Chapter 14
Sustainable Pavement Preservation and Maintenance Practices

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Abstract This chapter discusses the state-of-the-practice in sustainable pavement maintenance and preservation. Its focus is on quantifying and understanding how pavement preservation and maintenance practices minimize environmental impacts. The Federal Highway Administration (FHWA) differentiates between pavement preservation and pavement maintenance and uses this to allocate federal funds accordingly. While Canadian agencies recognize and practice the concepts of pavement preservation, there is no regulatory differentiation between it and maintenance as compared to the US. Pavement preservation promotes environmental sustainability by conserving energy, virgin materials, and reducing greenhouse gases by keeping good roads good. Therefore, a sustainable pavement maintenance program should consider allocating personnel and resources to pavement preservation.

14.1 Introduction

Increasing societal awareness of the environmental effects of constructing, operating, and maintaining the highway infrastructure has led to new demands on transportation agencies to conduct their business in a more sustainable fashion. One key approach is for agencies to utilize a pavement preservation program, restoring pavements while still in good condition and extending their service life. The United

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States (US) Federal Highway Administration (FHWA) considers pavement preservation a proactive approach to maintaining highways. Pavement preservation and maintenance treatments usually provide the least expensive pavement management strategy available on a life cycle cost basis (FHWA 2005).

This chapter synthesizes the current state-of-the-practice in usage and quantification of pavement preservation and maintenance practices in the context of their environmental impact. "Sustainability" refers to promoting environmentally friendly practices that also provide technical and economic benefits. Kober (2009) posited that the overall impact of infrastructure construction and maintenance activities to the environment could be analyzed using the following seven sustainability impact factor areas:

- virgin material usage;
- alternative material usage;
- program for pavement in-service monitoring and management;
- noise;
- air quality/emissions;
- water quality and energy usage.

The remainder of the chapter will examine the relationship between the above impact factors and the suite of typical pavement preservation and maintenance practices for all pavement types including: asphalt, concrete, composite, surface treated and gravel roads and pavements. The objective is to furnish a relative comparison of sustainability that can be used by public agencies to make pavement preservation treatment selections based on sustainability as well as cost and technical characteristics.

14.2 Background

Pavement infrastructure is critical to quality of life and prosperity of society. As the pavement structure deteriorates over time, proper pavement preservation and maintenance is necessary to achieve a high-performing, safe, and cost effective pavement network for the users. In a society today resources and funding are limited, making it important for transportation agencies to seek ways to utilize the resources to maximize benefits as part of daily operation. At the same time, attention to the notion of environmental sustainability has also increased. Environmental sustainability has been defined by the Bruntdland Commission as "[meeting] the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntdland 1987). Recently, the FHWA defined sustainable transportation as "providing exceptional mobility and access in a manner that meets development needs without compromising the quality of life of future generations. A sustainable transportation system is safe, healthy, affordable, renewable, operates fairly and limits emissions and the use of new and nonrenewable resources" (Harmon 2010).

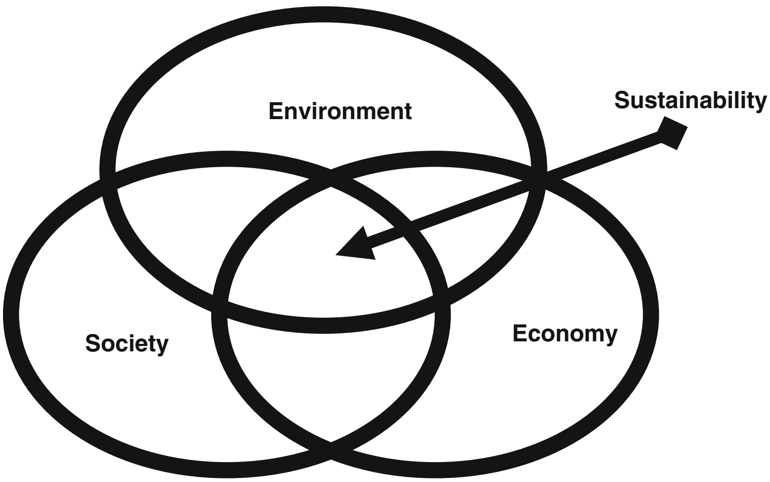

Fig. 14.1 Fundamental sustainability model (adapted from CH2 M Hill 2009)

The basis of environmental sustainability consists of the three elements shown in Fig. 14.1: economy, society, and environment. Sustainable pavement preservation and maintenance are a subset of sustainable transportation where the impacts of the treatments on the economy, environment and social equity are defined and evaluated. It can also be evaluated according to the technical and economic effectiveness and the associated impacts on the natural environment (Jeon 2005). It should be noted that a study of state DOTs indicates that while environmental sustainability is not explicitly mentioned in the mission and vision statements of most agencies, many do include the three elements (Amekudzi 2007; Ramani et al. 2009).

