these treatments are known as thin surface treatments (TSTs) or light surface treatments (LSTs) (Jahren et al., 2016). Other treatment options are basically applications of pavement replacement using recycled materials. The most common preventive maintenance treatments for flexible pavements are explained below.

2.4.3.1 Crack Sealing and Crack Filling

The main objective of sealing and filling surface cracks is to prevent water and incompressible materials from entering into the pavement layer. Figure 2.11 shows an example of sealed cracks on a flexible pavement surface. Low-severity cracks can be sealed from the top with an emulsified asphalt. When cracks are wide, they have to be filled using an appropriate filling material such as sand or specific asphalt filler. There are different practices for crack preparation and selecting the type of sealant materials. Crack seal and fill are commonly applied on longitudinal, transverse, block, and edge cracking. Neither crack sealing or filling can treat fatigue cracking because this type of distress affects the full depth of the asphalt layer. It is commonly recommended to implement a full-depth reclamation of the distressed pavement in the case of fatigue cracking (Caltrans, 2003).

Figure 2.11: Crack Sealing of Flexible Pavement (Wilde et al., 2014)

There are various criteria that need to be fulfilled when sealing and filling cracks such as:

- Sealant must remain adhered to the wall of the crack.

- Sealant should have the ability to expand and contract over a range of service temperatures without rupture.
- Sealant should resist abrasion and damage caused by traffic.

2.4.3.2 Chip Seal

Chip seal is one of the most common types of surface treatments and preventive maintenance among agencies. As shown in Figure 2.12, a chip seal is constructed by applying a layer of asphalt binder on the surface. Then a layer of single-sized aggregate is distributed with only limited compaction efforts. Chip seal looks like a gravel road at the beginning. When vehicles move on the chip seal, they compact the aggregate and make it tight with the binder. The main objective of chip sealing is to improve the surface friction. It is also used for waterproofing and sealing small cracks. One major problem in chip seal is when the aggregates are not adequately embedded in the asphalt, they fly up from tires. This leads to more windshield damage of moving vehicles. Therefore, chip seal is not recommended on high-speed roads because of the potential for windshield damage.

Figure 2.12: Applying a Chip Seal Layer on a Paved Road (Hafez, 2015)

There are many types of chip sealing used by agencies. Two main types are commonly used on low-volume roads, described below:

- Single Chip Seal – This seal is used as a pavement preservation treatment. It provides a new skid resistant wearing surface. Figure 2.13 shows a single chip seal application.

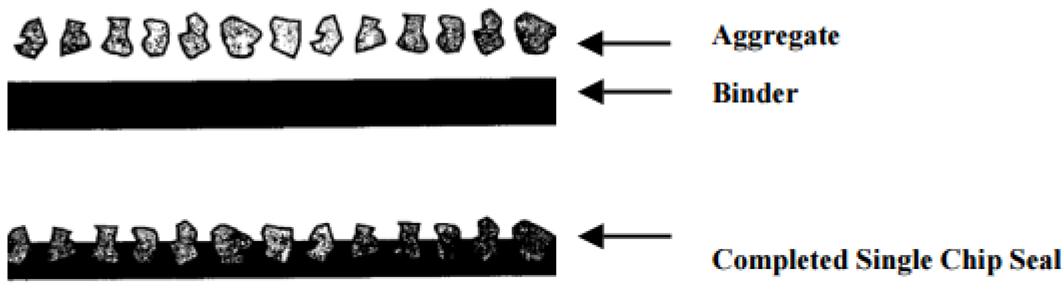


Figure 2.13: Single Chip Seal (Caltrans, 2003)

- Double Chip Seal – This treatment consists of two or multiple applications of chip seals. Some agencies use this application when a harder wearing and longer lasting surface treatment is needed.

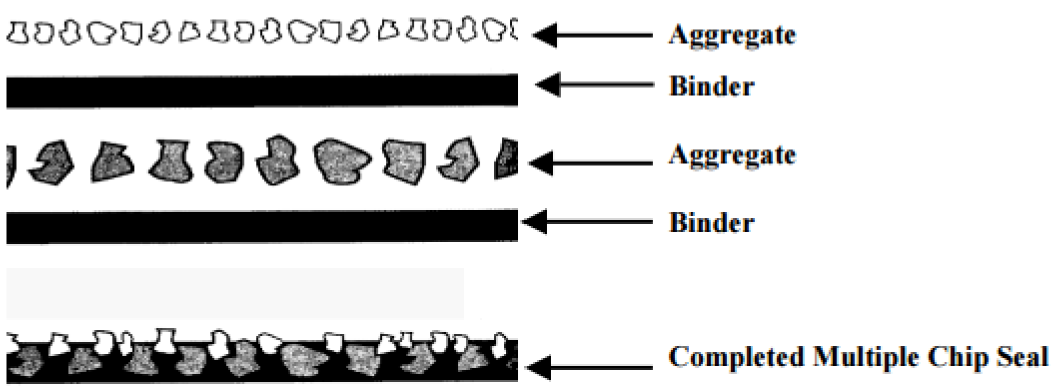
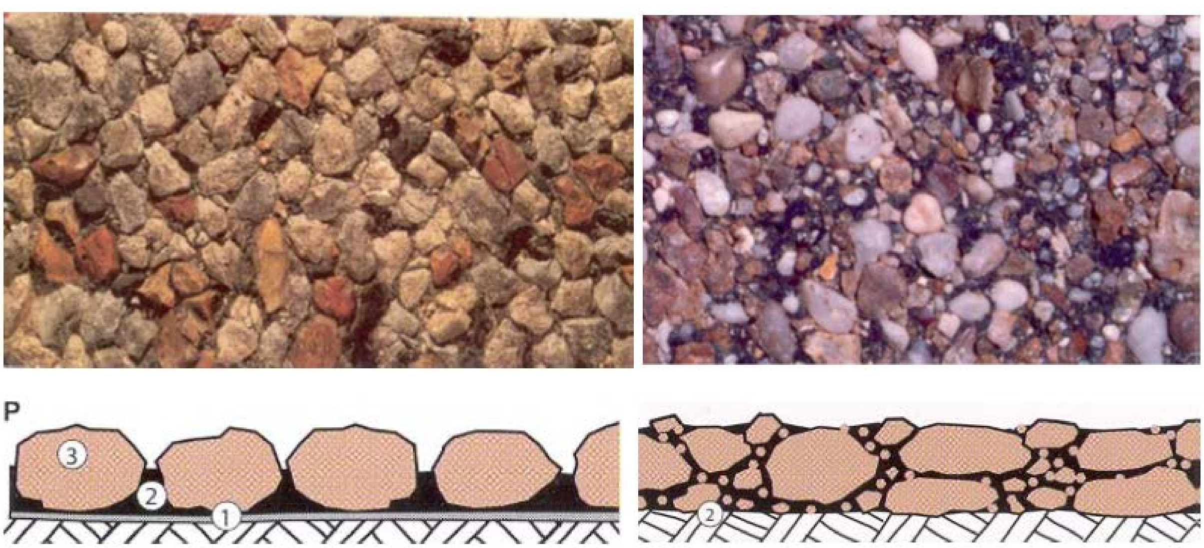


Figure 2.14: Double Chip Seal (Caltrans, 2003)

2.4.3.3 Otta Seal

Otta seal was originally developed by the Norwegian Road Research Laboratory (NRRL) in the early 1960s. It derives its name from the location in Norway where it was developed - the Otta Valley (Overby and Pinard, 2007). This is an asphalt surface treatment which is very similar to chip seal. Both Otta and chip seals are used to increase surface friction by adding an aggregate layer laid on soft asphalt. The main difference between chip seals and Otta seals is that Otta seals have graded aggregates while chip seals have single-size aggregates. This difference is shown in Figure 2.15 for single chip and Otta seals. Otta seals can be applied as single or double layers. The gradation of the aggregates ranges from open to dense gradation depending on the traffic amounts, with higher traffic volumes requiring denser materials.



(a) (b)

Figure 2.15: The Difference of Aggregate Gradations between (a) a Single Chip Seal, and (b) a Single Otta Seal (Overby and Pinard, 2007)

2.4.3.4 Slurry Seal

Slurry seal is an application to seal pavement surfaces by filling cracks and voids. These kinds of applications use a cold asphalt mixture which involves water, asphalt emulsion, and small crushed stone aggregates. Polymer is usually added to the emulsified asphalt to provide better mixture properties. As shown in Figure 2.16, no rolling is required for compacting the seal. The slurry seal layer is smoothed using a piece of burlap dragged behind the slurry truck. Hours later, the road can be opened to the traffic. Slurry seal and fog seals are similar applications with similar objectives, except fog seals do not include aggregates in the mixtures.

Figure 2.16: Applying and smoothing a Slurry Seal layer on the Surface (LA County, 2017a)

2.4.3.5 Microsurfacing

Like a chip seal, micro surfacing treatments are used to increase the skid resistance of the surface. Since micro surfacing mixtures hold small size aggregates, they can also be used for filling cracks and rutting. Rideability can be improved using this type of low cost treatment. Cold-mix mixtures are used with polymer additives and asphalt emulsion. Unlike slurry seals, no water is added to the asphalt mix which make the mixtures harden, ‘break’, without relying on the sun for water evaporation. Thus microsurfacing is recommended when the weather conditions do not allow slurry seals to be successfully placed. Figure 2.17 shows the final surface of microsurfacing treatment.

Figure 2.17: Application of Microsurfacing

2.4.3.6 Cold In-Place Recycling (CIR)

Cold in-place recycling (CIR) is considered an asphalt pavement rehabilitation. The application starts with milling the existing asphalt pavement to a depth between 2 to 4 inches. Then the cold milled materials are recycled by mixing with emulsified recycling agent. After that, the recycled mixture is spread and compacted on the surface. CIR is a cost-effective treatment option applied to build a structural value to the pavement. The benefits from applying CIR treatments are:

- Eliminating existing wheel ruts
- Crown and cross slope restore
- Eliminating potholes
- Eliminating transverse, reflective, and longitudinal cracks
- Suitable treatment for secondary low-volume roads that are located at a considerable distance from a central plant

Compared to the conventional mill-and-fill methods, CIR allows 100% of the recycled materials to be reused onsite. It can reduce the costs significantly compared to new HMA layers. Figure 2.18 shows a cold in-place recycling train consists of a milling machine; cold reclamation machine, which is capable of pulverization, sizing, and blending; and emulsion storage. Graders and compactors following the Cold in-place train restore the road profile and compact the CIR layer to achieve the desired density and strength.

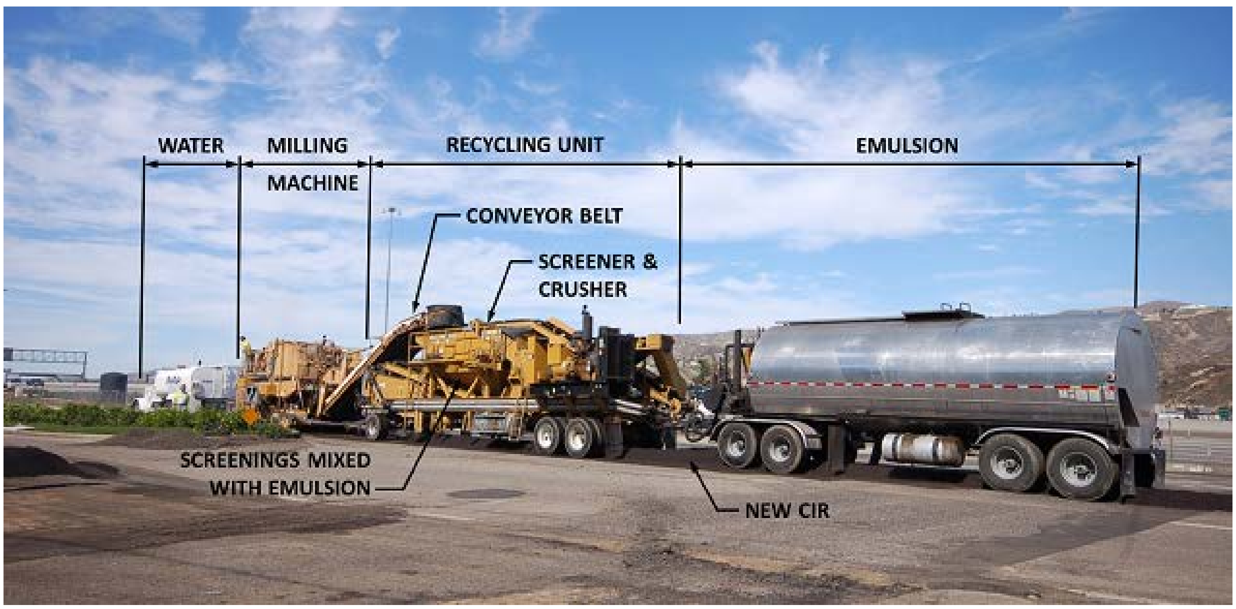


Figure 2.18: Cold In-Place Recycling Train (LA County, 2017b)

2.4.3.7 Full-Depth Reclamation (FDR)

FDR is a cold recycling treatment similar to CIR. However, FDR recycles the entire pavement thickness. FDR is also known as full-depth cold recycling, whereas CIR is partial-depth cold recycling. FDR is more effective in eliminating deep cracking patterns than CIR. It also reduces the chances of having reflective cracking. The application of FDR can be conducted using the same equipment as the CIR. However, it requires more compactive efforts because the overlaying recycled layer is thicker. FDR provides another cost-effective solution for pavement rehabilitation compared to the conventional new HMA layers. This technology is relatively new and the long term field performance has not been well evaluated (Jahren et al., 2016).

2.4.3.8 Thin and Ultra-Thin Overlay

Thin and ultra-thin overlays are used as a preventive maintenance to retard future deteriorations. Compared to chip seal and micro surfacing, thin overlays can add structural value and improve ride quality. Furthermore, thin overlays seal cracks, enhance skid resistance, and improve drainage by repairing slopes. It is considered one of the most cost-effective maintenance to enhance the long-term performance compared to the surface treatments. The increase in structural capacity varies depending on the thickness of the overlay and condition of the existing pavement. To achieve all of the mentioned benefits, the pavement should have about 75 percent of its service life remaining at the time of the overlay (Attoh-Okine and Park, 2007). Also some pre-treatments (sealing or milling) are highly recommended before applying overlays. Generally, thin overlays are applied with a thickness of 1.5 inches. They can also be placed very thin, close to about 0.5-in thick. Figure 2.19 shows an example of thin bonded wearing course application.

Figure 2.19: Thin Bonded Wearing Course Application (Wilde et al., 2014)

One type of thin overlay is Ultra-Thin Bonded HMA Wearing Course (UTBWC). UTBWC consists of a layer of HMA laid over a heavy asphalt emulsion layer. The thickness of UTBWC commonly ranges from 0.375 to 0.75 inches. This treatment can enhance the aggregate retention from polishing and raveling. However, it is not recommended to apply ultra-thin overlays on a pavement with longitudinal cracking that exceeds the medium severity level (Attoh-Okine and Park, 2007). Also, all the surface cracking should be cleaned, routed, and sealed before applying ultra-thin overlays.

All of the mentioned treatments have the ability to extend the serviceable life of pavements as long as the road is in relatively good condition. Life extension of roads using preventive maintenance has been investigated extensively. The effectiveness of the surface treatments when they are applied to a poor pavement has not been well investigated. Table 2.11 summarizes the expected life of the different types of preventive maintenance from previous studies. It is to be noted that chip seal treatments are widely used and they have been investigated extensively. Most of the studies have mentioned that chip seals can extend the serviceable life of good pavements from 3 up to 8 years. The reader should be aware that the results from the mentioned studies were developed from different projects where LVRs were applied with treatments that are used for preventive maintenance. Yu *et al.* (2015) mentioned that the surface preventive treatments can be applied on deteriorated roads as holding strategies to keep the road in serviceable conditions until funding is available for rehabilitation or reconstruction. When considering holding strategies, the expected service life of the different options can be estimated as the lower end of the life range mentioned by the different studies. Table 2.12 lists the typical costs associated with most common surface treatments and preventive maintenance. These costs were estimated by averaging the costs from different projects. These costs are subject to adjustment for inflation, but provide a good reference to be considered in LCCA techniques.

Table 2.11: Expected Life Extension in Years of Various Treatments

Treatment	**Geoffroy (1996)** (Geoffroy 1996)	**Hicks et al. (2000)** (Hicks, Seeds and Peshkin 2000)	**Maher et al. (2005)** (Maher, et al. 2005)	**Huang (2009)** (Huang and Dong 2009)	**Wu et al. (2010)** (Wu, et al. 2010)	**Michigan DOT (2011)** (Galehouse 2003)
Crack Sealing		2 to 5		Up to 3	0 to 4	Up to 3
Thin Asphalt Overlay		2 to 12		9 to 12	3 to 23	5 to 10
Chip Seal	4 to 7	3 to 7	3 to 5	3 to 5	3 to 8	3 to 6
Double Chip Seal			4 to 8			4 to 7
Microsurfacing	4 to 7	3 to 9	5 to 8	7 to 9	3 to 8	3 to 5
Slurry Seal	1 to 6	3 to 7	3 to 8	3 to 8	4 to 7	
Fog Seal		2 to 4	1 to 3		4 to 5	
Otta Seal			4 to 8	4 to 8		
Double Otta Seal			8 to 15			
Cold In-place Recycling			6 to 20		4 to 17	
Hot In-place Recycling			6 to 15		3 to 8	
Full Depth Reclamation			7 to 20		10 to 20	

Table 2.12: Cost per Square Meter of Various Treatments

Treatment	**Hicks et al. (2000)** (Hicks, Seeds and Peshkin 2000)	**Maher et al. (2005)** (Maher, et al. 2005)	**Huang (2009)** (Huang and Dong 2009)
Crack Sealing			$1 to $5
Thin Asphalt Overlay	$2.09	$1 to $1.5	$2.1 to $2.4
Chip Seal	$0.85	$1.5 to $3	$0.84 to $1.14
Microsurfacing	$1.25	$3.1 to $3.9	
Slurry Seal	$1.08	$0.9 to $1.8	$0.9 to $1.8
Fog Seal	$0.54	$0.25 to $0.6	
Otta Seal		$2 to $2.7	$2 to $2.7
Cold In-place Recycling		$4.2 to $4.8	
Hot In-place Recycling		$1.5 to $3.9	
Full Depth Reclamation		$5 to $8	

2.4.4 Pavement Structural Rehabilitation and Reconstruction

Unlike preventive maintenance, pavement rehabilitation is applied when the pavement deteriorates to very poor conditions due to the lack of regular maintenance. Rehabilitation adds new life to older asphalt by applying an asphalt overlay to the existing pavement or reconstructing the road pavement layers. Overlays are an effective treatment that cover all surface defects. However, cracking and rutting can be reflected to the new layer if suitable preparations have not been taken. The thicknesses of overlays can be classified into three categories:

- Thin overlays – have thicknesses less than 1.5 inches
- Medium overlays – have thicknesses ranging from 1.5 inches to 4 inches
- Thick overlays – have thicknesses greater than 4 inches

Overlays are applied on LVRs without exceeding a 3-inch layer thickness. They can be directly placed on the old surface when all the following are confirmed:

- Additional structure is needed
- No major issues on the pavement surface
- No vertical limitations

However, when the pavement surface exhibits high distresses and severe cracks, pre-overlay treatments should be considered. It is highly recommended to repair the top layer of pavement by sealing the minor cracks, filling the rutting, or milling the whole surface depending on the status of the surface. The decision of applying a full-pavement reconstruction is usually taken when major problems are occurred in the bottom layers of base, subbase, and subgrade. Pavement reconstruction is considered the most expensive decision that can be made to maintain a road.

2.4.5 States Maintenance Strategies for Low-Volume Paved Roads

When it comes to managing low-volume and local roads, a high percentage of roads require application of rehabilitation or reconstruction because they are in poor condition. However, several state and local agencies do not have sufficient financial resources to enhance all the deteriorated roads. As a consequence, each agency developed specific policies for maintaining LVRs in order to reach specific pavement performance targets. The strategy of low-cost surface treatments is extensively employed among local agencies and state DOTs on LVRs even if the pavement performance is poor.

2.4.5.1 Georgia DOT

Many state DOTs recommend constructing and preserving the pavement of low-volume roads using low-cost thin overlays due to the limited funding (Brown and Heitzman, 2013). Research studies were conducted in an effort to reduce the cost of mixtures and overlays without affecting the expected performance. Georgia DOT (GDOT) proposes applications of thinner overlays on low-volume roads compared to those applied on high volume roads. In order to properly place and compact the thin overlays, GDOT reduces the nominal maximum aggregate size (NMAS) to 4.75 mm. Table 2.13 shows the GDOT guidance for low-volume roads. It was found that using 4.75 mm asphalt mixtures allows the layer thickness to be reduced. Using thinner asphalt layers reduces the costs and makes these type of asphalt mixture more competitive among agencies. GDOT also provides recommendations about layer thicknesses of each mix type for thin overlays, as shown in Table 2.14.

Table 2.13: Georgia DOT Surface Treatment Materials on Low-Volume Roads (GDOT, 2006)

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

NOTE: ADTT = Average daily Truck Traffic (vehicles per day)

Table 2.14: Georgia DOT Recommended Maximum and Minimum Layer Thickness (GDOT, 2006)

Mix Type	Minimum Layer Thickness	Recommended Layer Thickness	Maximum Layer Thickness
4.75 mm	¾ in – 85 lbs/sq yd	7/8 in – 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

2.4.5.2 Nevada DOT

In the State of Nevada, alternative maintenance strategies were developed to balance between pavement preservation and capacity improvement strategies on low-volume paved roads. A combination of surface and rehabilitation treatments were investigated in 2007. The research results lead to the following conclusions (Maurer et al., 2007):

- The application of CIR treatment with double chip seal saves $100,000 per center-line mile compared to 2-inch HMA overlays
- A CIR with chip seal surface treatment can effectively rehabilitate a LVR at almost half the cost of placing a 2-in. plant mix bituminous surface (PBS) overlay and surface treatment.
- FDR is an effective treatment on LVRs where milled materials are cold-recycled. This treatment can increase the structural capacity of the road.

As a result, the Nevada DOT developed the treatment policies on LVRs when the roads need structural enhancement as shown in Figure 2.20.

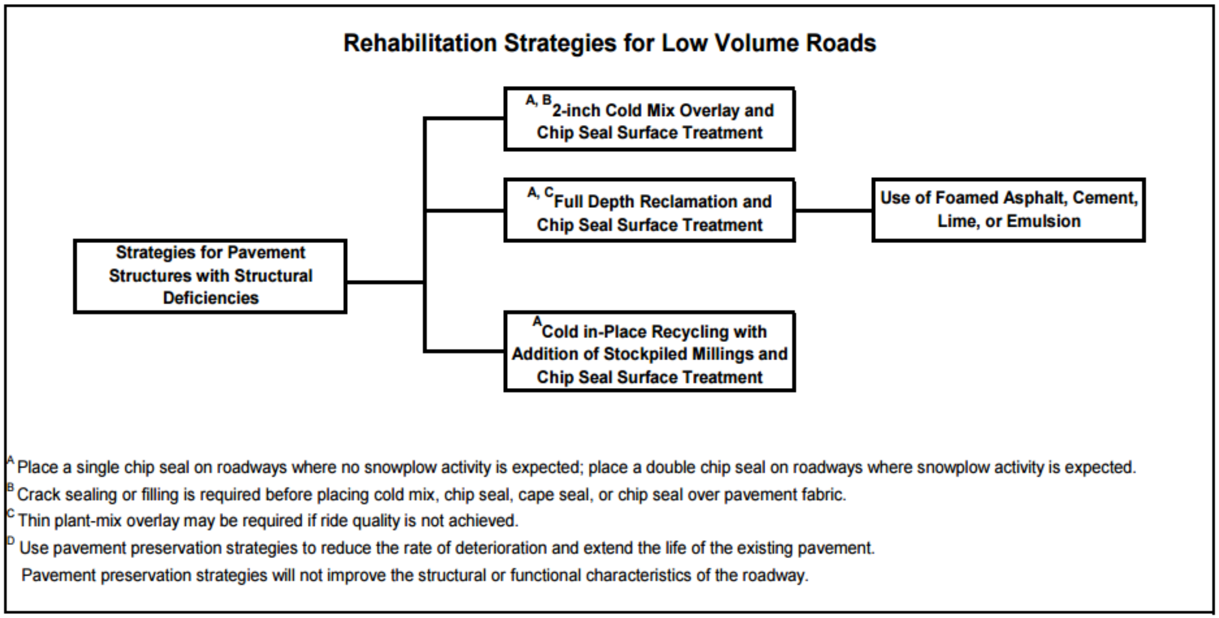


Figure 2.20 Nevada DOT Rehabilitation Strategies for Low-Volume Roads (Hoffman, 2008)

2.4.5.3 Minnesota DOT

Minnesota DOT (MNDOT) conducted a survey for county engineers in Minnesota and neighboring states to investigate any applied practices of recycling techniques on LVRs. The results from the survey revealed that CIR and FDR are extensively applied in Minnesota (Jahren et al., 2016). It was also found that chip seals were the only surface treatments applied directly to CIR and FDR layers. In the context of pavement preservation, several agencies apply other surface treatments such as microsurfacing, Otta seal, and ultra-thin asphalt overlay. The survey also indicates that most Minnesota counties make decisions about pavement rehabilitation based on past experience. Road surface, pavement age, and costs are the primary factors for such decisions. MNDOT found inconsistent decision making procedures for pavement rehabilitation on LVRs in Minnesota.

In order to find innovative solutions for pavement rehabilitation, MNDOT proposed four pavement rehabilitation alternatives involving recycling technologies. A study was conducted to investigate the performance and economic impacts of proposed alternatives by evaluating test sections (Jahren et al., 2016). The pavement rehabilitation alternatives include the following:

- CIR layer with thin overlay (AC)
- CIR layer surfaced with a chip seal
- FDR with thin overlay (AC)
- FDR surfaced with a chip seal

Based on the results of the survey conducted by MNDOT, 15 test sections were located in Minnesota to receive specific combinations of the proposed rehabilitations. A decision tree was developed to identify the appropriate alternative based on the structural status and targeted smoothness. Figure 2.21 shows the decision tree developed for the low-volume roads. Then a pavement condition survey was conducted to assess the performance of the treated sections. LCCA was also conducted over 30-year and 50-year analysis periods. LCCA results helped MNDOT to produce the preliminary decision tree for LVRs which involves information about the additional costs for smoothing assigned based on the user demand. Based on the expected performance, the benefit-cost ratio was determined for each alternative using the performance model of each section. The results of this study led to the following conclusions:

- All proposed rehabilitation alternatives are effective for rutting and roughness. However, all test sections with asphalt overlay had lower roughness levels than the sections with a chip seal surface. The alternative of FDR with chip seal produced the highest International Roughness Index (IRI) values compared to the other treatments.

- The expected service life of CIR with chip seal and FDR with chip seal was estimated to be 19 and 17 years, respectively.
- The rehabilitation strategies involving CIR and FDR with a chip seal have lower equivalent annual costs (EQACs) and higher benefit-cost (B/C) ratios than the strategies of CIR and FDR with an AC overlay.

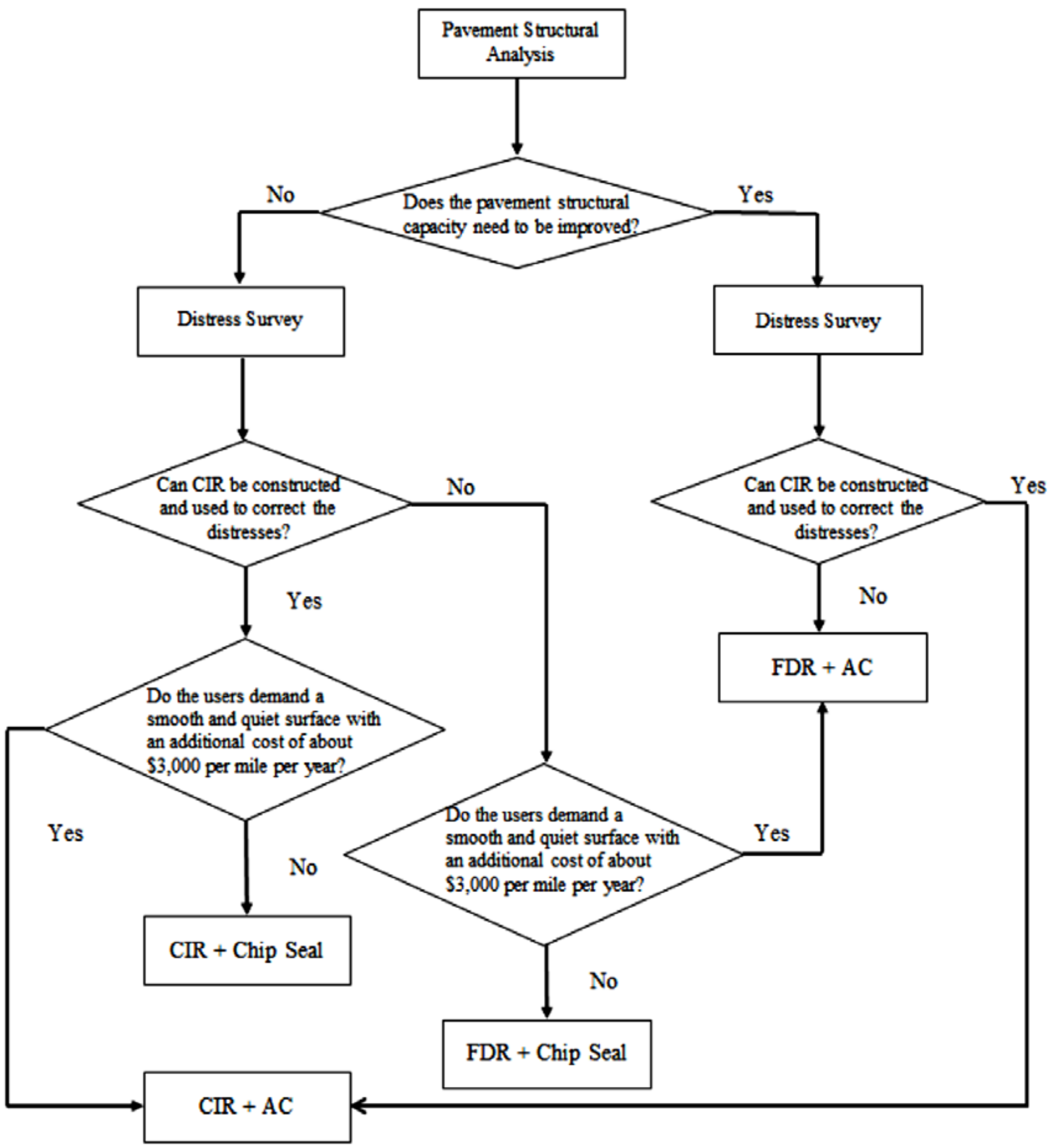


Figure 2.21: MNDOT Decision Tree for the Proposed Rehabilitation Strategies (Jahren et al., 2016)

2.4.5.4 Iowa DOT

In 2013, Iowa Department of Transportation (IDOT) sponsored a research project in conjunction with the Federal Highway Administration State Planning and Research Funding to evaluate various rehabilitation methods on LVRs. Although low-cost treatments may not be appropriate on severely distressed roads, IDOT thought that these treatments can hold the condition of pavement at an acceptable level until funding is available for traditional rehabilitation (Yu et al., 2015). The proposed holding strategy used different combinations of thin overlays, surface treatments, and in-place recycling technologies. IDOT constructed 10 test sections in 2013 which involved the following:

- 1.5” HMA overlay
- 1.5” HMA overlay + Single chip seal
- 1” interlay course + 0.75” ultra-thin HMA overlay
- 8” FDR + 1.5” HMA overlay
- 8” FDR + Double chip seal
- 2.5” CIR + Double chip seal
- 2.5” CIR + 1.5” HMA overlay
- 2” HMA overlay
- Leveling and strengthening course + Single chip seal
- Single chip seal

These sections were evaluated using pavement condition surveys and Falling Weight Deflectometer (FWD) tests. This project is still in progress to study the long-term performance; however findings about the construction process during different seasons were published (Yu et al., 2015). Also, the initial costs of the different strategies were compared to the conventional rehabilitation using a 3-inch HMA overlay. The alternative with FDR surfacing and 1.5-inch overlay was found to be more expensive than the conventional rehabilitation and it was excluded from the study. The costs of the other recycling and surfacing strategies were found to be 15% to 45% lower than the costs of 3-inch overlay. Recently, IDOT developed a preliminary selection table for agencies based on the desired holding life. The expected holding life for each strategy was estimated based on the literature. The agencies in Iowa can rely on the rehabilitation strategies listed in Table 2.15, until the performance of tested roads support these estimations.

Table 2.15: Iowa DOT Preliminary Treatment Selection Table (Yu et al., 2015)

Years of Holding	Proposed Treatment
1	scarification + chip seal
2 – 4	CIR + double chip seal
5 – 7	CIR + thin overlay
8 – 10	scarification + interlayer + ultra-thin overlay

2.5 Current Low-Volume Road Engineering Practices

Significant effort has been put forth by different agencies to develop guidelines for the process of design, construction, and rehabilitation of high-volume roads because of their great value. Other practices were developed for low-volume roads in an attempt to customize the current standards and practices to local needs. The following studies are introduced showing contributions toward cost-effective management systems for low-volume roads.

2.5.1 Practices for Long-Lasting Low-Volume Pavements

In Washington State, a set of six practices was developed and defined to ensure the pavement will have long-lasting performance on low-volume roads. The advantage of having long-lasting pavements for LVRs is that major rehabilitation and reconstruction projects would be limited. The maintenance strategies would emphasize periodic surface treatments that prevent top-down cracking from propagating into the whole depth of pavements, which would optimize the modest maintenance budgets allocated by state and local agencies on LVRs. Based on an extensive study on long-lasting low-volume and high-volume pavements owned by the Washington State Department of Transportation (WSDOT), the following practices were defined for LVRs (Muench et al., 2007):

2.5.1.1 Low-Volume Road Traffic Loading

In order to apply specific standards on the road as a low-volume road, a maximum amount of traffic load was defined. Low-volume roads endure less than one million 80 kN (18,000 lb) equivalent single axle loads (ESAL) over the pavement age of 40 years. This traffic limit was identified assuming no predicted or planned overweight vehicles over the pavement service life, such as farm equipment and tractor-trailer trucks.

2.5.1.2 Subgrade Minimum Support Strength

A minimum requirement of subgrade strength should be fulfilled to support long-lasting pavements. Having enough support for pavements prevents the vertical deformation on the subgrade surface which is an important criteria for increasing pavement rutting resistance. The study recommends having a subgrade with a CBR of 10% or more. Specific geotechnical analysis is performed for subgrades with a CBR less than 10%, and applications of using subbase layers and stabilization are also implemented.

2.5.1.3 Pavement Structure and Mix Design

The study identified minimum thicknesses for pavement structure which enable local agency practitioners to maintain the surface of pavements more efficiently. Having enough pavement thickness prevents initiating cracking at the bottom of hot mix asphalt (HMA) layers. It also allows application of mill-and-inlay rehabilitation on the surface without affecting the bulk of the HMA layer. Thus, a minimum thickness of five inches for the HMA layer is recommended. For aggregate base layers, a minimum thickness of six inches is recommended for better constructability. Other recommendations were presented to provide frost protection. The pavement structural thickness should be at least 50% of design freeze depth calculated using the modified Berggren formula in Modberg (free software by Cortez et al., 2006).

Some design standards were recommended for pavement mixtures on low-volume roads. The purpose was to increase the durability of asphalt and provide a mix design procedure that is consistent with the local practices. Fine dense-graded mixes were recommended since they are easier to compact. Also, higher optimum asphalt content was proposed to enhance the durability by reducing the compactive effort during mix design.

2.5.1.4 Construction Quality & Pavement Preservation

The study recommends including construction quality guidelines developed by the National Asphalt Pavement Association, Asphalt Institution, and Asphalt Pavement Association of Oregon, Colorado, and Indiana. Quality control tests should be conducted by the contractor, and the results should be sent to the owner. Minimum density specifications should be acquired for each HMA lift which is defined as 92-94% of theoretical maximum density. Also, a minimum compaction level is proposed to be defined.

Pavement preservation is very important since delaying the appropriate treatment could allow bottom-up cracking to propagate. As a consequence, more expensive rehabilitation will be required which, in many cases, cannot be afforded by local agencies. The study recommends apply maintenance strategies in a timely manner. Thin HMA layers with disposable pavements should be avoided since they commonly deteriorate from the bottom up through subgrade rutting and traditional fatigue cracking. Also, it was recommended to apply overlays with adequate thickness in curbed areas to ensure having adequate structure at the pavement's edges.

2.5.1.5 Financing

Although no specific funding plan is proposed, sufficient funding for low-volume pavement could be $7,000 to $9,000 per lane-mile not adjusted for inflation. The study emphasizes having consistent funding so that pavement condition can be preserved without costing much money to restore it to a predetermined level.

2.5.1.6 Marketing

The study promotes educating public officials about the costs and benefits of long-lasting low-volume pavements. Communication plans require collecting adequate information about the existing condition of pavements and the costs to maintain roads. LCCA can provide a more convincing demonstration of the importance of managing low-volume roads wisely and efficiently.

2.5.2 Low-Volume Roads Engineering Best Management Practices Field Guide

In 2003, the US Agency for International Development (USAID), in cooperation with USDA Forest Service International Program and Virginia Polytechnic Institute, developed a comprehensive field guide to plan, locate, survey, design, construct, and maintain low-volume roads (Keller and Sherar, 2003a). This guide introduces the concept of best management practices (BMPs). It defines the BMPs as practices that help produce well built, long-term cost-effective roads that minimize adverse environmental impacts. It combines the concept of addressing the social and environmental impacts with the persistent need for cost-effectiveness for low-volume roads. This guide was first developed in Honduras then it was extended by gathering information worldwide about low-volume roads. The key areas of application for best management practices were defined in order to have an "environmentally friendly" road (Keller and Sherar, 2003b). The guide is comprised of the following areas and topics of road management and design:

2.5.2.1 Environmental Analysis

The guide provides an interdisciplinary process to evaluate planning and managing low-volume roads considering the project environmental impacts. For example, Figure 2.22 shows how the different alternatives impact the environment. The corresponding ground disturbance, drainage conditions, surface erosion, and slope stabilization will be significantly different based on the selected alternative.

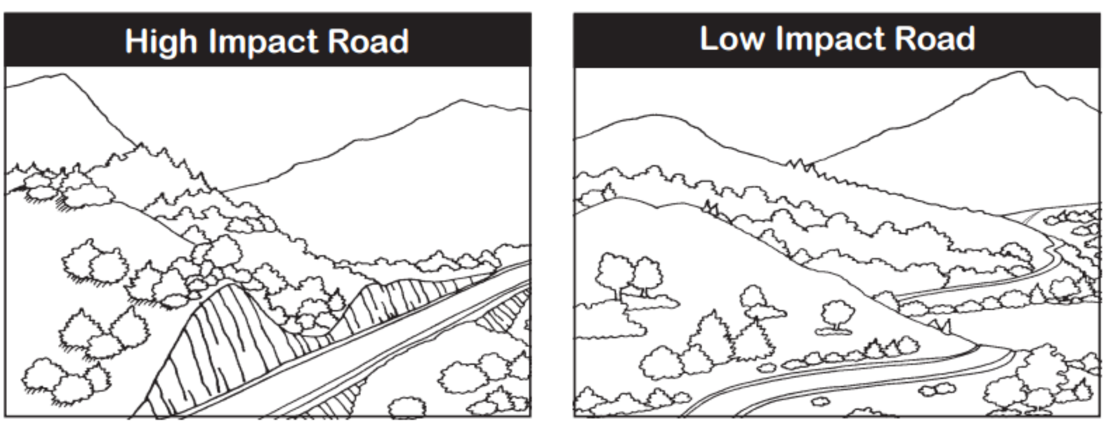


Figure 2.22: The Environmental Impact of Two Alternatives during Planning (Keller and Sherar, 2003a)

2.5.2.2 Hydrology for Drainage Design

Based on a reasonable design flow, well designed drainage systems are recommended. Figure 2.23 shows the impact of having positive surface drainage and adequately sized and appropriate drainage crossing structures. Therefore, it is highly recommended to consider the drainage of roads in the design process, which includes both the surface drainage for controlling the surface water and subsurface drainage collecting the ground water under roads in natural channels.

(a) (b)

Figure 2.23: The Impact of Drainage Design. (a) A poorly drained road with rutting and erosion problems; (b) An armored road surface with positive surface drainage using rolling dips (Keller and Sherar, 2003b)

For roads crossing a water stream, the guide provides recommendations about the design of cross drainage systems. Culverts can be installed and are commonly used to pass the water under the roads. These pipes should be large enough to pass the expected flow and they should be well protected from scour. Another application of water cross drainage is low-water crossings or what are called “fords”. These types of crossings are applied on low-volume roads where road use and stream flow conditions are appropriate. Another important consideration is to protect the downstream from scouring as shown in Figure 2.24. Although this type of drainage can cause occasional traffic delays, they can be a desirable alternative to culverts and bridges for stream crossings on a low-volume road. The costs would be significantly lower compared to low-water crossing structures.

Figure 2.24: A low-water crossing with an armored roadway surface in need of additional downstream scour protection (Keller and Sherar, 2003b)

2.5.2.3 Slope Stabilization and Stability of Cuts and Fills

The objective of this topic is to provide recommendations about the stability of slopes for cut and fill road sections. These recommendations are important in keeping cuts and fills stable over time, which reduce the costs of repairs and long-term maintenance. The guide also shows some applications of fixing fill failure surfaces and landslides at lower costs.

2.5.3 Previous Management Efforts for Local Agencies

DOTs have good expertise in pavement management. Numerous pavement management guidelines and policies have been developed to help local agencies understand the importance of PMS. Many PMS software packages have been developed for assisting agencies to manage State highways and higher-standard roads. However, adopting PMS standards for local agencies may not be cost-effective due to the lack of expertise and the low funding levels. As a result, different studies have introduced simple, effective and affordable PMS for local agencies and municipalities.

Starting in 2003, local agencies were encouraged to implement the software of Metropolitan Transportation Commission (MTC) PMS. The software had the ability to modify information and standards for supporting Governmental Accounting Standards Board (GASB) 34 requirements (Dewan and Smith, 2003). Douglas documented the outlines of PMSs designed for local agencies (Dogulas, 2011). Management systems at lower sophistication levels were recommended for introducing pavement management practices. However, the paper did not provide cost-effective solutions. New York LTAP center developed specific standards for designing, planning, and maintaining LVRs for local agencies in New York State (Orr, 2009). Washington DOT conducted a survey for managing LVRs among local agencies in Washington (White, 2012). The objective was to define the gaps among agencies and to unify the practices so that inconsistent data sets do not corrupt network-level maintenance decisions. Pavement condition data was proposed to be collected less frequently for county roads (Hafez et al., 2016). In this study, the condition data was collected for only 50 percent of the road network. The uncollected data was estimated as missing data using multiple imputation analysis (Schafer, 1997). The multiple imputation analysis can provide good estimation of the uncollected pavement-condition data so that the data can be collected at lower costs.

2.6 Summary

Low-volume roads constitute about 70 percent of the U. S. road network, and these roads are owned by local agencies and state DOTs. Usually, they are defined by maximum traffic volumes and truck volumes. The appropriate surface type on these roads is selected to fulfil the required local needs of different transportation modes. Several studies have identified the appropriate engineering, economic, and political issues that should be studied when deciding whether a LVR should be paved or unpaved. The most significant factors in such decisions are the agencies' available resources. When designing the pavement of LVRs, AASHTO provided a simplified design version of the AASHTO design method for flexible pavements. In this modified method, various parameters can be estimated using standard values without having to implement field and lab measurements. However, many states have developed specific low-volume pavement design procedures. These procedures are considered as 'non-AASHTO' design protocols and they have various complexity levels. In general, traffic data and soil strength of the subgrade are the most common inputs when designing low-volume roads.

Pavement preservation strategies apply low-cost surface and preventive treatments to extend the service life of the pavement before considerable deterioration. There are numerous types of preventive maintenance. Chip seal is one of the most common surface treatments applied on LVRs. The objective of applying surface treatments is to enhance the skid resistance of a surface by using different layer applications of chip seals and Otta seals. Chip seals are applied with single-sized aggregates while Otta seals integrate a gradation of aggregates. Another objective of surface treatment is to fill cracks and voids on the surface by using different applications of cold asphalt mixes as involved in slurry seals, fog seals, and microsurfacing.

Recycling technologies are being integrated extensively in the maintenance of LVRs. Cold in-place recycling (CIR) and full-depth reclamation (FDR) are preventive maintenance options applied to add structural value to the pavement. They allow for reduced costs of pavement materials by recycling the old asphalt with a percentage up to 100% using emulsion and in-place mixing equipment. Thin and ultra-thin overlays are applied to reduce the rate of deterioration and not to enhance the structural capacity of severely deteriorated roads. Pavement rehabilitation is applied to add a new life to older pavement by applying asphalt overlays or reconstructing the road pavement layers. However, LVRs commonly receive relatively thinner overlays that do not exceed a 3-inch layer thickness.

State DOTs are making efforts to develop specific maintenance policies for their LVRs. The objective is to use the most cost-effective preventive maintenance in the pavement preservation strategies. Most of these DOTs are combining recycling techniques with surface treatments and chip seals. Strategies of CIR with chip seals or thin overlays were studied and they can improve the structural status of pavements with lower costs. Using lower nominal maximum aggregate sizes was also proposed as a way to reduce the thickness of overlays so that costs can be lowered. Other engineering practices were defined for the pavement of LVRs. Different standards and criteria were defined for traffic amounts, structural properties, and construction qualities. These standards support long-lasting LVR pavements where major rehabilitation and reconstruction projects would be limited. The *Low-Volume Roads Engineering Best Management Practices Field Guide* is a comprehensive management guide developed to plan, locate, survey, design, construct, and maintain low-volume roads. The guide comprises environmental, hydrologic, and geotechnical issues that should be well investigated while managing LVRs.