14.2.1 Sustainability in Transportation

The concept of environmental sustainability and how it can be employed in various practice areas is gaining wide support from the general public, governments and professionals (Chan 2010; Muench 2010). The need to quantify sustainable practices is also challenging and requires a holistic approach. The initiatives by LEED™ (USGBC 2010), Greenroads (Muench 2010), GreenLITES (NYSDOT 2009) and GreenPave (MTO 2010) certification programs are common examples of programs that promote and quantify sustainable practices (Chan 2010). In addition, life cycle assessment (LCA) is another approach for modeling and quantifying environmental inputs and outputs from pavements and assessing their impacts on the environment and humans. Examples include the LCA software tool *PaLATE* (Horvath 2009) which uses both industrial process models and an approach called environmental input-output (EIO) to develop life cycle inventories of inputs and outputs). These and some other industry initiatives are described later. However, it is notable that while many of the environmental sustainability initiatives consider preservation and maintenance treatments and their contributions to long life pavements, there is limited explicit assessment of the treatments themselves in terms of environmental performance.

As noted in FHWA's newsletter, "Strategic, Safe and Sustainable: Today's Vision for Pavements", environmental sustainability is of critical importance (Stephanos 2009). It is noted in that article, in the new decade of environmental awareness, maximizing recycled materials in pavement construction and rehabilitation is a priority and this is further advanced through the FHWA participation in the Green Highways Partnership (GHP) which is an attempt to align various state specifications for using recycled materials. Other initiatives include using warm mix that generates fewer emissions and conducting research on expanding the types and amount of fly ash that can be used in concrete paving. Although these initiatives tend to focus primarily on usage in pavement construction and rehabilitation treatments, they are also an important part of pavement preservation and maintenance treatments.

Additionally, recent research in France and New Zealand (Ball et al. 2008) mirrors a US movement from solvent-based binders toward water-based emulsion binders for use in pavement preservation and maintenance treatments as a result of concern for the environment. Emulsions are "more… environmentally friendly than …cut back asphalts" (James 2006). A New Zealand study confirmed this assertion when it found: "Current indications are that chip sealing emulsions typically would be classified as safe…" (Ball et al. 2008). Thus, adding an environmental sustainability factor to the pavement preservation and maintenance decision-making process is both timely and appropriate.

14.2.2 Pavement Preservation Theory

Historically, most transportation agencies in North America would allow their pavements to deteriorate to fair or poor condition (Beatty et al. 2002). As a result of the national pavement preservation initiative, funding agencies are becoming familiar with the cost effectiveness of using preventive maintenance to preserve the infrastructure and are finding that chip seal research translates into a worthwhile investment. Figure 14.2 illustrates the concept of pavement preservation, where each dollar spent on maintenance before the age of rapid deterioration saves future rehabilitation costs (Hicks 1997) and could conceivably save even more when user delay and traffic control costs are added to the bottom-line.

One can see from Fig. 14.2 that the primary notion is to invest in keeping the road in good condition as long as possible. If successful, the overall sustainability of the network can potentially greatly enhanced by the reduction in the use of virgin materials and energy. The environment benefits from potential reductions in greenhouse gas emissions, hazardous material exposure, and deleterious construction

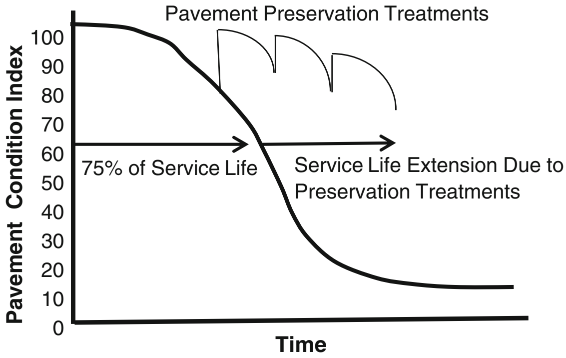

Fig. 14.2 Pavement preservation model

operations that expose the soil to erosion. Society can benefit where preservation results in reduced times of traffic disruption, which translate into fewer work zone accidents and a drop in injuries and/or fatalities. Finally, the public agency is better able to stretch its limited funding farther and address both replacement and capacity issues in its construction program. In asset management terms, pavement preservation enhances the overall condition of the network and simplifies resource distribution decisions. Thus, optimization of pavement preservation practices and keeping them adequately funded has the potential to improve sustainability.