Chapter 3: Pavement Management System Survey on Low-Volume Paved Roads

3.1 Introduction

The WYT^2/LTAP is working with Colorado DOT (CDOT) to evaluate maintenance strategies on LVRs. As part of these projects, an evaluation of current tools and treatments for managing LVRs was performed. In 2015, CSU and the WYT^2/LTAP developed online surveys for transportation officials responsible for preserving low-volume paved roads in Colorado and nationwide. These surveys had several questions which solicited information on the respondents' management of their LVRs. This study focuses only on the management of low-volume paved roads. The pavement management program for LVRs is recommended to integrate the most appropriate techniques resulting in better performance of the network. This report summarizes the responses and demonstrates the most widely applied practices and strategies recommended by various states/agencies.

3.2 Survey Methodology

In order to capture the knowledge from various LVRs experts, four online surveys were sent to transportation professionals with different management/experience types. The four groups targeted in the surveys are displayed in Figure 3.1. The surveys are listed below:

- A survey for Transportation Research Board (TRB) low-volume roads committee members
- A regional survey for different state DOTs nationwide
- A survey for local governments in Colorado

- A survey for members of the Material Advisory Committee (MAC) in Colorado Department of Transportation (CDOT)

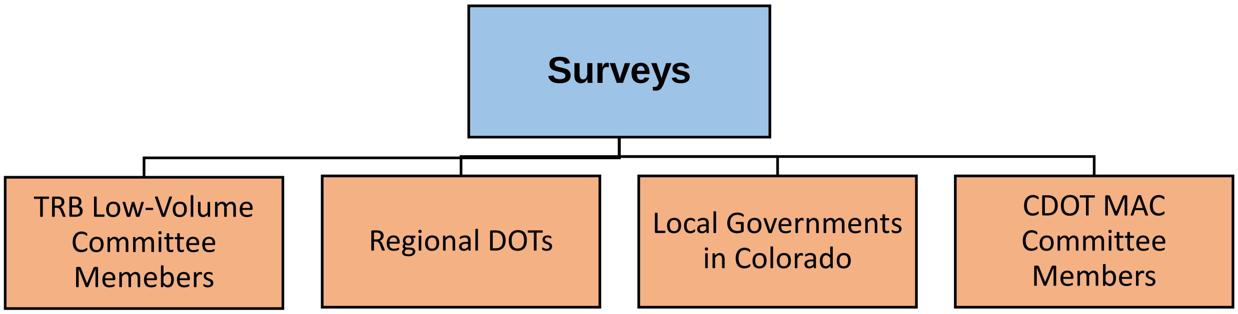


Figure 3.1: Surveys on PMS of Low-volume Paved Roads

3.2.1 TRB Low-Volume Committee Members Survey

The Transportation Research Board (TRB) committee AFB30 has had a great interest in low-volume roads since the early 1970s (TRB, 2015). This committee holds International conferences every four years for LVRs to exchange different experiences among attendants. These conferences are sponsored by federal agencies in the USA such as: FHWA, Forest Service, Bureau of Indian Affairs, and Army Corps of Engineers. The objective of the conference is to exchange experiences among people who are concerned with all aspects of low-volume roads. In August 2015, the first survey was sent to all TRB low-volume roads committee members and friends who are concerned with planning, design, construction, safety, maintenance, and operations on LVRs. This survey was conducted online using the SurveyMonkey® website and the feedback was received from 36 respondents representing 31 transportation agencies. A complete list of questions of the survey in addition to the response counts and percentages of different answers are shown in Appendix A-1 and Appendix A-2.

3.2.2 Regional Departments of Transportation Survey

State DOTs have various policies for managing their low-volume roads. DOTs try to match maintenance expenditures to available budgets. The objective of this survey is to highlight effective policies and recommended practices from various state DOTs. The results of this survey can provide practical strategies for low-volume roads in Colorado. These strategies provide cost-effective treatments that can be applied within the available resources. In January 2016, the following eight DOTs participated in the survey: Arizona, Kansas, Montana, Nebraska, New Mexico, Texas, Utah, and Wyoming. A complete list of questions of the survey in addition to the response counts and percentages of different answers are shown in Appendix B-1 and Appendix B-2.

3.2.3 Colorado Local Governments Survey

Local governments are responsible for the management of some low-volume roads in Colorado. As mentioned earlier, local governments are not required to implement a typical PMS on their local roads. Manuals are being developed by state DOTs and FHWA to encourage local governments to use a PMS. In many cases, the allocated funds for local governments are limited. In addition, previous experiences of some local governments can provide recommended practices based on the available resources. As a result, some local governments have their own policies for managing and maintaining low volume paved roads.

This survey investigates the efforts at the local level. It studies the importance of implementing specific policies on low-volume paved roads. It identifies appropriate tools and recommended treatments for LVRs developed by local governments. There are numerous local governments across the country with a variation in responsibilities and available resources. In addition, different programs are implemented with different levels of sophistication (FHWA, 2015). Therefore, this study focuses on the experience and challenges faced by local governments in Colorado. In October 2015, the survey was sent to local governments in Colorado and 53 transportation professionals from 32 local agencies in Colorado responded to this survey. The summary of this survey is presented in Appendix C-1 and Appendix C-2.

3.2.4 CDOT MAC Committee Members Survey

About 9,106 center-lane miles are managed and maintained by CDOT (Redd, 2013). More than 50% of these roads are not considered as NHS. However, CDOT has a transportation asset management system for different road systems. Recently, CDOT began evaluating the overall condition of pavements by the Drivability Life (DL) metric. DL is a measure, in years, of how long a road will have acceptable driving conditions (Redd, 2013). CDOT uses different standards for DL on different road classifications. DL is determined for asphalt pavement based on a trend analysis of 5 main distresses (Redd, 2013):

- IRI
- Rutting
- Transverse cracking
- Longitudinal cracking
- Fatigue cracking

All of the previous distresses are normalized into condition indices on a scale of 0 to 100, 100 being the best condition where the pavement is free of distress (Keleman et al., 2005). When CDOT applied DL-based evaluation, new pavement maintenance strategies were developed. At network level, LVRs are assigned with two different treatment categories recommended based on the available funding of the maintenance program. The first treatment category is called

“Surface Seal” and it is assigned for the lowest cost option of maintenance. This category includes basically general applications of chip seals and crack sealing. However, specific project-level maintenance can be executed on distressed spots as long as the total lane-mile cost is within the lowest cost category. The second treatment category includes ultra-thin overlay treatments for worse pavement conditions. The second category also can include any combination of treatments throughout the length of the project if the total lane-mile costs do not exceed the ultra-thin overlay category. Table 3.1 shows the percentage of investments considered generally for the different road classifications. It can be noted that low maintenance investments are made for LVRs due to the funding constraints. There is no readily available funding for significant pavement rehabilitation projects or reconstruction.

Table 3.1: Pavement Treatment Types (Redd, 2013)

Category	Chip Seal	Ultra-Thin	Preventive Maintenance	Minor Rehab.	Major Rehab.	Recon-struction	Total Investment
Interstate	N/A	N/A	2%	9%	3%	5%	19%
High Volume	N/A	N/A	3%	14%	9%	15%	42%
Medium Volume	7%	9%	0%	13%	N/A	N/A	29%
Low Volume	5%	6%	N/A	N/A	N/A	N/A	10%

The objective of this survey is to investigate the effectiveness of different policies assigned by CDOT for managing low-volume paved roads in Colorado. Recommendations and conclusions are developed based on the experience of responsible engineers on low-volume roads in the five CDOT regions shown in Figure 3.2.

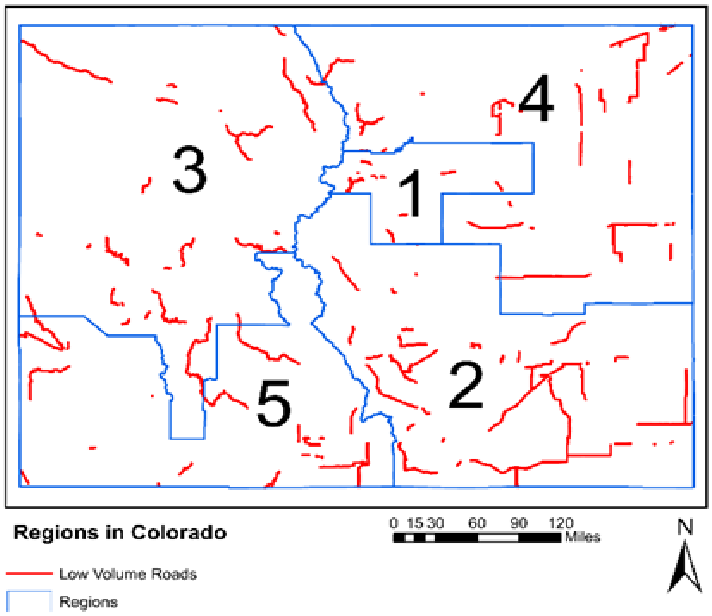


Figure 3.2: Low-Volume Roads in CDOT Regions (Atadero and Ksaibati, 2015)

In September 2015, the survey was disseminated online using the SurveyMonkey® website to the CDOT MAC committee. Eight MAC members out of nine participated in this survey. A copy of the survey is provided in Appendix D-1 and Appendix D-2 shows the response counts and percentages for the different answers.

3.3 Survey Sections

The surveys have 4 sections covering most relevant aspects of managing and maintaining low-volume paved roads. An additional section was provided for the CDOT MAC survey. The sections are introduced as follows:

3.3.1.1 Low-Volume Paved Road Definition

This section is to identify an appropriate definition of low-volume paved roads that should be considered when managing roadway networks.

3.3.1.2 Data Collection & Inspection Survey

This section provides recommendations about kinds of pavement management data that should be collected for managing low-volume paved roads.

3.3.1.3 Treatment Strategies

This section studies the expected service lives of common treatment options. It also provides recommendations about the decision making process and cost-effective treatments.

3.3.1.4 Resources Optimization

The objective from this section is to investigate the importance of applying optimization analysis. In addition, the section provides recommendations on pavement management parameters that should be considered in the optimization strategy of the whole low-volume network.

3.3.1.5 CDOT Policies on Low-Volume Roads

This section is for the CDOT MAC survey only. The objective is to evaluate the effectiveness of current CDOT policies on maintaining low-volume roads based on DL.

Chapter 4: Survey Data Analysis

This chapter introduces the results from the surveys. All relevant responses were combined from the four surveys to provide comprehensive information about PMS for managing LVRs. These findings are summarized in the sections below.

4.1 Section 1: Low-Volume Paved Road Definition

The first step is to define which roads are considered as LVRs. Nine DOTs, including CDOT, 34 TRB committee members, and 30 local governments in Colorado reported that they have upper limits of Average Daily Traffic (ADT) for LVRs. As shown in Table 4.1, most agencies and DOTs rely on the definition of the MUTCD which considers an ADT value of 400 vehicles per day as a maxim traffic volume for LVRs. However, other participants mentioned higher traffic volumes.

Table 4.1: Traffic Volume Considerations for Low-Volume Paved Roads (73 responses)

Upper Limit of Average Daily Traffic (ADT) (vehicles per day)	Response Count		
	TRB committee	State DOTs	Local Governments
400	17	KS, MT, NE, WY	18
500	5	NM, TX	2
1000	5	UT	6
1500	1	--	2
2000	5	CO	2
5000	1	AZ	0
Number of Responses	34	9	30
Skipped	2	0	5

NOTE: DOTs = Departments of Transportation

As shown in Figure 4.1, there is a direct relationship between statewide average traffic volumes and the responses of the DOTs for LVRs definitions. It can be noted that higher definitions for LVRs traffic volumes are selected when the states have higher ranges of traffic volumes statewide. If a state encounters higher ranges of traffic volumes, then the corresponding number of miles of high-volume road network would be large. As a consequence, the state increases the traffic volume used to define LVRs to keep the high volume road network of manageable size. At the local level, it can be noted that most local governments in Colorado do not follow the definition of LVRs developed by CDOT. They use significantly lower traffic volume to define their LVRs.

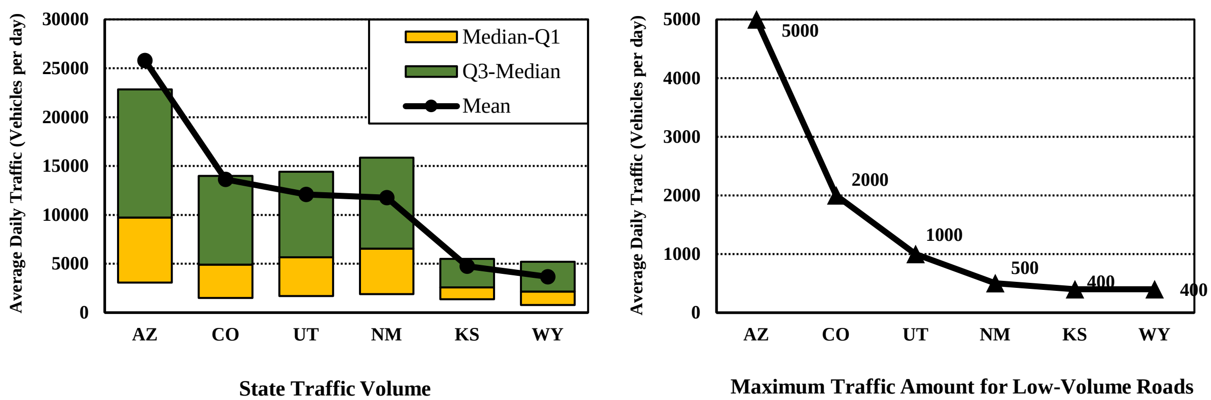


Figure 4.1: ADT Distribution vs. Traffic Volumes for Low-Volume Paved Roads

Another important variable when defining low-volume paved roads is the truck loading. Truck traffic is a critical load that affects the performance of pavement over time. 89% of the TRB respondents confirmed that the truck traffic should be considered in defining low-volume paved roads (TRB Survey: Q3). Also, 78% of the regional survey respondents recommended considering truck traffic volumes for LVRs (Regional DOTs Survey: Q3), while 94% of local governments respondents consider truck volumes for LVRs (Local Governments Survey: Q4).

Hence, low-volume paved roads should have an upper limit of truck volume. A maximum value of average daily truck traffic (ADTT) can be considered when defining low-volume paved roads. Table 4.2 shows a summary of the responses for the upper limits of ADTT that should be considered for LVRs. Most of the responses rely on the definition by MUTCD for ADTT values of 50 vehicles per day.

Table 4.2: Truck Traffic Volume Consideration for Low-Volume Paved Roads (61 responses)

Upper Limit of Average Daily Truck Traffic (ADTT) (vehicles per day)	Response Count		
	TRB committee	State DOTs	Local Governments
No Limit	4	AZ, NE	2
50	15	NM, UT, WY	16
100	6	KS, CO	5
150	2	--	3
200	4	TX, MT	0
Other	1	--	2
Number of Responses	32	9	28
Skipped	4	0	7

NOTE: DOTs = Departments of Transportation

4.2 Section 2: Data Collection & Inspection Survey

The basic step in building a pavement management system is data collection, and there are different kinds of data that can be collected. For the purpose of managing low-volume paved roads, some of these data may not be needed. Sometimes, they don't provide any useful information to the decision making process. Collecting these data would lead to spending unnecessary money and effort in building the pavement management database for low-volume paved roads. Therefore, the survey asked about kinds of data that should be collected when managing and maintaining low-volume paved roads. The response rate for this part was 88% for all surveys. Figure 4.2 shows the responses in each survey for three main types of data; Traffic counts, structural data, and pavement condition. All nine state DOTs, including CDOT, collect pavement condition data. All TRB respondents recommended collecting pavement condition data. However, funding constraints resulted in only 58% (14 responses) of local governments in Colorado recommending collecting condition data. In addition, pavement condition data is very complex and needs tools requiring expertise to operate and understand (Douglas, 2011). Local agencies, lack the required expertise to collect/analyze pavement condition data on low-volume paved roads.

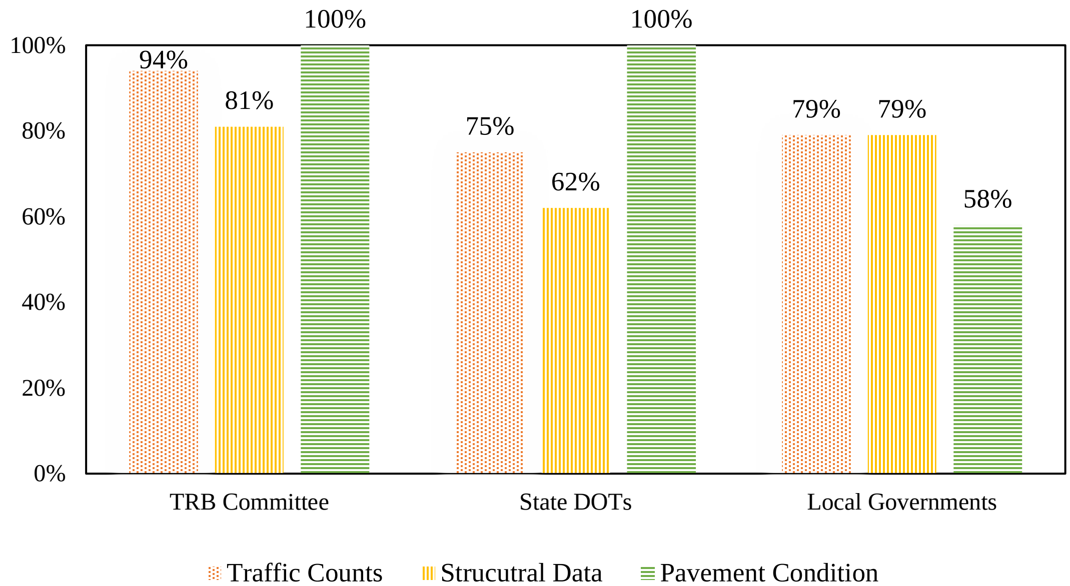


Figure 4.2: Pavement Management Data Collection for Low-Volume Paved Roads

Of the eight participating states, Arizona and New Mexico DOTs do not collect traffic data on LVRs. Ninety-four percent (30 responses) of TRB committee members recommended collecting traffic data for the LVRs PMS. As shown in Figure 4.3, most responses from the TRB survey recommended collecting actual traffic volumes. It is commonly known that pavement has different deterioration rates depending on major factors such as traffic and truck volumes. Traffic can be reasonably predicted for low-volume roads where there are not significant changes in the traffic volumes or patterns. However, it was found that counting actual traffic volumes is recommended rather than using different algorithms to predict current and future traffic volumes. 81% of respondents recommended actual traffic volumes, and 41% recommended predicted volumes. Some responses mentioned other kinds of traffic data such as non-motorized and pedestrian volumes. Another response mentioned a specific practice of counting traffic where ADT can be calculated based on a 15-minute count during a specific time of the day.

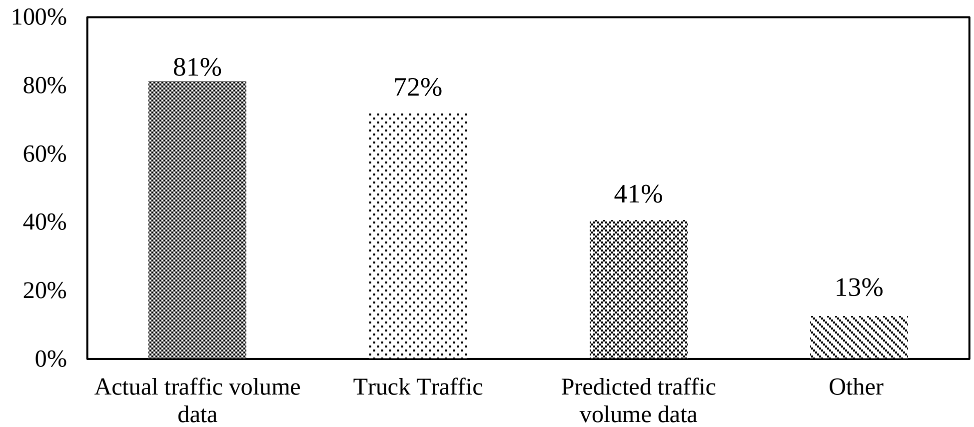


Figure 4.3: Recommended traffic data for managing low-volume paved roads (TRB Survey: Q6)

It was also found that the structural data is an important type of data for managing low-volume paved roads with an agreement of 81% of TRB members (26 responses), 63% of participating states (5 state DOTs) and 79% of local governments in Colorado. For the structural data, Figure 4.4 shows the most common parameters collected as an indication of the structural quality for low-volume paved roads. Pavement thicknesses and material characteristics are the most recommended structural data collected for managing low-volume paved roads (90% and 87% respectively). At the network level, non-destructive instruments are used to determine pavement thicknesses. One of those instruments is known as Ground Penetrating Radar (GPR). The radar waves are directed into the ground. Then pavement thicknesses are determined based on the time required for the return of any reflected signals (NCHRP, 1998). In addition, 43% of respondents selected collecting the deflection data obtained from a FWD test to study the structural quality for low-volume paved roads. However, it was also mentioned that the FWD test is only useful for highways with higher truck traffic.

For the pavement condition data, Figure 4.5 shows a list of the most commonly used condition indices utilized for low-volume paved roads. Pavement Condition Index (PCI) is the most widely recommended index among respondents. However, only New Mexico and Wyoming DOTs collect PCI data. It can be noticed that PCI, International Roughness Index (IRI), and rut measurements are the most recommended condition indices. Surface Rating (SR) and Pavement Surface Evaluation Rating (PASER) are more common for LVRs as a visual inspection survey.

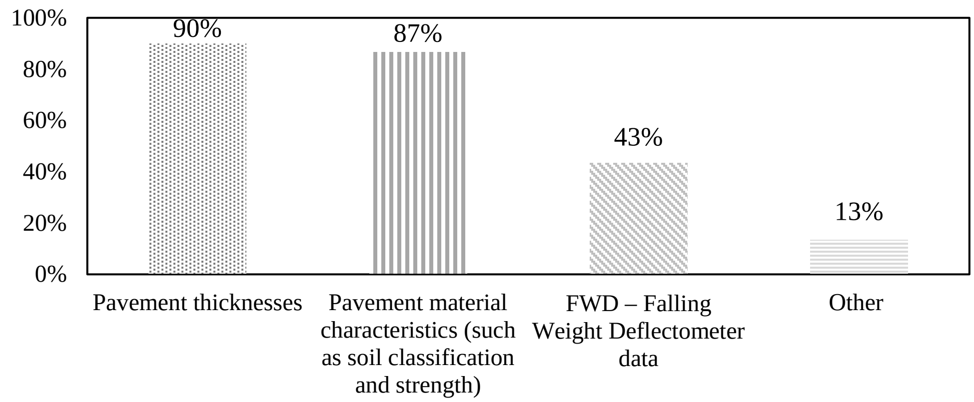


Figure 4.4: Recommended structural data for managing low-volume paved roads (TRB Survey: Q7)

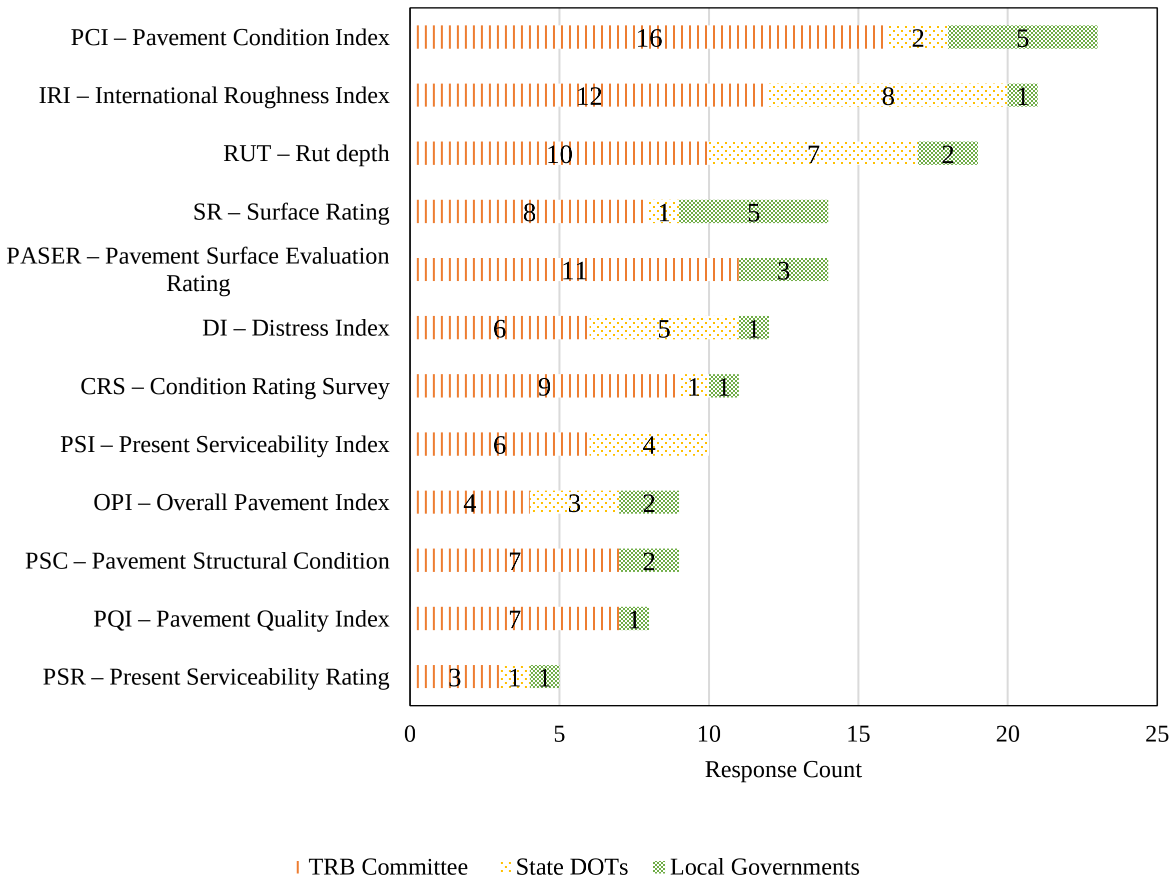


Figure 4.5: Condition Indices Used for Low-Volume Paved Roads

In addition, the surveys included questions intended to identify the method and frequency of collecting PMS data. Two methods are commonly used for data collection: manual and automated methods. They may be used alone or in conjunction with one another. Five state DOTs collect condition data on LVRs automatically. The other state DOTs collect data using a composite system of manual and automated techniques. At the local level, only 7% of local governments collect data automatically. Figure 4.6 shows the most accepted data collection frequencies among agencies for LVRs. Although LVRs have relatively low deterioration rates compared to high-volume roads, collecting data annually was recommended by 35% of respondents (18 responses). Reducing the frequency of data collection was acceptable to 65% of respondents (33 responses). Montana DOT selected a frequency up to 5 years. Some local governments mentioned that they collect the condition data as needed.

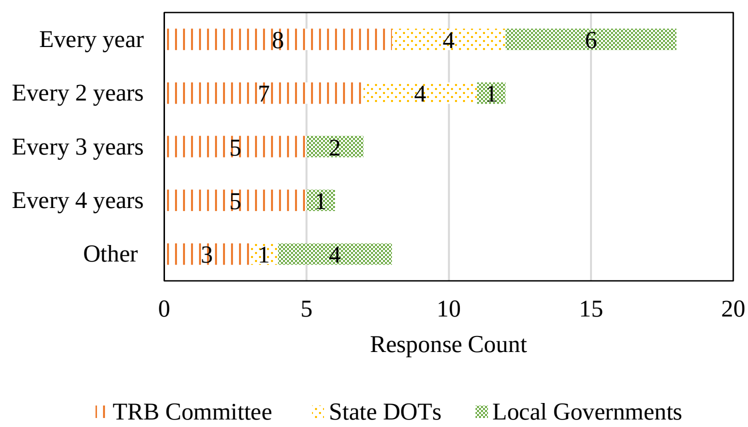


Figure 4.6: Data Collection Frequency of Pavement Condition Data

4.3 Section 3: Treatment Strategies

Some agencies provide specific policies for the process of maintenance and rehabilitation on low-volume paved roads. Different treatments are identified for roads based on different methods. One of the simplest decision making process in PMSs is using decision trees or trigger values. The survey asked about the importance of using a decision tree for selecting M&R treatments. For the TRB survey, 82% of respondents recommended using a decision tree to identify pavement treatments for low-volume paved roads (TRB Survey: Q10). The rest of respondents think that treatments may be defined on low-volume roads directly without taking different variables into consideration in a decision tree. This kind of decision making may be used when agencies have fewer options. Some agencies have only one or two treatment options allowed on LVRs .

Figure 4.7 presents the variables recommended for inclusion in decision trees. It can be noticed that traffic-based treatments is the most accepted strategy when managing LVRs by 86% of respondents (19 responses were received for ADTs). Fifty percent of respondents (11 responses) consider pavement conditions, represented by PCI, for decision trees.

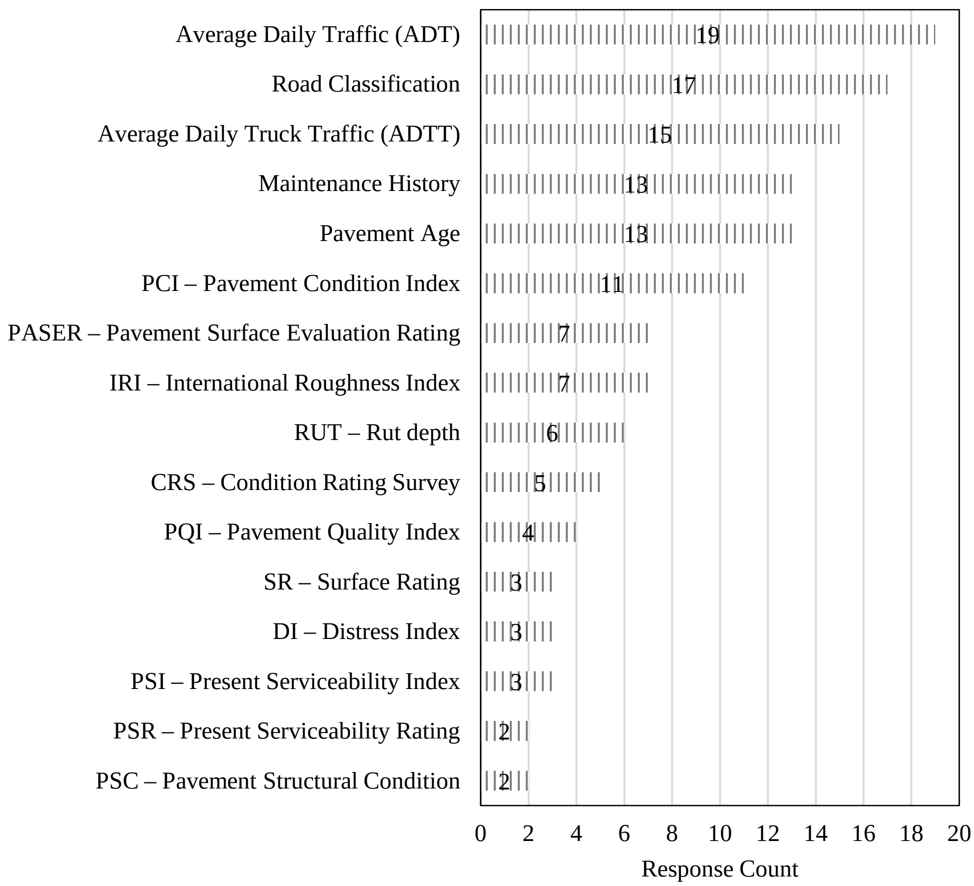


Figure 4.7: Recommended Variables for a Decision Tree (TRB Survey: Q11)

The state DOTs survey asked about the most important maintenance policy followed by the state. Four state DOTs indicated that they have specific polices when it comes to managing LVRs. Most states' policies depend on road classification. There is a lack of adequate funding to consider all possible treatments. Consequently, surface treatments such as crack sealing, chip seals, and surface repairs are widely applied to LVRs. The local government survey revealed that

75% of local agencies in Colorado do not follow CDOT's policy for maintaining LVRs. Chip seal is applied by some of the local agencies in a periodic manner every 5 to 7 years. Other agencies apply treatments which should not exceed a thickness of 1.5 inches. Overlays are limited and some local governments have policies of applying overlays every 15 years or as funds are available.

It is clear from most survey responses that treatment strategies for LVRs are affected considerably by funding levels. Most agencies avoid applying expensive treatments on low-volume paved roads. However, the previous experience of pavement managers show that inexpensive strategies are not very effective. As shown in Figure 4.8, 67% of regional survey participants (6 state DOTs) and 49% of local government participants do not think that eliminating expensive treatments provides cost-effective solutions.

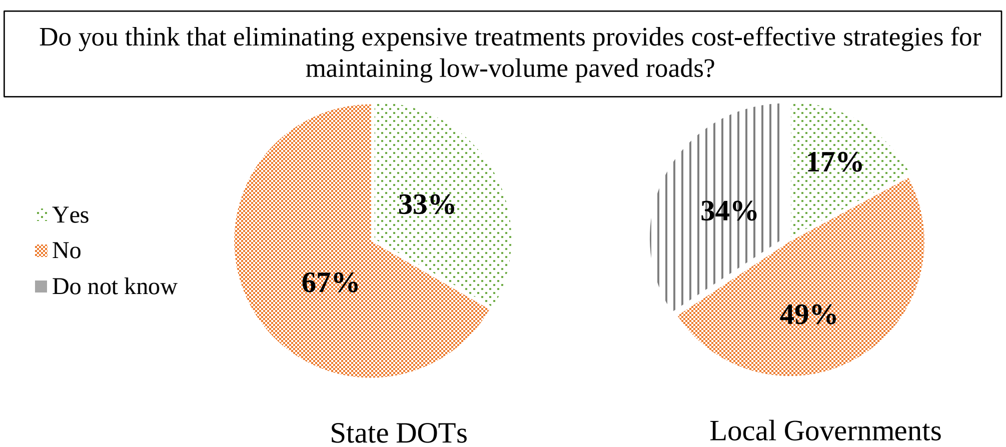


Figure 4.8: Effectiveness of Eliminating Expensive Treatments on LVRs

For current treatment policies, Figure 4.9 shows the most common treatments applied to LVRs. It is clear that chip seal is the most widely used treatment by agencies. Thin overlays with thicknesses less than 1.5 inches are the most common pavement rehabilitation applied on low-volume paved roads. Respondents that selected other treatments mentioned applying slurry seal, Hot In-Place Recycling (HIR), and another application of chip sealing using recycled materials.

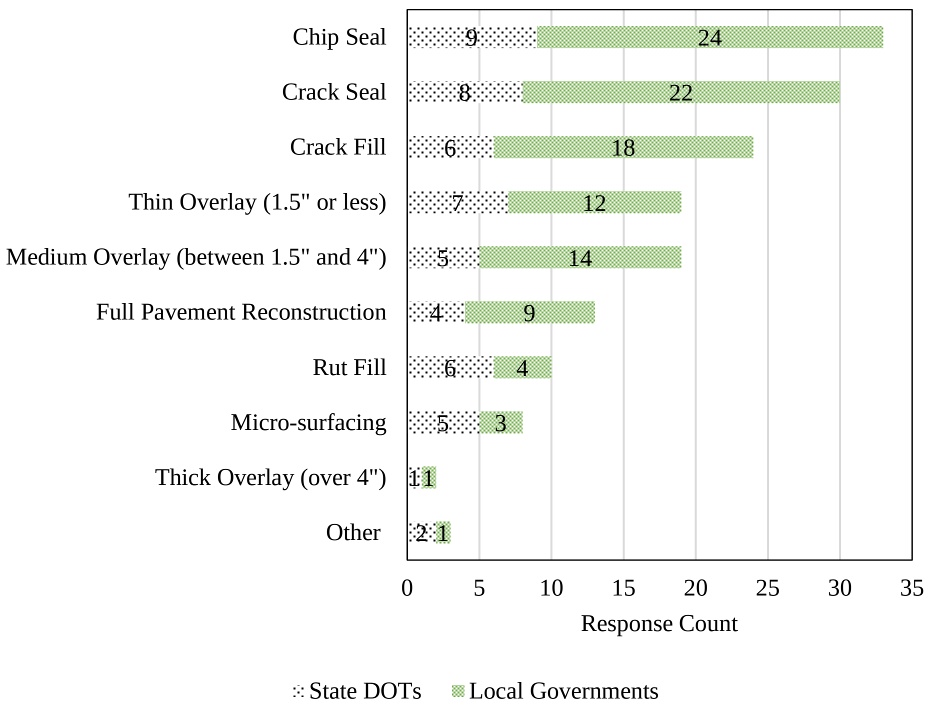


Figure 4.9: Treatments Allowed on Low-Volume Paved Roads

The identified LVRs treatments were further investigated. The surveys asked about the expected service life of each treatment option. Results were received from the TRB low-volume roads committee, regional DOTs, local governments, and CDOT MAC committee. The responses were combined together as shown in Figure 4.10. The results show that chip seal has anticipated service life ranging from 3 to 8 years. Crack seal and crack fill are commonly serviceable for a period from 3 to 5 years.

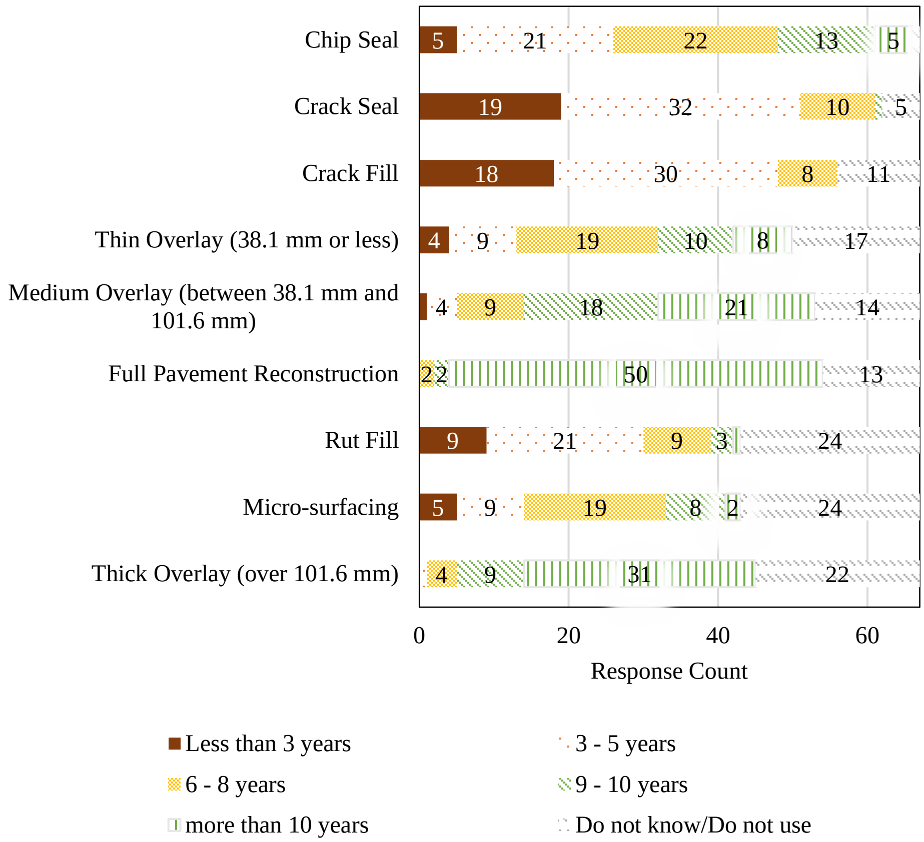


Figure 4.10: Expected Service Lives of Treatments Applied on LVRs (67 Responses)

The surveys also investigated the effectiveness of treatments on severely distressed pavements for low-volume paved roads. Usually, when a low-volume paved road deteriorates to a very poor level, agencies may not be able to afford full pavement reconstructions. Some kind of surface treatment is applied instead, to increase the remaining service lives of low-volume paved roads. The survey asked if this strategy is effective on severely distressed roads. According to the results shown in Figure 4.11, surface treatments were found to be not effective by most participants. Forty-one percent of respondents (22 respondents) are convinced that thin overlays with a thickness less than 1.5 inches are effective treatments on severely distressed roads. Most responses from local governments indicated that they do not know the expected effectiveness of treatments because of the limited application of these strategies.

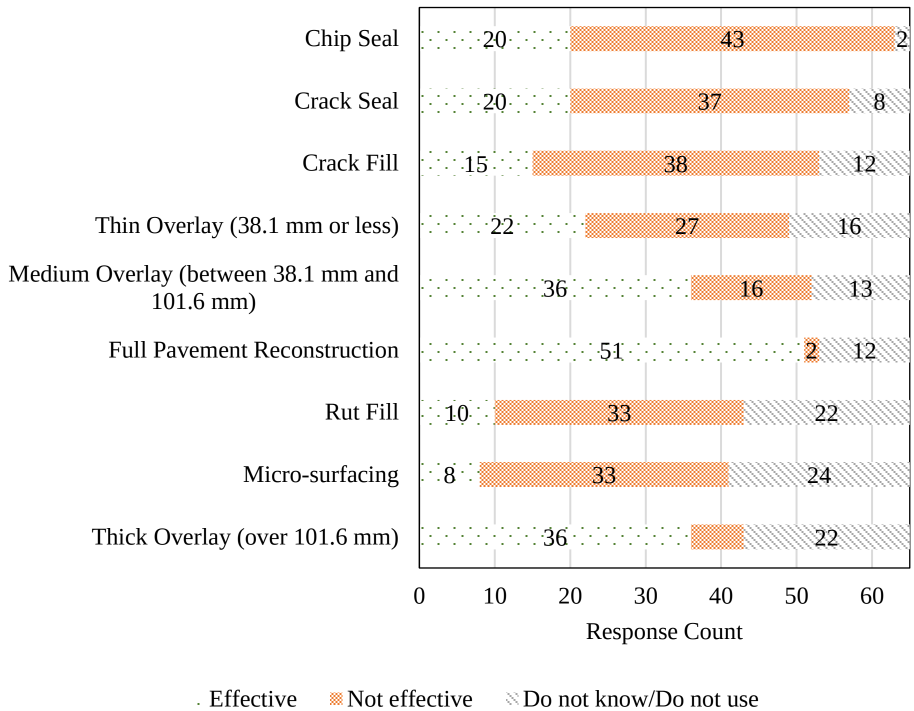


Figure 4.11: Effectiveness of Treatments on Severely Distressed Roads (65 Responses)

Agencies were also asked about a proposed treatment strategy of targeted rehabilitation. This strategy is applied on severely distressed areas within LVRs prior to the application of surface treatments. The results show that 89% of participating DOTs and 76% of local governments recommended this strategy. The advantage of applying targeted rehabilitation is that it can improve the structural capacity of severely distressed spots on the surface. As a consequence, subsequent overlays are expected to have a better performance than regular overlays. Then the respondents were asked to provide information on when full length rehabilitation becomes necessary. For state DOTs, the responses implied that pavement condition and distresses are the most important factors for such decisions. Full length rehabilitation is necessary for roads having severe pavement roughness, rutting, and distresses. At the local level, treatment costs, pavement condition, and agencies' policies are the factors affecting such decisions. Other participants of local governments mentioned that this is a decision determined by road managers and the chief engineer since these sorts of rehabilitation may not be allowed.

4.4 Section 4: Resources Optimization

Optimization models are mathematical programming techniques which are used to provide recommendations for maintenance, rehabilitation, and reconstruction (MR&R) strategies. MR&R strategies should maximize the overall benefits associated with maintenance expenditures. This section of the survey was designed to collect recommendations pertaining to optimization analysis on low-volume paved roads. Eighty-five percent of TRB participants and all participating DOTs and local agencies responded affirmatively about the importance of utilizing optimization analysis when selecting treatments on LVRs. Figure 4.12 displays parameters and objectives recommended in optimization analysis. Participants were able to select multiple responses. Since all MR&R strategies are constrained with the network-level budgets, 68% of respondents recommended optimizing budgets on LVRs. The most important objective was found to be maximizing Remaining Service Life (RSL) (68% of respondent selected Maximizing RSL). Pavement condition can also be optimized by applying treatments. PCI was found to be the most recommended condition index to be maximized.

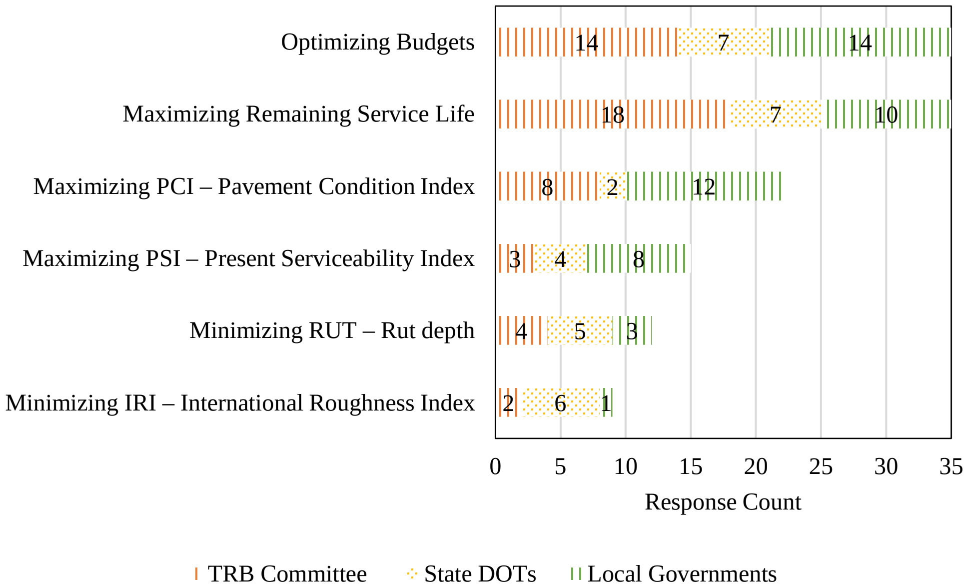


Figure 4.12: Recommended Objectives in Optimization Strategies (51 Responses)

At the end, the survey asked the participants about how the total available budget should be distributed on the full network. Respondents were asked to assign funds to three condition levels: 1) worst segments, 2) rapidly deteriorating segments, and 3) segments requiring routine maintenance. Figure 4.13 shows recommendations about budget assignments to the three condition levels. Since slightly different responses were received, the recommended percentages were computed using a weighted average. The TRB survey results show that the budget can be equally divided among the three parts. The state DOTs participants think that relatively more investments should be allocated to roads having rapid deterioration rates. At the local level, local governments assigned relatively higher budget to routine maintenance because of the lack of funding available for extensive repair and rehabilitation.

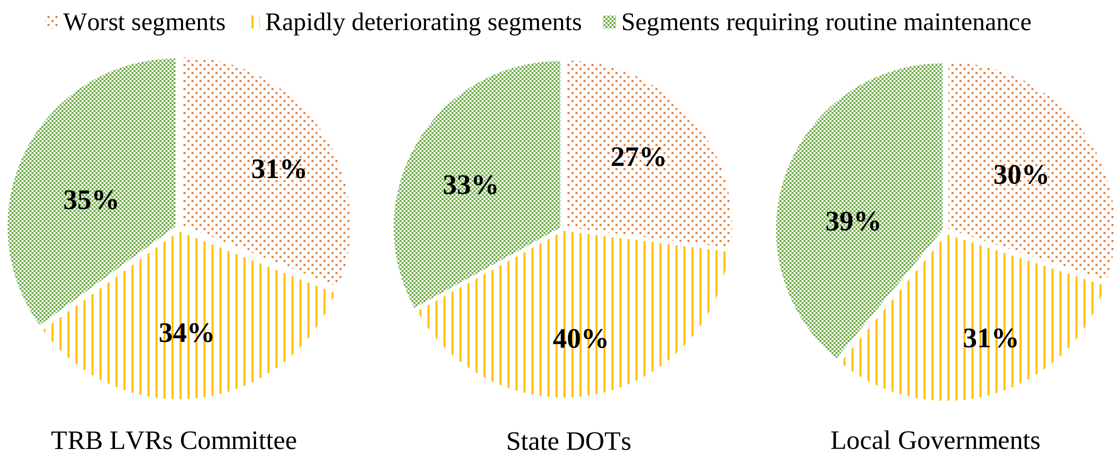


Figure 4.13: Budget Assignments on Different Condition Levels (48 Responses)

4.5 CDOT's Policy on Low-Volume Paved Roads

Since CDOT has a policy of applying low-cost treatments on low-volume paved roads even if the DL is low, the survey asked if the participants agree with that policy. Fifty percent of participant don't agree with that policy (CDOT Survey: Q5). In addition, 40% of respondents don't think that eliminating expensive treatments provides cost-effective alternatives on LVRs (CDOT Survey: Q14). The location of LVRs seems not to be the reason of rejecting that policy. The following question asked respondents about their reasons and how this policy should be changed to better manage low-volume paved roads (CDOT Survey: Q6). Some of the respondents mentioned that applying thin overlay treatments are not always effective. The minor treatments present short-term effectiveness on LVRs with low DL values. The justification of selecting such treatments is the funding constraints on LVRs. Another respondent stated that the policy does not need to be changed. Instead, a prior surface treatments can be applied before overlaying.

The survey investigated how the new policy affected decisions about maintaining low-volume paved roads (CDOT Survey: Q7). Some responses mentioned there are some changes for the decision making process. In the context of the DL evaluation metric, the treatment type should enhance the smoothness of the pavement surfaces. For low-volume paved roads, there are funding-related issues. New treatment options are developed focusing on surface treatments rather than structural improvements. It was found that DL can be improved using cheaper treatments such as chip seal. However, another respondent argued that these kinds of treatments have a short-term effect.

For the targeted rehabilitation strategy, all participants of the CDOT survey recommend this strategy (CDOT Survey: Q12). The survey then asked about the appropriate time when full length rehabilitation becomes necessary (CDOT Survey: Q13). It was mentioned that the combined costs of targeted rehabilitation and surface repairs, sometimes, are more than the costs of full length rehabilitation when road distresses are extensive. Another important consideration for full length rehabilitation is the rate of deterioration and the available budget. The severely distressed areas are expected to have higher deterioration rates. Therefore, the full length rehabilitation was highly recommended in these situations especially if the treatment cost can fit in the available budget.

Chapter 5: Conclusions

This report provides a comprehensive review of the best practices utilized by various transportation agencies to effectively manage and maintain low-volume roads (LVRs). The limited availability of financial resources encouraged many agencies to study and investigate the effectiveness of applying alternative maintenance strategies on their low-volume paved roads.

5.1 Literature Conclusions

The following summarizes the conclusions from the literature:

- Low-volume roads are extensively distributed in rural communities and low-population areas. They comprise the vast majority of the United States road network. However, these roads are owned by local governments and state DOTs which suffer from funding constraints, and they have a considerable maintenance backlog for maintaining optimal serviceability on roads.
- Various states have their own pavement design procedures for low-volume paved roads. They deal very effectively with different input variables required for the pavement design process. Traffic data and soil strength of the subgrade are the most common inputs when designing LVRs. Most of the design procedures follow the principles of the AASHTO design method, but they were simplified to the restricted capabilities of local agencies. It was revealed that most of these procedures, however, have different levels of complexity and the input variables are not readily available to some agencies.
- Maintenance decisions for LVRs are initially investigated in the context of "to pave or not to pave". In some cases, the decision of upgrading aggregate-surfaced roads likely

requires greater investment than continuing to maintain the aggregate of the surface. Also, some LVRs may have issues that recommend converting the pavement into an aggregate surface. The decision of selecting the appropriate surface type should be investigated from engineering; economic; and political stand points.

- In the context of pavement preservation strategies, numerous research studies have emphasized the cost-effectiveness of applying low-cost and surface treatments as a preventive maintenance. However, they should be applied to roads where the pavement is still performing well. The preventive strategies include sealing practices such as chip seals. Chip seals are the most commonly applied surface treatment. On-site pavement rehabilitations using recycling techniques are also implemented as preventive maintenance strategies which provide lower-cost materials and better construction practices for LVRs.
- When applying preventive maintenance on severely distressed low-volume paved roads, these strategies have different effectiveness depending on the initial pavement performance and the surrounding environment. Some of the applied treatments may provide only short-term effectiveness and agencies make unnecessary expenditures when applying these strategies.
- Innovative techniques combining surface treatments and pavement rehabilitation are being investigated extensively. The recycling technologies in cold in-place and full depth reclamation techniques enable agencies to add structural value to the deteriorated pavement. When integrating these techniques with surface treatments such as chip seals, the performance of the rehabilitated pavement is expected to extend the life of the

pavement. These strategies are very interesting since they provide cost-effective solutions to deteriorated LVRs.

5.2 Surveys Conclusions

The PMS survey responses of the TRB low-volume roads committee, eight DOTs, local governments in Colorado, and CDOT MAC committee surveys were summarized. The findings provide transportation agencies nationwide with comprehensive guidelines for managing LVRs. They also provide feedback about the effectiveness of common treatment strategies applied on LVRs by different states at different management levels. The participants emphasized the need for some innovative techniques recommended for LVRs. The responses of the surveys lead to the following conclusions:

- LVRs have different traffic volume ranges among states. Transportation agencies are encouraged to consider appropriate traffic volumes and truck volumes for LVRs depending on the traffic volume distribution in their jurisdictions.
- Traffic, maintenance history, and structural data are important to collect when building a PMS database for low-volume paved roads. These kinds of data will help agencies identify treatments that have direct beneficial impact on the LVR network.
- Although traffic volumes can be determined using reasonable prediction models, it is more often recommended that actual traffic and truck volumes be collected.
- The most common structural data are collected at the network level using nondestructive techniques. The structural status of pavements is commonly represented using two practices. The first practice is by measuring the thicknesses of pavement layers using

Ground Penetrating Radar (GPR) and determining pavement material characteristics. The second practice is by evaluating the structural quality using FWD deflection tests.

- Pavement condition data should be collected at the network level. PCI, IRI, and rut depths are the most common condition data as measured indices, whereas PASER is the most common visual inspection survey.
- Data collection frequency can be reduced to optimize costs of data collection. The rate of pavement deterioration is low on LVRs and there is no need to collect the condition data annually.
- Decision trees are recommended to be used for selecting treatments. Trigger values of traffic volumes, road classification, maintenance history, and PCI values can be considered in the decision tree. Traffic volumes have the highest impact to select treatments on LVRs.
- Among treatment strategies implemented by agencies at different management levels, LVRs are commonly applied with specific maintenance strategies. The lack of adequate funding forces agencies not to consider all possible and recommended treatments on LVRs. The most common maintenance strategies on LVRs are surface treatments, such as: crack sealing, chip seals, and surface repairs. They are widely applied while overlays should not exceed a thickness of 1.5 inches.
- Local governments have their own objectives for LVRs and they do not usually follow state DOT’s maintenance policies. Chip seals are commonly applied on a frequency from 5 to 7 years. Overlays are applied when surgical repairs are needed; however, overlay application is very limited and is applied every 15 years or as funds are available.

- Although most agencies are avoiding applying expensive treatments on LVRs, they believe that low-cost treatments are not always effective based on their previous experience.
- Different kinds of treatments have common service lives when they are applied to LVRs. Surface treatments can extend the service life of pavements up to eight years while rehabilitation options have service lives more than 10 years.
- Although some agencies apply a thin overlay on severely damaged roads, it may not be an effective treatment. The surface minor treatments and light rehabilitations on poor roads are more likely to have only short-term effectiveness in enhancing the performance of pavements.
- Based on the previous experience of state agencies, pre-overlay treatments and targeted rehabilitations exhibit better performance of the overlaid pavement layers on LVRs. This strategy can cost-effectively extend the service life of overlays without having to apply another layer of asphalt pavement. However, full-length pavement rehabilitation is more recommended when severe roughness and rutting are extensively distributed on the LVR pavement surfaces.
- Optimization analysis is highly recommended for identifying MR&R strategies on low-volume paved roads. Maximizing remaining service lives within available budgets is the most important objective in optimization strategies.
- Five condition indices were considered in managing LVRs in Colorado when CDOT started evaluating the pavements in terms of DLs. The maintenance decisions are commonly taken based on Fatigue and Longitudinal indices. However, some maintenance

strategies are applied to increase the overall drivability life taking all conditions into consideration.

- The DL- based evaluation process provides higher estimates of pavement service lives. Therefore, treatment options focus more on surface treatments compared to structural enhancement recommended from RSL-based evaluation processes.
- Based on the experience of CDOT MAC members, The CDOT policy of low-cost treatments on LVRs provides short-term effectiveness on roads with low DL values. The funding constraints are the controlling factor for applying low-cost and surface treatments on deteriorated low-volume paved roads.

Chapter 6: Recommendations to Colorado DOT

Based on the findings of this report, it is highly recommended for CDOT to identify the specific needs and desired benefits from managing LVRs. All practices have different impacts depending on the expected outcome for both CDOT and road users. However, this report provides the following recommendations for consideration:

- For LVRs, the concept of limiting ADT to a value of 2000 vehicles per day and ADTT to a value of 100 vehicles per day is an appropriate consideration in Colorado due to the high amounts of traffic statewide.
- Since CDOT provides a unique process of evaluating the condition of pavements using drivability life metrics, roughness is an important criteria affecting driving conditions. As a result, smoothness should be more emphasized on low-volume pavement surfaces to increase the drivability life. That is, CDOT is recommended to include treatments that have significant effectiveness on road roughness.
- A practice for evaluating the structural quality of pavements should be defined on LVRs.
- It is recommended to lower the frequency of collecting condition data when costs of data collection affect CDOT's LVRs management budgets. There is no need to collect the pavement distresses and roughness data annually on LVRs. The condition indices can be determined every other year. The cost savings can be used to apply more treatments on LVRs.
- A maintenance decision tree is recommended to be developed for LVRs in Colorado. The treatment type should not be selected based on the overall drivability value. Instead, the decision should be based on the five condition indices.

- The maintenance of chip seals and ultra-thin overlays are expected to be cost-effective as long as the road is in good DL categories. When a LVR falls into poor drivability conditions, a combination of treatments within the available total lane-mile costs can be applied to add a structural value to the pavement. However, the potential impact of these combinations need to be investigated before application.
- Because of the limitation of applying low-cost treatments on LVRs in Colorado, innovative maintenance alternatives are recommended to be considered for severely deteriorated pavements.
- CDOT is advised to study the potential cost-effectiveness on the drivability conditions when applying some in-practice innovative surface treatments on LVRs. Light rehabilitation techniques using recycling technologies can be combined with surface treatments or sealing practices. For example, cold in-place recycling may enhance the performance of the applied ultra-thin overlays and extend the drivable life of poor LVRs.
- Other innovative treatments are also recommended to be evaluated on LVRs. Applying chip seals over paving fabrics has the potential to reduce reflective fatigue cracking in the newly applied overlays or chip seals. Another technique includes applying absorbing membranes such as fiber mat or rubberized asphalt binder. This technique increases the flexibility of pavement surfaces and enhances the ability to relieve stresses on the pavement layer. Some of these practices still need further investigation.
- Pre-overlay treatments are recommended to be applied on roads restricted by low funding amounts to enhance the effectiveness of inexpensive surface treatments. Also, targeted rehabilitation before applying overlays is recommended to be evaluated. This technique could increase the structural quality of the deteriorated spots and enhance the overall

performance of the applied overlays so that an overlay can last longer compared to the regular practice applied on LVRs.

- Further research is needed to document the cost-effectiveness of the proposed treatment options. CDOT is advised to compare between current and all future treatments proposed for LVRs using life-cycle cost analysis and not initial construction costs. However, the limited funding on LVRs may continue to restrict CDOT's maintenance decisions on LVRs.
- Maintenance strategies on the LVRs are recommended to be identified using optimization analysis. A state-wide optimization tool is recommended for LVRs to maximize the overall weighted drivability life given the budgets constraints. CDOT is also advised to develop multi-year maintenance plans to determine the requirements for capital improvement plans (CIP) for all treatments that are in place or recommended for LVRs.

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Appendix A-1: TRB Low-Volume Committee AFB30 Survey

General Information

* 1. Please enter your contact information:

Name:	
Title:	
Agency:	
Email Address:	
Phone Number:	

2. Low-volume paved roads can be defined as roads carrying an Average Daily Traffic (ADT):

- ◯ Less than 400 vehicles per day
- ◯ Less than 500 vehicles per day
- ◯ Less than 1000 vehicles per day
- ◯ Less than 1500 vehicles per day
- ◯ Less than 2000 vehicles per day
- ◯ Other (please specify)

3. Should truck traffic be considered when defining low-volume paved roads?

- ◯ Yes
- ◯ No

General Information

4. Low-volume paved roads can be defined as roads carrying an Average Daily Truck Traffic (ADTT):

- ◯ Less than 50 vehicles per day
- ◯ Less than 100 vehicles per day
- ◯ Less than 150 vehicles per day
- ◯ Less than 200 vehicles per day
- ◯ Other (please specify)

5. What kind of data should be collected when managing and maintaining low-volume paved roads?

- [ ] Road Classification
- [ ] Traffic
- [ ] Pavement Condition
- [ ] Maintenance History
- [ ] Structural Data
- [ ] Other (please specify)

Data collection: Inspection Survey

6. What traffic data should be obtained for managing and maintaining low-volume paved roads?

- [ ] Actual traffic volume data
- [ ] Predicted traffic volume data
- [ ] Truck Traffic
- [ ] Other (please specify)

Data collection: Inspection Survey

7. Which of the following structural data is useful for managing and maintaining low-volume paved roads?

- [ ] Pavement thicknesses
- [ ] Pavement material characteristics (such as soil classification and strength)
- [ ] FWD – Falling Weight Deflectometer data
- [ ] Other (please specify)

8. Which of the following indices should be used to summarize the condition of low-volume paved roads?

- [ ] PSI – Present Serviceability Index
- [ ] PCI – Pavement Condition Index
- [ ] IRI – International Roughness Index
- [ ] RUT – Rut depth
- [ ] DI – Distress Index
- [ ] OPI – Overall Pavement Index
- [ ] SR – Surface Rating
- [ ] PQI – Pavement Quality Index
- [ ] PSC – Pavement Structural Condition
- [ ] PQI – Pavement Quality Index
- [ ] PSR – Present Serviceability Rating
- [ ] CRS – Condition Rating Survey
- [ ] PASER – Pavement Surface Evaluation Rating
- [ ] Other (please specify)

Data collection: Inspection Survey

9. What is the optimum pavement condition data collection frequency for low-volume paved roads?

- ○ Every year
- ○ Every 2 years
- ○ Every 3 years
- ○ Every 4 years
- ○ Other (please specify)

10. Some agencies use decision trees to select pavement treatments for their low-volume paved roads. Do you think that developing a decision tree for selecting pavement treatments is beneficial?

- ◯ Yes
- ◯ No

Treatment Strategy

11. Which indices / data should be included in the decision tree to identify treatments for low-volume paved roads?

- ☐ Road Classification
- ☐ Pavement Age
- ☐ Average Daily Traffic (ADT)
- ☐ Average Daily Truck Traffic (ADTT)
- ☐ Maintenance History
- ☐ PSI – Present Serviceability Index
- ☐ PCI – Pavement Condition Index
- ☐ IRI – International Roughness Index
- ☐ RUT – Rut depth
- ☐ DI – Distress Index
- ☐ OPI – Overall Pavement Index
- ☐ SR – Surface Rating
- ☐ PQI – Pavement Quality Index
- ☐ PSC – Pavement Structural Condition
- ☐ PQI – Pavement Quality Index
- ☐ PSR – Present Serviceability Rating
- ☐ CRS – Condition Rating Survey
- ☐ PASER – Pavement Surface Evaluation Rating
- ☐ Other (please specify)

12. Based on your experience, what would be the expected service lives for the most widely used pavement treatments for low-volume paved roads?

	Less than 3 years	3 - 5 years	6 - 8 years	9 - 10 years	more than 10 years
Chip Seal	◯	◯	◯	◯	◯
Micro-surfacing	◯	◯	◯	◯	◯
Crack Seal	◯	◯	◯	◯	◯
Crack Fill	◯	◯	◯	◯	◯
Rut Fill	◯	◯	◯	◯	◯
Thin Overlay (1.5" or less)	◯	◯	◯	◯	◯
Medium Overlay (between 1.5" and 4")	◯	◯	◯	◯	◯
Thick Overlay (over 4")	◯	◯	◯	◯	◯
Full Pavement Reconstruction	◯	◯	◯	◯	◯

Other (please specify)

13. Based on your experience, what would be the effectiveness of pavement treatments used for severely damaged low-volume paved roads?

	Effective	Not effective
Chip Seal	◯	◯
Micro-surfacing	◯	◯
Crack Seal	◯	◯
Crack Fill	◯	◯
Rut Fill	◯	◯
Thin Overlay (1.5" or less)	◯	◯
Medium Overlay (between 1.5" and 4")	◯	◯
Thick Overlay (over 4")	◯	◯
Full Pavement Reconstruction	◯	◯

14. Are you aware of any new innovative techniques/treatments which might be effective when maintaining low-volume paved roads?

◯ Yes

◯ No

Treatment Strategy

15. Please identify these techniques.

Resources Optimization

16. Do you think that optimization techniques should be used when selecting treatments and managing low-volume paved roads?

◯ Yes

◯ No

Resources Optimization

17. Which parameters should be optimized?

- [ ] Maximizing PSI – Present Serviceability Index
- [ ] Maximizing PCI – Pavement Condition Index
- [ ] Minimizing IRI – International Roughness Index
- [ ] Minimizing RUT – Rut depth
- [ ] Optimizing Budgets
- [ ] Maximizing Remaining Service Life
- [ ] Other (please specify)

18. When optimizing budget expenditures, what is the approximate percentage of total budgets that should be allocated to each of the following segment condition levels?

Percentages must add up to 100%

	10%	20%	30%	40%	50%	60%	70%	80%
Worst segments	○	○	○	○	○	○	○	○
Rapidly deteriorating segments	○	○	○	○	○	○	○	○
Segments requiring routine maintenance	○	○	○	○	○	○	○	○

19. Would you like to get a copy of the results of the survey?

○ Yes

○ No

Appendix A-2: TRB Low-Volume Committee AFB30 Responses

Q1. Please enter your contact information:

Respondent #	Name:	Title:	Agency:	Email Address:	Phone Number:
1	James Honn	WY State Engineer	Bureau of Land Management	jhonn@blm.gov	+1 3077756233
2	Elaine Lopez	NMSO Engineer	Bureau of Land Management	elopez@blm.gov	+1 5057618904
3	Scott DeBock	Civil Engineer	BLM	sdebock@blm.gov	+1 4068965207
4	Brian Thauland	Transportation Program Support	BLM	bthaulan@blm.gov	+1 5038086598
5	Gordon Keller	Geotechnical Engineer	Genesee Geotechnical-Former USFS	gordon.r.keller@gmail.com	+1 5302846441
6	thomas wood	research project supervisor	mndot	thomas.wood@state.mn.us	+1 6513665573
7	Ed Johnson	research project engineer	MnDOT	eddie.johnson@state.mn.us	+1 6513665465
8	Richard Domonkos	Training Specialist	Indiana LTAP	rdomonko@purdue.edu	+1 7654944255
9	G. Randy Albert	Municipal Services Supervisor	PENNDOT	galbert@pa.gov	+1 8147650408
10	Robert Goo	Environmental Protection Specialist	US EPA	goo.robert@epa.gov	+1 2025661201
11	Donaldson MacLeod	CEO	DR MacLeod	maclark@xplornet.ca	+1 6135253597
12	Asif Faiz	Dr.	World Bank and Asian Dev. Bank.	afaiz29@gmail.com	+1 7039652545
13	Ali Hangul	Assistant Director	TDOT	ali.hangul@tn.gov	+1 6157410840
14	Gloria Burke	Field Engineer	MD State Highway Administration	gburke@sha.state.md.us	+1 4433869266
15	Chett Siefring	Senior Geotechnical Engineer	TTL Associates, Inc.	csiefring@ttlassoc.com	+1 4192145006
16	Bruce Drewes	Instructional Consultant	3T Gtoup	bdrewes@3tgroup.org	+1 2088675405
17	Jenny Liu	Professor	University of Alaska Fairbanks	jliu6@alaska.edu	+1 9074745764
18	Joe Ruffer	County Engineer/Public Works Director	Mobile County, Alabama	jruffer@mobilecounty.net	+1 2516055745
19	Mark Russell	Civil Engineer	USDA Forest Service	mlrussell@fs.fed.us	+1 9099297073
20	Michael Marti	Principal	SRF Consulting Group, Inc.	mmarti@srfconsulting.com	+1 6125548703
21	Mark Nahra	County Engineer	Woodbury County	mnahra@woodburycountyiowa.go v	+1 7128733215
22	Christopher Bennett	Lead Transport Specialist	The World Bank	cbennett2@worldbank.org	+64 35403404
23	Davd Orr	Director	Cornell Local Roads Program	david.orr@cornell.edu	+1 6072558033

Respondent #	Name:	Title:	Agency:	Email Address:	Phone Number:
24	robert vitale	ceo	midwest indsutrial supply inc	bob.vitale@midwestind.com	+1 3304563121
25	Paul Herbison	Director	WalknRoll International Ltd	paul@walknrollpackers.co.nz	+1 642908306
26	Alonso Ulate	Ing.	Lanamme Universidad de Costa Rica	alonso.ulate@ucr.ac.cr	+506 25114125
27	Neil Bennett	Road Asset Manager	Fulton Hogan	neil.bennett@fultonhogan.com	+64 274821268
28	Brandon Jutz	Regional Transportation Coordinator	US Fish and Wildlife Service	brandon_jutz@fws.gov	+1 6127135407
29	Jerry	Geib	MnDOT	jerry.geib@state.mn.us	+1 6514262738
30	Don Watson	Research Engineer	NCAT	watsode@auburn.edu	+1 3348447306
31	James Foster	Traffic Manager	Mobile County Engineer Office	jfoster@mobilecounty.net	+1 2514017641
32	Victoria Beale	Ohio LTAP Center Director	Ohio LTAP Center	victoria.beale@dot.ohio.gov	+1 6144663129
33	Uday Manepalli	Consultant	Private	udaymanepalli59@gmail.com	+1 5733089089
34	Ricky Mitchell	Deputy Public Work Director	Mobile County, Alabama	rmitchell@mobilecounty.net	+1 2515748595
35	Larry Galehouse	Director	National Center for Pavement Preservation	galehou3@egr.msu.edu	+1 5174328220
36	Steven Latoski	Director	Mohave County Public Works	steven.latoski@mohavecounty.us	+1 9287570910

Q2. Low-volume paved roads can be defined as roads carrying an Average Daily Traffic (ADT):

Answer Options	Response Count	Response Percent
Less than 400 vehicles per day	17	50%
Less than 500 vehicles per day	5	15%
Less than 1000 vehicles per day	5	15%
Less than 1500 vehicles per day	1	3%
Less than 2000 vehicles per day	5	15%
Other	1	3%
Answered question	34	94%
Skipped question	2	6%

Other Answers:

- Less than 5000 vehicles per day.

Q3. Should truck traffic be considered when defining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	31	89%
No	4	11%
Answered question	35	97%
Skipped question	1	3%

Q4. Low-volume paved roads can be defined as roads carrying an Average Daily Truck Traffic (ADTT):

Answer Options	Response Count	Response Percent
Less than 50 vehicles per day	15	54%
Less than 100 vehicles per day	6	21%
Less than 150 vehicles per day	2	7%
Less than 200 vehicles per day	4	14%
Other	1	4%
Answered question	28	78%
Skipped question	8	22%

Other Answers:

- Less than 10 vehicles per day.

Q5. What kind of data should be collected when managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Pavement Condition	32	100%
Traffic	30	94%
Maintenance History	30	94%
Structural Data	26	81%
Road Classification	24	75%
Other	10	31%
Answered question	32	89%
Skipped question	4	11%

Other Answers:

- Drainage condition evaluation
- Non-motorized and pedestrian traffic
- Accident history
- Establishment and right of way easement. In addition, Fee title information
- Land classification around highway
- Basic geometry (such as: length and width of roads)
- Accident-related infrastructure (such as: culverts, lighting, and guardrails)
- Cost of treatment options
- Age
- roadbed soil classification

Q6. What traffic data should be obtained for managing and maintaining low-volume paved roads?

Answer Options	**Response Count**	**Response Percent**
Actual traffic volume data	26	81%
Truck Traffic	23	72%
Predicted traffic volume data	13	41%
Other	4	13%
Answered question	32	89%
Skipped question	4	11%

Other Answers:

- Bridge Load Rating
- All-terrain vehicles (ATVs)
- Non-motorized transportation (NMT) and pedestrian
- Daily traffic calculated by 15-minute counts

Q.7 Which of the following structural data is useful for managing and maintaining low-volume paved roads?

Answer Options	**Response Count**	**Response Percent**
Pavement thicknesses	27	90%
Pavement material characteristics (such as soil classification and strength)	26	87%
FWD – Falling Weight Deflectometer data	13	43%
Other	4	13%
Answered question	30	83%
Skipped question	6	17%

Other Answers:

- Shoulder width (if any) for pavement edge stability.
- FWD needs to be seasonal and only useful on highways with larger amounts of truck traffic.

Q8. Which of the following indices should be used to summarize the condition of low-volume paved roads?

Answer Options	Response Count	Response Percent
PCI – Pavement Condition Index	16	57%
IRI – International Roughness Index	12	43%
PASER – Pavement Surface Evaluation Rating	11	39%
RUT – Rut depth	10	36%
CRS – Condition Rating Survey	9	32%
SR – Surface Rating	8	29%
PSC – Pavement Structural Condition	7	25%
PSI – Present Serviceability Index	6	21%
DI – Distress Index	6	21%
PQI – Pavement Quality Index	7	25%
OPI – Overall Pavement Index	4	14%
PSR – Present Serviceability Rating	3	11%
Other	5	18%
Answered question	28	78%
Skipped question	8	22%

Other Answers:

- Ride Quality Index (RQI)

Q9. What is the optimum pavement condition data collection frequency for low-volume paved roads?

Answer Options	Response Count	Response Percent
Every year	8	29%
Every 2 years	7	25%
Every 3 years	5	18%
Every 4 years	5	18%
Other	3	11%
Answered question	28	78%
Skipped question	8	22%

Other Answers:

- Every five years

- In Costa Rica, data is collected every five years for low-volume paved roads.

Q10. Some agencies use decision trees to select pavement treatments for their low-volume paved roads. Do you think that developing a decision tree for selecting pavement treatments is beneficial?

Answer Options	Response Count	Response Percent
Yes	23	82%
No	5	18%
Answered question	28	78%
Skipped question	8	22%

Q11. Which indices / data should be included in the decision tree to identify treatments for low-volume paved roads?

Answer Options	Response Count	Response Percent
Average Daily Traffic (ADT)	19	86%
Road Classification	17	77%
Average Daily Truck Traffic (ADTT)	15	68%
Pavement Age	13	59%
Maintenance History	13	59%
PCI – Pavement Condition Index	11	50%
IRI – International Roughness Index	7	32%
PASER – Pavement Surface Evaluation Rating	7	32%
RUT – Rut depth	6	27%
CRS – Condition Rating Survey	5	23%
PQI – Pavement Quality Index	4	18%
PSI – Present Serviceability Index	3	14%
DI – Distress Index	3	14%
SR – Surface Rating	3	14%
PSC – Pavement Structural Condition	2	9%
PSR – Present Serviceability Rating	2	9%
OPI – Overall Pavement Index	0	0%
Other	1	5%
Answered question	22	61%
Skipped question	14	39%

Q12. Based on your experience, what would be the expected service lives for the most widely used pavement treatments for low-volume paved roads?

Answer Options	Response Percent						Response Count
	Less than 3 years	3 - 5 years	6 - 8 years	9 - 10 years	more than 10 years	No Response	
Chip Seal	19%	30%	26%	19%	7%	0%	27
Micro-surfacing	15%	19%	41%	7%	7%	11%	24
Crack Seal	48%	30%	11%	4%	0%	7%	25
Crack Fill	44%	37%	11%	0%	0%	7%	25
Rut Fill	22%	48%	15%	4%	0%	11%	24
Thin Overlay (1.5” or less)	11%	19%	30%	26%	7%	7%	25
Medium Overlay (between 1.5" and 4”)	4%	7%	19%	30%	33%	7%	25
Thick Overlay (over 4”)	0%	4%	4%	26%	59%	7%	25
Full Pavement Reconstruction	0%	0%	4%	4%	93%	0%	27
Other (please specify)							3
Answered question							27
Skipped question							9

Other Answers:

- It depends on traffic loads and climate.
- All of these vary greatly for various traffic, material, and drainage conditions. The values marked are for typical LVR (moderate drainage, thin surface, marginal quality).

Q13. Based on your experience, what would be the effectiveness of pavement treatments used for severely damaged low-volume paved roads?

Answer Options	Response Percent			Response Count
	Effective	Not effective	No Response	
Chip Seal	19%	81%	0%	26
Micro-surfacing	8%	85%	8%	24
Crack Seal	12%	81%	8%	24
Crack Fill	15%	77%	8%	24
Rut Fill	15%	77%	8%	24
Thin Overlay (1.5" or less)	35%	50%	15%	22
Medium Overlay (between 1.5" and 4")	54%	38%	8%	24
Thick Overlay (over 4")	62%	23%	15%	22
Full Pavement Reconstruction	92%	4%	4%	25
Answered question				26
Skipped question				10

Q14. Are you aware of any new innovative techniques/treatments which might be effective when maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	10	38%
No	16	62%
Answered question	26	72%
Skipped question	10	28%

Q15. Please identify these techniques.

Answers:

- TX-underseal prior to overlay
- Cold in-place recycling with asphalt rejuvenator; Hot in-place recycling

- Fiber Mat
- Otta seals, slurry/sand seals; Cold recycling pavers; Geocells; Roller compacted concrete; PCC slabs
- Paving fabric with Chip Seal; Polymer modified or engineered emulsions/binders; Cold in-place recycling; Foamed asphalt stabilized base
- Cement recycled asphalt base
- Recycling; Cape seal; Cold mix with a hot mix overlay, Fabrics, Spot improvements
- Ultra-thin bonded wearing course; Thin overlay with modified asphalt binder
- Chip seal based Stress Absorbing Membrane treatments (e.g., rubberized asphalt binder, Fiber Mat)

Q16. Do you think that optimization techniques should be used when selecting treatments and managing low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	22	85%
No	4	15%
Answered question	26	72%
Skipped question	10	28%

Q17. Which parameters should be optimized?

Answer Options	Response Count	Response Percent
Maximizing Remaining Service Life	18	82%
Optimizing Budgets	14	64%
Maximizing PCI – Pavement Condition Index	8	36%
Minimizing RUT – Rut depth	4	18%
Maximizing PSI – Present Serviceability Index	3	14%
Minimizing IRI – International Roughness Index	2	9%
Other	0	0%
Answered question	22	61%
Skipped question	14	39%

Q18. When optimizing budget expenditures, what is the approximate percentage of total budgets that should be allocated to each of the following segment condition levels? “Percentages must add up to 100%”

Answer Options	0%	10%	20%	30%	40%	50%	60%	70%	80%	Response Count	Weighted Average
Worst segments	1	3	5	3	3	6	0	0	0	21	31%
Rapidly deteriorating segments	0	1	1	14	2	2	0	1	0	21	34%
Segments requiring routine maintenance	0	1	9	3	1	3	2	1	1	21	35%
Answered question										21	
Skipped question										15	

Appendix B-1: Regional Departments of Transportation Survey

Regional Survey of Low-Volume Paved Roads

General Information

2. Low-volume paved roads are defined as roads carrying an Average Daily Traffic (ADT):

- ◯ Less than 400 vehicles per day
- ◯ Less than 500 vehicles per day
- ◯ Less than 1000 vehicles per day
- ◯ Less than 1500 vehicles per day
- ◯ Less than 2000 vehicles per day
- ◯ Other (please specify)

3. Should truck traffic be considered when defining low-volume paved roads?

- ◯ Yes
- ◯ No

4. Low-volume paved roads can be defined as roads carrying an Average Daily Truck Traffic (ADTT):

- ◯ Less than 50 vehicles per day
- ◯ Less than 100 vehicles per day
- ◯ Less than 150 vehicles per day
- ◯ Less than 200 vehicles per day
- ◯ Other (please specify)

Regional Survey of Low-Volume Paved Roads

General Information

5. How many miles of low-volume paved roads are in your state?

- More than 250 miles
- 200 – 250 miles
- 150 – 199 miles
- 100 – 149 miles
- 50 – 99 miles
- 10 – 49 miles
- Less than 10 miles

6. What is the approximate annual funding level to maintain low-volume paved roads in your state?

- Less than $5,000,000
- $5,000,000 - $9,999,999
- $10,000,000 - $19,999,999
- $20,000,000 - $29,999,999
- $30,000,000 - $39,999,999
- $40,000,000 - $49,999,999
- $50,000,000 - $74,999,999
- $75,000,000 - $100,000,000
- More than $100,000,000

Regional Survey of Low-Volume Paved Roads

Data collection: Inspection Survey

7. Do you consider traffic data when managing and maintaining low-volume paved roads?

- ◯ Yes
- ◯ No

8. What traffic data is obtained for managing and maintaining low-volume paved roads?

- ☐ Actual traffic volume data
- ☐ Predicted traffic volume data
- ☐ Truck Traffic
- ☐ Other (please specify)

9. Do you consider any structural data when managing and maintaining low-volume paved roads?

- ◯ Yes
- ◯ No

10. Which of the following structural data is useful for managing and maintaining low-volume paved roads?

- ☐ Pavement thicknesses
- ☐ Pavement material characteristics (such as soil classification and strength)
- ☐ FWD – Falling Weight Deflectometer data
- ☐ Other (please specify)

Regional Survey of Low-Volume Paved Roads

Data collection: Inspection Survey

11. Do you collect any pavement condition data on low-volume paved roads?

- ○ Yes
- ○ No

12. How do you collect the pavement condition data of low-volume paved roads in your region?

- ◯ Manual data collection system
- ◯ Automated data collection system
- ◯ Manual and automated data collection systems
- ◯ Other (please specify)

13. How frequently is pavement condition data collected?

- ◯ Every year
- ◯ Every 2 years
- ◯ Every 3 years
- ◯ Every 4 years
- ◯ Other (please specify)

Regional Survey of Low-Volume Paved Roads

Data collection: Inspection Survey

14. Which of the following indices are used to summarize low-volume pavement conditions? Check all that apply

- ☐ PSI – Present Serviceability Index
- ☐ PCI – Pavement Condition Index
- ☐ IRI – International Roughness Index
- ☐ RUT – Rut depth
- ☐ DI – Distress Index
- ☐ OPI – Overall Pavement Index
- ☐ SR – Surface Rating
- ☐ PQI – Pavement Quality Index
- ☐ PSC – Pavement Structural Condition
- ☐ PSR – Present Serviceability Rating
- ☐ CRS – Condition Rating Survey
- ☐ PASER – Pavement Surface Evaluation Rating

Regional Survey of Low-Volume Paved Roads

Treatment Strategy

15. Do you use a specific pavement maintenance policy or guidelines for maintaining low-volume paved roads?

- ◯ No
- ◯ Yes (Please highlight the most important item in your policy)

16. Some agencies don't allow applying expensive treatments on their low-volume paved roads. Do you have similar policy when maintaining low-volume paved roads?

- ◯ Yes
- ◯ No

17. Do you think that eliminating expensive treatments provides cost-effective strategies for maintaining low-volume paved roads?

- ◯ Yes
- ◯ No

Regional Survey of Low-Volume Paved Roads

Treatment Strategy

18. What are treatments allowed for maintaining low-volume paved roads? Check all that apply.

- [ ] Chip Seal
- [ ] Micro-surfacing
- [ ] Crack Seal
- [ ] Crack Fill
- [ ] Rut Fill
- [ ] Thin Overlay (1.5” or less)
- [ ] Medium Overlay (between 1.5" and 4”)
- [ ] Thick Overlay (over 4”)
- [ ] Full Pavement Reconstruction
- [ ] Other (please specify)

19. Do you recommend or routinely perform targeted rehabilitation of severely distressed areas within low-volume paved roads prior to application of surface treatments?

- ○ Yes
- ○ No

20. How do you determine when full length rehabilitation becomes necessary?

Regional Survey of Low-Volume Paved Roads

Treatment Strategy

21. Identify the expected service lives for the most widely used pavement treatments for low-volume paved roads.

	Less than 3 years	3 - 5 years	6 - 8 years	9 - 10 years	more than 10 years	Don't know / Don't use
Chip Seal	○	○	○	○	○	○
Micro-surfacing	○	○	○	○	○	○
Crack Seal	○	○	○	○	○	○
Crack Fill	○	○	○	○	○	○
Rut Fill	○	○	○	○	○	○
Thin Overlay (1.5" or less)	○	○	○	○	○	○
Medium Overlay (between 1.5" and 4")	○	○	○	○	○	○
Thick Overlay (over 4")	○	○	○	○	○	○
Full Pavement Reconstruction	○	○	○	○	○	○

Other (please specify)

Regional Survey of Low-Volume Paved Roads

Treatment Strategy

22. Identify the effectiveness of each pavement treatment when placed directly on severely distressed surfaces within low-volume paved roads.

	Effective	Not effective	Don't know / Don't use
Chip Seal	○	○	○
Micro-surfacing	○	○	○
Crack Seal	○	○	○
Crack Fill	○	○	○
Rut Fill	○	○	○
Thin Overlay (1.5" or less)	○	○	○
Medium Overlay (between 1.5" and 4")	○	○	○
Thick Overlay (over 4")	○	○	○
Full Pavement Reconstruction	○	○	○

23. Are you aware of any new innovative techniques/treatments which might be effective when maintaining low-volume paved roads?

○ No

○ Yes (please specify)

Regional Survey of Low-Volume Paved Roads

Resources Optimization

24. Do you think that optimization techniques should be used when selecting treatments and managing low-volume paved roads?

- ◯ Yes
- ◯ No

25. Which parameters should be optimized?

- ☐ Maximizing PSI – Present Serviceability Index
- ☐ Maximizing PCI – Pavement Condition Index
- ☐ Minimizing IRI – International Roughness Index
- ☐ Minimizing RUT – Rut depth
- ☐ Optimizing Budgets
- ☐ Maximizing Remaining Service Life
- ☐ Other (please specify)

26. When optimizing budget expenditures, what is the approximate percentage of total budgets that should be allocated to each of the following segment condition levels?

Percentages must add up to 100%

	10%	20%	30%	40%	50%	60%	70%	80%
Worst segments	◯	◯	◯	◯	◯	◯	◯	◯
Rapidly deteriorating segments	◯	◯	◯	◯	◯	◯	◯	◯
Segments requiring routine maintenance	◯	◯	◯	◯	◯	◯	◯	◯

Appendix B-2: Regional Departments of Transportation Responses

Q1. Please enter your contact information:

Respondent #	Name	Title:	Agency	Email Address:	Phone Number:
1	Michael Vigil	Maintenance Operations Engineer	NMDOT	mike.vigil@stat.nm.us	+1 5058275393
2	Kevin Robertson	Surface Treatment Engineer	AZDOT	krobertson2@azdot.gov	+1 6027123131
3	Rick Miller	Pavement Management Engineer	KSDOT	rick@ksdot.org	+1 7852913842
4	Magdy Mikhail	Director Pavements Branch	TXDOT	Magdy.Mikhail@txdot.gov	+1 5128327210
5	Scott Andrus	Utah DOT State Materials Engineer	UDOT	scottandrus@utah.gov	+1 8019654859
6	Matt Beran	Assistant Flexible Pavements Engineer	NEDOT	matt.beran@nebraska.gov	+1 4024794663
7	Mike Farrar	Pavement Management Engineer	WYDOT	michael.farrar@wyo.gov	+1 3077774075
8	Jim Davies	Pavement Analysis Engineer	MTDOT	jdavies@mt.gov	+1 4064443424
9	Gary Kuhl	Pavement Management Engineer - UDOT	UDOT	gkuhl@utah.gov	+1 8019644552

Q2. Low-volume paved roads are defined by your agency as roads carrying an Average Daily Traffic (ADT):

Answer Options	Response Count	Response Percent
Less than 400 vehicles per day	4	44%
Less than 500 vehicles per day	2	22%
Less than 1000 vehicles per day	2	22%
Other	1	11%
Answered question	9	100%
Skipped question	0	0%

Other Answers:

- Less than 5000 vehicles per day.

Q3. Should truck traffic be considered when defining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	7	78%
No	2	22%
Answered question	9	100%
Skipped question	0	0%

Q4. Low-volume paved roads can be defined as roads carrying an Average Daily Truck Traffic (ADTT):

Answer Options	Response Count	Response Percent
Less than 50 vehicles per day	3	43%
Less than 100 vehicles per day	1	14%
Less than 200 vehicles per day	3	43%
Answered question	7	78%
Skipped question	2	22%

Q5. How many miles of low-volume paved roads are in your state?

Answer Options	Response Count	Response Percent
More than 250 miles	8	100%
200 – 250 miles	0	0%
150 – 199 miles	0	0%
100 – 149 miles	0	0%
50 – 99 miles	0	0%
10 – 49 miles	0	0%
Less than 10 miles	0	0%
Answered question	8	89%
Skipped question	1	11%

Q6. What is the approximate annual funding level to maintain low-volume paved roads in your state?

Answer Options	Response Count	Response Percent
Less than $5,000,000	2	40%
$5,000,000 - $9,999,999	2	40%
$10,000,000 - $19,999,999	0	0%
$20,000,000 - $29,999,999	0	0%
$30,000,000 - $39,999,999	0	0%
$40,000,000 - $49,999,999	1	20%
$50,000,000 - $74,999,999	0	0%
$75,000,000 - $100,000,000	0	0%
More than $100,000,000	0	0%
Answered question	5	56%
Skipped question	4	44%

Q7. Do you consider traffic data when managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	6	67%
No	3	33%
Answered question	9	100%
Skipped question	0	0%

Q8. What traffic data is obtained for managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Actual traffic volume data	5	83%
Predicted traffic volume data	4	67%
Truck Traffic	6	100%
Other	0	0%
Answered question	6	67%
Skipped question	3	33%

Q9. Do you consider any structural data when managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	6	67%
No	3	33%
Answered question	9	100%
Skipped question	0	0%

Q10. Which of the following structural data is useful for managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Pavement thicknesses	5	83%
Pavement material characteristics	5	83%
FWD – Falling Weight Deflectometer data	5	83%
Other	0	0%
Answered question	6	67%
Skipped question	3	33%

Q11. Do you collect any pavement condition data on low-volume paved roads managed by your agency?

Answer Options	Response Count	Response Percent
Yes	9	100%
No	0	0%
Answered question	9	100%
Skipped question	0	0%

Q12. How do you collect the pavement condition data of low-volume paved roads in your county?

Answer Options	Response Count	Response Percent
Manual and automated data collection systems	4	44%
Manual data collection system	0	0%
Automated data collection system	5	56%
Other	0	0%
Answered question	9	100%
Skipped question	0	0%

Q13. How frequently is pavement condition data collected?

Answer Options	Response Count	Response Percent
Every year	4	44%
Every 2 years	4	44%
Every 3 years	0	0%
Every 4 years	0	0%
Other	1	11%
Answered question	9	100%
Skipped question	0	0%

Other Answers:

- Every 5 years network level.

Q14. Which of the following indices are used to summarize low-volume pavement conditions?

Answer Options	Response Count	Response Percent
IRI – International Roughness Index	8	89%
RUT – Rut depth	7	78%
DI – Distress Index	5	56%
PSI – Present Serviceability Index	4	44%
OPI – Overall Pavement Index	3	33%
PCI – Pavement Condition Index	2	22%
SR – Surface Rating	1	11%
PSR – Present Serviceability Rating	1	11%
CRS – Condition Rating Survey	1	11%
PASER – Pavement Surface Evaluation Rating	0	0%
PSC – Pavement Structural Condition	0	0%
PQI – Pavement Quality Index	0	0%
Answered question	9	100%
Skipped question	0	0%

Q15. Do you use a specific pavement maintenance policy or guidelines for maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	4	44%
No	5	56%
Answered question	9	100%
Skipped question	0	0%

Please highlight the most important item in your policy:

- The policy depends on the road classification. There is no traffic volume-based treatment policies.
- Due to the funding we are not able to follow our pavement program completely on low volume roads. Surface treatments is most important item in our pavement management for these roads.

- We use collected and processed pavement data to determine appropriate treatments at appropriate times.
- It's in the process of being changed since we received additional funding for maintaining our low volume roads, but we had limited the work to what our state forces could do - crack seals, chip seals & repairs.

Q16. Some agencies don't allow applying expensive treatments on their low-volume paved roads. Do you have similar policy when maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	1	11%
No	8	89%
Answered question	9	100%
Skipped question	0	0%

Q17. Do you think that eliminating expensive treatments provides cost-effective strategies for maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	3	33%
No	6	67%
Answered question	9	100%
Skipped question	0	0%

Q18. What are treatments allowed for maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Chip Seal	9	100%
Crack Seal	9	100%
Crack Fill	6	67%
Thin Overlay (1.5" or less)	6	67%
Rut Fill	6	67%
Medium Overlay (between 1.5" and 4")	5	56%
Micro-surfacing	5	56%
Full Pavement Reconstruction	4	44%
Thick Overlay (over 4")	1	11%
Other	2	22%
Answered question	9	100%
Skipped question	0	0%

Other Answers:

- HIR
- We'll start doing some surface recycling & thin overlays, but I expect that they'll still be a chip sealed surface.

Q19. Do you recommend or routinely perform targeted rehabilitation of severely distressed areas within low-volume paved roads prior to application of surface treatments?

Answer Options	Response Count	Response Percent
Yes	8	89%
No	1	11%
Answered question	9	100%
Skipped question	0	0%

Q20. How do you determine when full length rehabilitation becomes necessary?

Answers:

- Pavement Distress

- IRI and Condition Surveys
- When distress requires and budget is available.
- We review annual maintenance cost, and when the maintenance strategy will have a short service life.
- A combination of factors such as PCI, RUT, ADT, AADT, PSR, etc.
- We determine that from our ride, rut and cracking data in addition to the District's input.
- It starts with a high IRI & then it gets investigated.

Q21. Identify the expected service lives for the most widely used pavement treatments for low-volume paved roads.

Answer Options	Response Percent						Response Count
	Less than 3 years	3 - 5 years	6 - 8 years	9 - 10 years	more than 10 years	Don’t Know/Don’t Use	
Chip Seal	0%	33%	44%	22%	0%	0%	9
Micro-surfacing	0%	0%	44%	22%	0%	33%	9
Crack Seal	11%	78%	11%	0%	0%	0%	9
Crack Fill	22%	33%	11%	0%	0%	33%	9
Rut Fill	0%	33%	22%	11%	0%	33%	9
Thin Overlay (1.5” or less)	0%	11%	22%	22%	0%	44%	9
Medium Overlay (between 1.5" and 4”)	0%	0%	0%	44%	22%	33%	9
Thick Overlay (over 4”)	0%	0%	0%	0%	56%	44%	9
Full Pavement Reconstruction	0%	0%	0%	0%	78%	22%	9
Other (please specify)							0
Answered question							9
Skipped question							0

Q22. Identify the effectiveness of each pavement treatment when placed directly on severely distressed surfaces within low-volume paved roads.

Answer Options	Response Percent			Response Count
	Effective	Not effective	Don't Know/Don't Use	
Chip Seal	25%	63%	13%	8
Micro-surfacing	13%	63%	25%	8
Crack Seal	50%	38%	13%	8
Crack Fill	13%	50%	38%	8
Rut Fill	38%	38%	25%	8
Thin Overlay (1.5" or less)	13%	50%	38%	8
Medium Overlay (between 1.5" and 4")	38%	50%	13%	8
Thick Overlay (over 4")	63%	13%	25%	8
Full Pavement Reconstruction	88%	0%	13%	8
Answered question				8
Skipped question				1

Q23. Are you aware of any new innovative techniques/treatments which might be effective when maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes (Please Specify)	4	44%
No	5	56%
Answered question	9	100%
Skipped question	0	0%

Answers:

- Thin Bonded Overlays (TBO's)
- Cold and Hot in place recycle, fibers, hi-polymer binders
- Scrub seals cold in place recycling
- We're looking into how well they Kevlar type fibers perform in the thin overlays

Q24. Do you think that optimization techniques should be used when selecting treatments and managing low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	9	100%
No	0	0%
Answered question	9	100%
Skipped question	0	0%

Q25. Which parameters should be optimized?

Answer Options	Response Count	Response Percent
Optimizing Budgets	7	78%
Maximizing Remaining Service Life	7	78%
Minimizing IRI – International Roughness Index	6	67%
Minimizing RUT – Rut depth	5	56%
Maximizing PSI – Present Serviceability Index	4	44%
Maximizing PCI – Pavement Condition Index	2	22%
Other	1	11%
Answered question	9	100%
Skipped question	0	0%

Other Answers:

- Our deterioration model optimizes a combined condition index, using ride, rutting, environmental & fatigue cracking indexes.

Q26. When optimizing budget expenditures, what is the approximate percentage of total budgets that should be allocated to each of the following segment condition levels?

Answer Options	0%	10%	20%	30%	40%	50%	60%	70%	80%	Response Count	Weighted Average
Worst segments	0	1	1	3	1	0	0	0	0	6	27%
Rapidly deteriorating segments	0	0	1	1	1	3	0	0	0	6	40%
Segments requiring routine maintenance	0	0	3	0	1	2	0	0	0	6	33%
Answered question										6	
Skipped question										3	

Appendix C-1: Colorado Local Governments Survey

Low-Volume Paved Roads Survey for Local Governments in Colorado

General Information

* 1. Please identify your position:

* 2. Please enter your contact information:

Name:

Title:

Agency:

Email Address:

Phone Number:

Low-Volume Paved Roads Survey for Local Governments in Colorado

General Information

3. Low-volume paved roads are defined by your agency as roads carrying an Average Daily Traffic (ADT):

- ◯ Less than 400 vehicles per day
- ◯ Less than 500 vehicles per day
- ◯ Less than 1000 vehicles per day
- ◯ Less than 1500 vehicles per day
- ◯ Less than 2000 vehicles per day
- ◯ Other (please specify)

4. Should truck traffic be considered when defining low-volume paved roads?

- ◯ Yes
- ◯ No

Low-Volume Paved Roads Survey for Local Governments in Colorado

General Information

5. Low-volume paved roads can be defined as roads carrying an Average Daily Truck Traffic (ADTT):

- ◯ Less than 50 vehicles per day
- ◯ Less than 100 vehicles per day
- ◯ Less than 150 vehicles per day
- ◯ Less than 200 vehicles per day
- ◯ Other (please specify)

Low-Volume Paved Roads Survey for Local Governments in Colorado

General Information

6. What is approximate total length in miles of low-volume paved roadways owned and maintained by your agency?

- ◯ More than 250 miles
- ◯ 200 – 250 miles
- ◯ 150 – 199 miles
- ◯ 100 – 149 miles
- ◯ 50 – 99 miles
- ◯ 10 – 49 miles
- ◯ Less than 10 miles

7. What is your agency's approximate annual funding level to maintain low-volume paved roads?

- ◯ Less than $500,000
- ◯ $500,000 - $999,999
- ◯ $1,000,000 - $1,999,999
- ◯ $2,000,000 - $3,000,000
- ◯ More than $3,000,000

Low-Volume Paved Roads Survey for Local Governments in Colorado

Data collection: Inspection Survey

8. Do you consider traffic data when managing and maintaining low-volume paved roads?

- ◯ Yes
- ◯ No

Low-Volume Paved Roads Survey for Local Governments in Colorado

Data collection: Inspection Survey

9. What traffic data is obtained for managing and maintaining low-volume paved roads?

- [ ] Actual traffic volume data
- [ ] Predicted traffic volume data
- [ ] Truck Traffic
- [ ] Other (please specify)

Low-Volume Paved Roads Survey for Local Governments in Colorado

Data collection: Inspection Survey

10. Do you consider any structural data when managing and maintaining low-volume paved roads?

- ○ Yes
- ○ No

Low-Volume Paved Roads Survey for Local Governments in Colorado

Data collection: Inspection Survey

11. Which of the following structural data is useful for managing and maintaining low-volume paved roads?

- ☐ Pavement thicknesses
- ☐ Pavement material characteristics (such as soil classification and strength)
- ☐ FWD – Falling Weight Deflectometer data
- ☐ Other (please specify)

Low-Volume Paved Roads Survey for Local Governments in Colorado

Data collection: Inspection Survey

12. Do you collect any pavement condition data on low-volume paved roads managed by your agency?

- ◯ Yes
- ◯ No

13. Do you follow any CDOT procedures when collecting pavement condition data of low-volume paved roads?

- ◯ Yes
- ◯ No

14. Please specify this procedure.

Low-Volume Paved Roads Survey for Local Governments in Colorado

Data collection: Inspection Survey

15. How do you collect the pavement condition data of low-volume paved roads in your county?

- ◯ Manual data collection system
- ◯ Automated data collection system
- ◯ Manual and automated data collection systems
- ◯ Other (please specify)

16. How frequently is pavement condition data collected?

- ◯ Every year
- ◯ Every 2 years
- ◯ Every 3 years
- ◯ Every 4 years
- ◯ Other (please specify)

Low-Volume Paved Roads Survey for Local Governments in Colorado

Data collection: Inspection Survey

17. Which of the following indices are used by your agency to summarize low-volume pavement conditions? Check all that apply

- ☐ PSI – Present Serviceability Index
- ☐ PCI – Pavement Condition Index
- ☐ IRI – International Roughness Index
- ☐ RUT – Rut depth
- ☐ DI – Distress Index
- ☐ OPI – Overall Pavement Index
- ☐ SR – Surface Rating
- ☐ PQI – Pavement Quality Index
- ☐ PSC – Pavement Structural Condition
- ☐ PQI – Pavement Quality Index
- ☐ PSR – Present Serviceability Rating
- ☐ CRS – Condition Rating Survey
- ☐ PASER – Pavement Surface Evaluation Rating

Low-Volume Paved Roads Survey for Local Governments in Colorado

Treatment Strategy

18. Do you use a specific pavement maintenance policy or guidelines for maintaining low-volume paved roads?

- ◯ No
- ◯ Yes (Please highlight the most important item in your policy)

Low-Volume Paved Roads Survey for Local Governments in Colorado

Treatment Strategy

19. Some agencies such as CDOT don't allow applying expensive treatments on their low-volume paved roads. Do you have similar policy when maintaining low-volume paved roads?

- ◯ Yes
- ◯ No

20. Do you think that eliminating expensive treatments provides cost-effective strategies for maintaining low-volume paved roads?

- ◯ Yes
- ◯ No

Low-Volume Paved Roads Survey for Local Governments in Colorado

Treatment Strategy

21. What are treatments allowed by your agencies for maintaining low-volume paved roads? Check all that apply.

- ☐ Chip Seal
- ☐ Micro-surfacing
- ☐ Crack Seal
- ☐ Crack Fill
- ☐ Rut Fill
- ☐ Thin Overlay (1.5” or less)
- ☐ Medium Overlay (between 1.5" and 4”)
- ☐ Thick Overlay (over 4”)
- ☐ Full Pavement Reconstruction
- ☐ Other (please specify)

22. Do you recommend or routinely perform targeted rehabilitation of severely distressed areas within low-volume paved roads prior to application of surface treatments?

- ○ Yes
- ○ No

23. How do you determine when full length rehabilitation becomes necessary?

Low-Volume Paved Roads Survey for Local Governments in Colorado

Treatment Strategy

24. Identify the expected service lives for the most widely used pavement treatments for low-volume paved roads by your agency.

	Less than 3 years	3 - 5 years	6 - 8 years	9 - 10 years	more than 10 years	Don't know / Don't use
Chip Seal	◯	◯	◯	◯	◯	◯
Micro-surfacing	◯	◯	◯	◯	◯	◯
Crack Seal	◯	◯	◯	◯	◯	◯
Crack Fill	◯	◯	◯	◯	◯	◯
Rut Fill	◯	◯	◯	◯	◯	◯
Thin Overlay (1.5” or less)	◯	◯	◯	◯	◯	◯
Medium Overlay (between 1.5" and 4”)	◯	◯	◯	◯	◯	◯
Thick Overlay (over 4”)	◯	◯	◯	◯	◯	◯
Full Pavement Reconstruction	◯	◯	◯	◯	◯	◯

Other (please specify)

Low-Volume Paved Roads Survey for Local Governments in Colorado

Treatment Strategy

25. Identify the effectiveness of each pavement treatment used by your agency for <u>severely distressed</u> surfaces within low-volume paved roads.

	Effective	Not effective	Don't know / Don't use
Chip Seal	○	○	○
Micro-surfacing	○	○	○
Crack Seal	○	○	○
Crack Fill	○	○	○
Rut Fill	○	○	○
Thin Overlay (1.5" or less)	○	○	○
Medium Overlay (between 1.5" and 4")	○	○	○
Thick Overlay (over 4")	○	○	○
Full Pavement Reconstruction	○	○	○

26. Has your agency implemented any new pavement treatments not listed above for low-volume paved roads?

○ Yes

○ No

27. Please identify these treatments.

Low-Volume Paved Roads Survey for Local Governments in Colorado

Treatment Strategy

28. Are you aware of any new innovative techniques/treatments which might be effective when maintaining low-volume paved roads?

- ○ No
- ○ Yes (please specify)

29. Do you think that optimization techniques should be used when selecting treatments and managing low-volume paved roads?

- ○ Yes
- ○ No

Low-Volume Paved Roads Survey for Local Governments in Colorado

Resources Optimization

30. Which parameters should be optimized?

- [ ] Maximizing PSI – Present Serviceability Index
- [ ] Maximizing PCI – Pavement Condition Index
- [ ] Minimizing IRI – International Roughness Index
- [ ] Minimizing RUT – Rut depth
- [ ] Optimizing Budgets
- [ ] Maximizing Remaining Service Life
- [ ] Other (please specify)

31. When optimizing budget expenditures, what is the approximate percentage of total budgets that should be allocated to each of the following segment condition levels?

Percentages must add up to 100%

	10%	20%	30%	40%	50%	60%	70%	80%
Worst segments	○	○	○	○	○	○	○	○
Rapidly deteriorating segments	○	○	○	○	○	○	○	○
Segments requiring routine maintenance	○	○	○	○	○	○	○	○

Low-Volume Paved Roads Survey for Local Governments in Colorado

32. Would you like to get a copy of the results of the survey?

- Yes
- No

If you have any questions about this survey, please contact:

Dr. Khaled Ksaibati
Director, Wyoming Technology Transfer Center
Professor of Civil Engineering
University of Wyoming
e-mail:khaled@uwyo.edu
Office Phone: (307) 766-6230
Fax Number: (307) 766-6784

To submit please hit the "Done" button. You will not be able to edit your responses once submitted.

Thank you for your participation.

Appendix C-2: Colorado Local Governments Responses

Q1. Please enter your contact information:

Respondent #	Name	Title:	Position:	Agency	Email Address:	Phone Number:
1	Bill Clark	Assistant Superintendent	County	Grand County	bclark@co.grand.co.us	+1 9705310633
2	Todd Juergens	Road and Bridge Director	County	Larimer County	tjuergens@larimer.org	+1 9704985653
3	Rod Meredith	Director	County	Public Works Operations	rmeredith@douglas.co.us	+1 3036607480
4	Linda G. DeRose	Manager	County	Moffat County Road & Bridge	lderose@moffatcounty.net	+1 9708243211
5	richard smith	engineer	Other	raymond smith and associates	richard.smith3@yahoo.com	+1 3036465492
6	Darren Garcia	Road & Bridge coordinator	County	Otero County	dgarcia@oterogov.org	+1 7193833092
7	Maria D'Andrea	Director of Public Works	City	City of Commerce City	mdandrea@c3gov.com	+1 3032898156
8	Josh English	Street Operations Supervisor	City	City of Cherry Hills Village	jenglish@cherryhillsvillage.com	+1 3037892541
9	John Gooman	Road manager	County	Morgan county	jgoodman@co.morgan.co.us	+1 9705423561
10	David Van Winkle	Street Superintendent	City	City of Steamboat Springs	dvanwinkle@steamboatsprings.net	+1 9708791807
11	Rick Miller	District Supervisor	County	Douglas County Public Works Operations	rmiller@douglas.co.us	+1 3036607480
12	Patrick Sullivan	Road Supervisor	County	Rio Grande County	rgcroaddept@riograndecounty.org	+1 7198524781
13	Rene Valdez	Transportation Stormwater and Infrastructure Manager	County	Adams County	rvaldez@adcogov.org	+1 7205236961
14	Stan Merritt	Roads & Grounds Supervisor	Other	Lockheed-Martin	stan.merritt@lmco.com	+1 3039776210
15	alan Trudell	Inspector	City	commerce city	atrudell@c3gov.com	+1 3032898178
16	Donald Oswald	County Commissioner	County	Kiowa County, Colorado	oswalddonald@hotmail.com	+1 7192005436
17	John Palmer	Deputy Maintenance Superintendent	State DOT	CDOT	john.palmer@state.co.us	+1 9707492386
18	Steve Williams	Supervisor	County	Washington County R&B Dist#3	road3supervisor@co.washington.co.us	+1 9705540680

Respondent #	Name	Title:	Position:	Agency	Email Address:	Phone Number:
19	jim davis	dir. of public works	County	la plata county	jim.davis@co.laplata.co.us	+1 9703826372
20	Dan Goin	District foreman	County	Garfield county	dgoin@garfield-county.com	+1 9706258601
21	Phillip Martinez	Construction Inspector	City	City of Ft Collins	pmartinez@fcgov.com	+1 9706726041
22	andy norris	supervisor	County	jackson county r&b	jcrbsupr@aol.com	+1 9707234481
23	Richard Scott	commissioner	County	kiowa county	rsscott@fairpoint.net	+1 7197274663
24	Stephen Henry	Pavement Manager	State DOT	CDOT	stephen.henry@state.co.us	+1 3033986579
25	Lance Wenholz	Supervisor	Municipality	Metro Wastewater	lwenholz@mwrd.dst.co.us	+1 3032863231
26	Cy Chavez	Administrative Director	City	City Of Rocky Ford	cchavez@ci.rocky-ford.co.us	+1 7192547414
27	Ann Marie Verde	Road Operations and Maintenance	Other	US Forest Service	averde@fs.fed.us	+1 3032755181
28	Brad Trujillo	Public Works Director	Municipality	Town of Severance	btrujillo@townofseverance.org	+1 9707958077
29	Rod Hamilton	Public Works Director	County	Clear Creek County	rhamilton@co.clear-creek.co.us	+1 3036792317
30	Scott Mattice	Road and Bridge Superintendent	County	Pitkin County	scott.mattice@pitkincounty.com	+1 9709205046
31	Randal Arredondo	Supervisor	County	Saguache County	rarredondo@saguachecounty-co.gov	+1 7192212709
32	Nolan Merrill	manager R&B	Municipality	Town of Mountain Village	nmerrill@mtnvillage.org	
33	Jeff Tatkenhorst	Deputy Maintenance Superintendent	State DOT	CDOT	Jeff.Tatkenhorst@state.co.us	+1 3033657102
34	Ted Plank	Road Maintenance Division Manager	County	Boulder County Transportaton Department	tplank@bouldercounty.org	+1 3034413962
35	Josh English	Street Operations Supervisor	City	City of Cherry Hills Village	jenglish@cherryhillsvillage.com	+1 3034785493

Q3. Low-volume paved roads are defined by your agency as roads carrying an Average Daily Traffic (ADT):

Answer Options	Response Count	Response Percent
Less than 400 vehicles per day	18	60%
Less than 500 vehicles per day	2	7%
Less than 1000 vehicles per day	6	20%
Less than 1500 vehicles per day	2	7%
Less than 2000 vehicles per day	2	6%
Other	0	0%
Answered question	30	86%
Skipped question	5	14%

Q4. Should truck traffic be considered when defining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	29	94%
No	2	6%
Answered question	31	89%
Skipped question	4	11%

Q5. Low-volume paved roads can be defined as roads carrying an Average Daily Truck Traffic (ADTT):

Answer Options	Response Count	Response Percent
Less than 50 vehicles per day	16	62%
Less than 100 vehicles per day	5	19%
Less than 150 vehicles per day	3	12%
Less than 200 vehicles per day	0	0%
Other	2	8%
Answered question	26	74%
Skipped question	9	26%

Other Answers:

- 500 vehicles per day.
- 400 vehicles per day.

Q6. What is approximate total length in miles of low-volume paved roadways owned and maintained by your agency?

Answer Options	Response Count	Response Percent
More than 250 miles	6	24%
200 – 250 miles	4	16%
150 – 199 miles	1	4%
100 – 149 miles	1	4%
50 – 99 miles	5	20%
10 – 49 miles	6	24%
Less than 10 miles	2	8%
Answered question	25	71%
Skipped question	10	29%

Q7. What is your agency's approximate annual funding level to maintain low-volume paved roads?

Answer Options	Response Count	Response Percent
Less than $500,000	11	44%
$500,000 - $999,999	4	16%
$1,000,000 - $1,999,999	6	24%
$2,000,000 - $3,000,000	1	4%
More than $3,000,000	3	12%
Answered question	25	71%
Skipped question	10	29%

Q8. Do you consider traffic data when managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	19	76%
No	6	24%
Answered question	25	71%
Skipped question	10	29%

Q9. What traffic data is obtained for managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Actual traffic volume data	15	79%
Predicted traffic volume data	9	47%
Truck Traffic	8	42%
Other	0	0%
Answered question	19	54%
Skipped question	16	46%

Q10. Do you consider any structural data when managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	19	76%
No	6	24%
Answered question	25	71%
Skipped question	10	29%

Q11. Which of the following structural data is useful for managing and maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Pavement thicknesses	16	89%
Pavement material characteristics (such as soil classification and strength)	12	67%
FWD – Falling Weight Deflectometer data	5	28%
Other	1	6%
Answered question	18	51%
Skipped question	17	49%

Other Answers:

- Road surface conditions.

Q12. Do you collect any pavement condition data on low-volume paved roads managed by your agency?

Answer Options	Response Count	Response Percent
Yes	14	58%
No	10	42%
Answered question	24	69%
Skipped question	11	31%

Q13. Do you follow any CDOT procedures when collecting pavement condition data of low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	3	23%
No	10	77%
Answered question	13	37%
Skipped question	22	63%

Q14. Please specify this procedure.

Answers:

- CDOT standards are applied to develop the rating system parameters.
- Annual condition survey to identify pavement conditions, structure and drainage systems and roadside facilities. Additionally, all traffic devices and striping.
- HUTF

Q15. How do you collect the pavement condition data of low-volume paved roads in your county?

Answer Options	Response Count	Response Percent
Manual and automated data collection systems	8	57%
Manual data collection system	5	36%
Automated data collection system	1	7%
Other	0	0%
Answered question	14	40%
Skipped question	21	60%

Q16. How frequently is pavement condition data collected?

Answer Options	Response Count	Response Percent
Every year	6	43%
Every 2 years	1	7%
Every 3 years	2	14%
Every 4 years	1	7%
Other	4	29%
Answered question	14	40%
Skipped question	21	60%

Other Answers:

- Every 5 years
- As Needed

Q17. Which of the following indices are used by your agency to summarize low-volume pavement conditions?

Answer Options	Response Count	Response Percent
PCI – Pavement Condition Index	5	38%
SR – Surface Rating	5	38%
PASER – Pavement Surface Evaluation Rating	3	23%
RUT – Rut depth	2	15%
OPI – Overall Pavement Index	2	15%
PSC – Pavement Structural Condition	2	15%
IRI – International Roughness Index	1	8%
DI – Distress Index	1	8%
PQI – Pavement Quality Index	1	8%
PSR – Present Serviceability Rating	1	8%
CRS – Condition Rating Survey	1	8%
PSI – Present Serviceability Index	0	0%
Other	3	23%
Answered question	13	37%
Skipped question	22	63%

Other Answers:

- Drivability Life
- None
- RQI

Q18. Do you use a specific pavement maintenance policy or guidelines for maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	5	22%
No	18	78%
Answered question	23	66%
Skipped question	12	34%

Please highlight the most important item in your policy:

- Chip seal every 5 to 7 years and overlay every 15 years or as funds are available.
- 7-year rotating program focused on routine, preventive and corrective maintenance. Priority is given to preventive maintenance.
- Cracking and potholing
- Utilizing the pavement management model to evenly distribute funding throughout the area allowing for systematic minor repairs to surgically address areas of concern while waiting for longer term fixes to be approved.
- Treatments on Low Volume Roads shall not exceed 1.5" thickness, with the exception of isolated, surgical repairs

Q19. Some agencies such as CDOT don't allow applying expensive treatments on their low-volume paved roads. Do you have similar policy when maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	6	25%
No	18	75%
Answered question	24	69%
Skipped question	11	31%

Q20. Do you think that eliminating expensive treatments provides cost-effective strategies for maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	6	26%
No	17	74%
Answered question	23	66%
Skipped question	12	34%

Q21. What are treatments allowed by your agencies for maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Chip Seal	24	96%
Crack Seal	22	88%
Crack Fill	18	72%
Medium Overlay (between 1.5" and 4")	14	56%
Thin Overlay (1.5" or less)	12	48%
Full Pavement Reconstruction	9	36%
Rut Fill	4	16%
Micro-surfacing	3	12%
Thick Overlay (over 4")	1	4%
Other	1	4%
Answered question	25	71%
Skipped question	10	29%

Other Answers:

- Slurry Seal

Q22. Do you recommend or routinely perform targeted rehabilitation of severely distressed areas within low-volume paved roads prior to application of surface treatments?

Answer Options	Response Count	Response Percent
Yes	19	76%
No	6	24%
Answered question	25	71%
Skipped question	10	29%

Q23. How do you determine when full length rehabilitation becomes necessary?

Answers:

- Based on available funds. Should happen when PCI goes below 75.
- OCI below 15 and/or need to replace utilities beneath the pavement
- It is determined by the road manager
- Overall road surface conditions
- When other treatments are no longer sufficient.
- By policy, we are not allowed to perform full length rehabs. This would require Chief Engineer concurrence.
- On an as-needed basis.
- Money
- Visual observation
- Condition index
- Base and pavement condition
- Engineering STIP does.
- Based on pavement survey and field evaluation of entire section.

Q24. Identify the expected service lives for the most widely used pavement treatments for low-volume paved roads by your agency.

Answer Options	Response Percent						Response Count
	Less than 3 years	3 - 5 years	6 - 8 years	9 - 10 years	more than 10 years	Don't Know/Don't Use	
Chip Seal	0%	26%	35%	22%	13%	4%	22
Micro-surfacing	0%	13%	4%	9%	0%	74%	11
Crack Seal	17%	52%	17%	0%	0%	13%	20
Crack Fill	9%	52%	13%	0%	0%	26%	17
Rut Fill	4%	9%	4%	4%	4%	74%	9
Thin Overlay (1.5" or less)	0%	0%	22%	4%	26%	48%	13
Medium Overlay (between 1.5" and 4")	0%	4%	13%	9%	35%	39%	15
Thick Overlay (over 4")	0%	0%	9%	4%	17%	70%	11
Full Pavement Reconstruction	0%	0%	4%	4%	48%	43%	14
Other (please specify)							1
Answered question							23
Skipped question							12

Other Answers:

- Slurry Seal-3-5 years

Q25. Identify the effectiveness of each pavement treatment used by your agency for severely distressed surfaces within low-volume paved roads.

Answer Options	Response Percent			Response Count
	Effective	Not effective	Don't Know/Don't Use	
Chip Seal	57%	39%	4%	22
Micro-surfacing	17%	9%	74%	12
Crack Seal	57%	22%	22%	20
Crack Fill	43%	26%	30%	18
Rut Fill	13%	13%	74%	12
Thin Overlay (1.5" or less)	43%	17%	39%	15
Medium Overlay (between 1.5" and 4")	48%	9%	43%	16
Thick Overlay (over 4")	30%	0%	70%	12
Full Pavement Reconstruction	52%	4%	43%	14
Answered question				23
Skipped question				12

Q26. Has your agency implemented any new pavement treatments not listed above for low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	3	13%
No	20	87%
Answered question	23	66%
Skipped question	12	34%

Q27. Please identify these treatments.

Answers:

- Slurry seal
- Full depth reclamation
- Cape seal and Haco

Q28. Are you aware of any new innovative techniques/treatments which might be effective when maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes (Please Specify)	4	17%
No	19	83%
Answered question	23	66%
Skipped question	12	34%

Answers:

- Thin lift overlays
- Double pinned chip seal
- Cold-in-Place Recycle with rejuvenating agent and a chip seal

- Double chip seals
- Full depth rec to non-paved

Q29. Do you think that optimization techniques should be used when selecting treatments and managing low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	21	100%
No	0	0%
Answered question	21	60%
Skipped question	14	40%

Q30. Which parameters should be optimized?

Answer Options	Response Count	Response Percent
Optimizing Budgets	14	67%
Maximizing PCI – Pavement Condition Index	12	57%
Maximizing Remaining Service Life	10	48%
Maximizing PSI – Present Serviceability Index	8	38%
Minimizing RUT – Rut depth	3	14%
Minimizing IRI – International Roughness Index	1	5%
Other	1	5%
Answered question	21	60%
Skipped question	14	40%

Other Answers:

- Maximizing Drivability Life

Q31. When optimizing budget expenditures, what is the approximate percentage of total budgets that should be allocated to each of the following segment condition levels?

Answer Options	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**Response Count**	**Weighted Average**
Worst segments	0	4	7	3	1	4	1	0	1	21	30%
Rapidly deteriorating segments	0	2	6	7	1	3	1	0	1	21	31%
Segments requiring routine maintenance	1	1	4	4	1	2	6	2	0	21	39%
Answered question										21	
Skipped question										14	

Appendix D-1: Colorado Department of Transportation Material Advisory Committee Survey

General Information

* 1. Please enter your contact information:

Name:

Title:

CDOT Region

Email Address:

Phone Number:

2. How many miles of low-volume paved roads are in your region?

- More than 250 miles
- 200 – 250 miles
- 150 – 199 miles
- 100 – 149 miles
- 50 – 99 miles
- 10 – 49 miles
- Less than 10 miles

3. The current CDOT definition for low-volume paved roads includes roads carrying:
Average Daily Traffic (ADT) less than 2000 vehicles per day, and Average Daily Truck Traffic (ADTT) less than 100 vehicles per day. Do you agree with this definition?

- ◯ Yes
- ◯ No

General Information

4. Based on your experience, a low-volume paved road should have which of the following traffic volume?

	Volume
ADT	
ADTT	

General Information

5. According to current CDOT policy, low-volume paved roads are maintained mainly with minor rehabilitation pavement treatments (less than 1.5" in thickness with isolated, surgical, and structural repair) when the drivability is low. Do you agree with this policy?

- ◯ Yes
- ◯ No

General Information

6. How should this policy be changed to better maintain low-volume paved roads?

7. Recently, CDOT started using the Drivability Life (DL) to evaluate the overall condition of low-volume paved roadways. How did this change affect your decision making when it comes to maintaining low-volume paved roads?

Treatment Strategy

8. CDOT evaluates pavement conditions of low-volume paved asphalt roads in terms of Fatigue Index, Longitudinal Index, Transverse Index, Ride Index and Rut Index. Do you select pavement treatments of low-volume paved roads based on any of those indices?

- ◯ Yes
- ◯ No

Treatment Strategy

9. What are the pavement condition indices included when selecting the suitable pavement treatments on low-volume paved road?

- ☐ FATIG_IDX – Fatigue Index
- ☐ LONG_IDX – Longitudinal Index
- ☐ TRANSV_IDX – Transverse Index
- ☐ RIDE_IDX – Ride Index
- ☐ RUT_IDX – Rut Index
- ☐ Other (please specify)

10. Other agencies use decision trees to identify pavement treatment options on their low-volume paved roads.
Do you think that developing a decision tree for identifying pavement treatment options is needed?

- Yes
- No

Treatment Strategy

11. Which indices/data should be included in the project decision making process to identify treatments for a specific low-volume paved roads?

- Road Classification
- Pavement Age
- Average Daily Traffic (ADT)
- Average Daily Truck Traffic (ADTT)
- Maintenance History
- FATIG_IDX – Fatigue Index
- LONG_IDX – Longitudinal Index
- TRANSV_IDX – Transverse Index
- RIDE_IDX – Ride Index
- RUT_IDX – Rut Index
- DL - Drivability Life
- Project Site Evaluation Data (cores, soils, distress survey)
- Degree of Localized Distress Areas
- Performance of Past Treatments
- Cost of Treatment Options
- Cost of Single versus Mix of Combined Treatments
- Available Budget for Low Volume Road System
- Other (please specify)

12. Do you recommend or routinely perform targeted rehabilitation of severely distressed areas within low-volume paved roads prior to application of surface treatments?

- [ ] Yes
- [ ] No

Treatment Strategy

13. How do you determine when full length rehabilitation becomes necessary?

Treatment Strategy

14. According to the current CDOT policy, CDOT applies only two types of low-cost treatments on low-volume paved roads. Do you think eliminating expensive treatments provides cost-effective strategies for maintaining low-volume paved roads?

- [ ] Yes
- [ ] No

15. Identify the expected service lives for the most suitable pavement treatments for low-volume paved roads.

	Less than 3 years	3 - 5 years	6 - 8 years	9 - 10 years	more than 10 years	Don't know / Don't use
Chip Seal	◯	◯	◯	◯	◯	◯
Micro-surfacing	◯	◯	◯	◯	◯	◯
Crack Seal	◯	◯	◯	◯	◯	◯
Crack Fill	◯	◯	◯	◯	◯	◯
Rut Fill	◯	◯	◯	◯	◯	◯
Thin Overlay (1.5" or less)	◯	◯	◯	◯	◯	◯
Medium Overlay (between 1.5" and 4")	◯	◯	◯	◯	◯	◯
Thick Overlay (over 4")	◯	◯	◯	◯	◯	◯
Full Pavement Reconstruction	◯	◯	◯	◯	◯	◯

Treatment Strategy

16. Identify the effectiveness of each pavement treatment when placed directly on<u>severely distressed</u> surfaces within low-volume paved roads.

	Effective	Not effective	Don't know / Don't use
Chip Seal	◯	◯	◯
Micro-surfacing	◯	◯	◯
Crack Seal	◯	◯	◯
Crack Fill	◯	◯	◯
Rut Fill	◯	◯	◯
Thin Overlay (1.5" or less)	◯	◯	◯
Medium Overlay (between 1.5" and 4")	◯	◯	◯
Thick Overlay (over 4")	◯	◯	◯
Full Pavement Reconstruction	◯	◯	◯

17. Are there any techniques you would like to learn more about through this study?

- ◯ Yes
- ◯ No

Treatment Strategy

18. Please identify these techniques.

Appendix D-2: Colorado Department of Transportation Material Advisory Committee Responses

Q1. Please enter your contact information:

Res.#	Name	Title:	CDOT Region:	Email Address:	Phone Number:
1	Michael Stanford	Asphalt Program Manager - HQ	Staff Materials	michael.stanford@state.co.us	+1 3033986576
2	Bob Mero	Pavement Manager	1	bob.mero@state.co.us	+1 3033986703
3	James Chang	Region Materials Engineer South and West	1	james.chang@state.co.us	+1 3033986702
4	Bill Schiebel	CDOT Materials and Geotechnical Branch Manager	CO	bill.schiebel@state.co.us	+1 3033986501
5	Gary Dewitt	Region 4 Materials Engineer	CO	gary.dewitt@state.co.us	+1 9703502379
6	Craig Wieden	Materials Engineer	Region 2	craig.wieden@state.co.us	+1 7195465438
7	Jay Goldbaum	Pavement Design Program Manager	Colorado	Jay.Goldbaum@state.co.us	+1 3033986561
8	Jeremy Lucero	Region Materials Engineer	3	jeremy.lucero@state.co.us	+1 9706837562

Q2. How many miles of low-volume paved roads are in your region?

Answer Options	Response Count	Response Percent
More than 250 miles	5	63%
200 – 250 miles	0	0%
150 – 199 miles	0	0%
100 – 149 miles	0	0%
50 – 99 miles	2	25%
10 – 49 miles	0	0%
Less than 10 miles	1	13%
Answered question	8	
Skipped question	0	

Q3. The current CDOT definition for low-volume paved roads includes roads carrying: Average Daily Traffic (ADT) less than 2000 vehicles per day, and Average Daily Truck Traffic (ADTT) less than 100 vehicles per day. Do you agree with this definition?

Answer Options	Response Count	Response Percent
Yes	7	88%
No	1	12%
Answered question	8	
Skipped question	0	

Q4. Based on your experience, a low-volume paved road should have which of the following traffic volume?

Answer Options	Response Count	Response Percent
ADT	0	0%
ADTT	0	0%
Answered question	0	
Skipped question	8	

Q5. According to current CDOT policy, low-volume paved roads are maintained mainly with minor rehabilitation pavement treatments (less than 1.5" in thickness with isolated, surgical, and structural repair) when the drivability is low. Do you agree with this policy?

Answer Options	Response Count	Response Percent
Yes	4	50%
No	4	50%
Answered question	8	
Skipped question	0	

Q6. How should this policy be changed to better maintain low-volume paved roads?

Answers:

- I understand the philosophy and why we have to do this, but we are finding that these thin treatments right now are showing issues. In an ideal world, we would not be under a restriction such as this.
- Should consider the condition of the road for value gained of minor treatments. Many roads will only see a 1 to 2 year temporary appearance fix with minor treatments.
- I don't think the policy needs to be changed. There is an allowance to do a more substantial treatment, but it is a length involved process needed to get a more substantial treatment approved on a low volume road.
- It should be based on cost per mile and not allowable treatments.

Q7. Recently, CDOT started using the Drivability Life (DL) to evaluate the overall condition of low-volume paved roadways. How did this change affect your decision making when it comes to maintaining low-volume paved roads?

Answers:

- Does not affect my role as Asphalt Program Manager
- Not at all.
- It affected the type of treatment selected a little bit since the treatment would have to emphasize smoothness a lot more was previously done in addition to other distresses.
- New treatment types and combination of treatment options are now needed

- Surface treatment with little or no structural value are considered more important than structural improvements.

- I look for the cheapest treatment that can be done that will improve the DL. Often, a chip seal is recommended through our pavement management system on a low volume road that has a low DL based on IRI. This type of treatment is not effective at addressing the cause of the low DL.

- Increased the life without any increase in budgets.

- It tends to provide shorter term solutions.

Q8. CDOT evaluates pavement conditions of low-volume paved asphalt roads in terms of Fatigue Index, Longitudinal Index, Transverse Index, Ride Index and Rut Index. Do you select pavement treatments of low-volume paved roads based on any of those indices?

Answer Options	**Response Count**	**Response Percent**
Yes	8	100%
No	0	0%
Answered question	8	
Skipped question	0	

Q9. What are the pavement condition indices included when selecting the suitable pavement treatments on low-volume paved road?

Answer Options	Response Count	Response Percent
FATIG_IDX – Fatigue Index	6	75%
LONG_IDX – Longitudinal Index	6	75%
TRANSV_IDX – Transverse Index	5	63%
RIDE_IDX – Ride Index	4	50%
RUT_IDX – Rut Index	5	63%
Other	4	50%
Answered question	8	
Skipped question	0	

Other Answers:

- Regional Decision
- This is similar to what we look at for other pavements. All parameters are considered, however, in the overall evaluation.
- Age as evident by oxidation, alligator cracking, proximity to heavy industry
- All are used, but the treatment needs to address the reason for the low DL

Q10. Other agencies use decision trees to identify pavement treatment options on their low-volume paved roads. Do you think that developing a decision tree for identifying pavement treatment options is needed?

Answer Options	Response Count	Response Percent
Yes	5	63%
No	3	38%
Answered question	8	
Skipped question	0	

Q11. Which indices/data should be included in the project decision making process to identify treatments for a specific low-volume paved roads?

Answer Options	Response Count	Response Percent
Road Classification	5	100%
Pavement Age	3	60%
Average Daily Traffic (ADT)	4	80%
Average Daily Truck Traffic (ADTT)	4	80%
Maintenance History	3	60%
FATIG_IDX – Fatigue Index	4	80%
LONG_IDX – Longitudinal Index	4	80%
TRANSV_IDX – Transverse Index	4	80%
RIDE_IDX – Ride Index	2	40%
RUT_IDX – Rut Index	3	60%
DL - Drivability Life	3	60%
Project Site Evaluation Data (cores, soils, distress survey)	5	100%
Degree of Localized Distress Areas	5	100%
Performance of Past Treatments	5	100%
Cost of Treatment Options	5	100%
Cost of Single versus Mix of Combined Treatments	3	60%
Available Budget for Low Volume Road System	4	80%
Other	1	20%
Answered question	5	
Skipped question	3	

Other Answers:

- Tenth-mile condition data to I.D. localized repair options. Climate conditions. Winter maintenance activities and amount. Cost of mix of fixes vs cost of rehab options.

Q12. Do you recommend or routinely perform targeted rehabilitation of severely distressed areas within low-volume paved roads prior to application of surface treatments?

Answer Options	Response Count	Response Percent
Yes	5	100%
No	0	0%
Answered question	5	
Skipped question	3	

Q13. How do you determine when full length rehabilitation becomes necessary?

Answers:

- When "surgical" repairs out-weigh full length rehabilitation.
- It should be an iterative process through data review and field investigations.
- It depends on how quickly the pavement is "deteriorating" and the available budget.
- Combined cost of targeted rehab and repairs plus final full length surface treatment vs cost of full length rehab options (including final riding surface treatment).
- When the distress becomes too severe and the amount is very large.

Q14. According to the current CDOT policy, CDOT applies only two types of low-cost treatments on low-volume paved roads. Do you think eliminating expensive treatments provides cost-effective strategies for maintaining low-volume paved roads?

Answer Options	Response Count	Response Percent
Yes	3	60%
No	2	40%
Answered question	5	
Skipped question	3	

Q15. Identify the expected service lives for the most suitable pavement treatments for low-volume paved roads.

Answer Options	Response Percent						Response Count
	Less than 3 years	3 - 5 years	6 - 8 years	9 - 10 years	more than 10 years	No Response	
Chip Seal	0%	50%	38%	13%	0%	0%	8
Micro-surfacing	13%	13%	38%	25%	0%	13%	8
Crack Seal	13%	63%	25%	0%	0%	0%	8
Crack Fill	25%	63%	13%	0%	0%	0%	8
Rut Fill	25%	38%	25%	0%	0%	13%	8
Thin Overlay (1.5” or less)	13%	38%	50%	0%	0%	0%	8
Medium Overlay (between 1.5" and 4”)	0%	13%	13%	50%	25%	0%	8
Thick Overlay (over 4”)	0%	0%	13%	13%	75%	0%	8
Full Pavement Reconstruction	0%	0%	0%	0%	88%	13%	8
Other (please specify)							0
Answered question							8
Skipped question							0

Q16. Identify the effectiveness of each pavement treatment when placed directly on severely distressed surfaces within low-volume paved roads.

Answer Options	Response Percent			Response Count
	Effective	Not effective	No Response	
Chip Seal	0%	100%	0%	8
Micro-surfacing	13%	50%	38%	8
Crack Seal	0%	100%	0%	8
Crack Fill	0%	100%	0%	8
Rut Fill	0%	88%	13%	8
Thin Overlay (1.5” or less)	25%	75%	0%	8
Medium Overlay (between 1.5" and 4”)	100%	0%	0%	8
Thick Overlay (over 4”)	100%	0%	0%	8
Full Pavement Reconstruction	100%	0%	0%	8
Answered question				8
Skipped question				0

Q17. Are there any techniques you would like to learn more about through this study?

Answer Options	Response Count	Response Percent
Yes	6	75%
No	2	25%
Answered question	8	
Skipped question	0	

Q18. Please identify these techniques.

Answers:

- Advanced and Innovative Microsurfacing.
- Paving with fabric was discussed in the presentation at CDOT. CDOT has had problems with the inclusion of fabric due to problems milling it up and problems with water retention. It would be interesting to see if there is a better method / best practice / decision tree to include fabric in our pavement that doesn't cause these problems. Though RMEs do have quite a bit of exposure to various techniques, we would like the researchers to identify any promising / innovative methods are out there.
- Multiple layer chip seal, Microsurfacing and slurry seals, combination/cape seals, crack seal+chip/slurry/micro, Cold and Hot Recycle with above treatments as surfacing.
- On highly distress roadways, is it more cost effective to place a 1 1/2" HMA overlay rather than a FDR with 4" HMA considering a 40-year time frame?
- Microsurfacing, sealcoat, Cold in place recycling, full depth reclamation with asphalt emulsion/cement.
- Microsurfacing.