14.3 Sustainability Impact Factor Areas

Measuring environmental sustainability is an emerging field in the transportation industry, and even more so with respect to the pavement maintenance treatment selection process. The literature seems rife with newly coined terms to describe a given treatment's impact on the environment (Takamura et al. 2001; James 2006; Ball et al. 2008; Chaignon and Mueller 2009; Muench 2010; Lane 2009). "The terms 'Green', 'Sustainable Development', 'Environmental Impact', 'Energy Efficiency', 'Global Warming', 'Greenhouse Gases', and 'Eco-efficiency', are becoming more widely recognized…" (Chehovitz and Galehouse 2010).

Unfortunately, each article or manual focuses its evaluation of environmental impact on a different set of impacts. For example, Takamura et al. (2001) coined the term "eco-efficiency" to describe the comparative analysis of six parameters: virgin material consumption, energy consumption, land use, emissions, toxicity, and risk potential. Pittenger's research (2010) included virgin material consumption, life cycle cost, and a factor from the Greenroads certification program (Muench 2010); whereas Chehovitz and Galehouse (2010) confined their analysis to greenhouse gas emissions and energy consumption. Thus, it is difficult to adopt a single, universally-recognized term to identify the process of evaluating competing pavement preservation and maintenance treatment options on the basis of relative environmental sustainability. As a result, this report will use the term "environmental performance" to globally describe attributes of various treatments that accomplish one or more of the following outputs:

- Reduce the impact on the environment by minimizing the consumption of energy and virgin materials.
- Reduce the amount of harmful substances that are produced during manufacturing, transportation, and installation of the given treatment.
- Enhance the potential for increase safety for the traveling public and maintenance work crews by minimizing the amount of time traffic is disrupted for maintenance operations.

The American Association of State Highway and Transportation Officials (AASHTO) Center for Environmental Excellence (CEE) provides an excellent basis for identifying and promoting environmental excellence in the efficient delivery of transportation services (Kober 2009). The CEE evaluates sustainability parameters through identifying focus areas. Consequently, seven sustainability impact factor areas identified by the CEE will be considered in this synthesis. Each one of the areas is described herein and how they relate to pavement preservation and maintenance treatments. It should be noted that life cycle assessment tools such as the ISO 14040 Standard are becoming more available and many of these do cite other environmental sustainability impact factors (International Organization for Standardization (ISO) 2006). However, for the purpose of this discussion, the seven aforementioned factors have been examined.

- Virgin material usage examines reducing the need to use non-renewable resources. Pavement materials can be expensive and some resources may be limited, so it is important to make good utilization of available materials. The primary focus of this area is to consider the reduced need for virgin material usage and demand of virgin materials for treatments. Many maintenance treatments involve in-place recycling, which enables re-use of the materials already committed to roadways, although they also typically require some new materials as well. Prolonging the time between major rehabilitation and reconstruction through proper pavement treatment selection is an effective way to reduce virgin material usage.
- Alternative Material Usage looks at the opportunity to replace virgin materials with recycled materials and as well to use nontraditional materials in the pavement structure during preservation and maintenance. This could mean incorporating Reclaimed Asphalt Pavement (RAP), Recycled Concrete Aggregate (RCA), Recycled Asphalt Shingles (RAS), Recycled Rubber Tire (RRT), glass, or any other materials that might be appropriate. Proper processing of these materials can result in equivalent performance to virgin aggregate (Infraguide 2005). Careful blending and crushing of recycled materials is required to achieve consistent gradation and performance of the material (Infraguide 2005).

- Programs for Pavement In-Service Monitoring and Management are required to alert agencies in a timely manner to pavement deterioration so that they can intervene with preservation treatments before the road becomes so bad that preservation is no longer an option. In short, they support putting the right treatment on the right pavement at the right time. Robust information systems help determine existing and forecasted pavement conditions so that decisions can be accurately made and funds programmed for network improvements. Pavement in-service monitoring and management would consider the life cycle and associated serviceability of the treatment.
- Noise is defined as the unwanted or excessive sound associated with pavement construction and improvements. Studies show that the most pervasive sources of noise in the environment relate to transportation. Therefore, noise is examined as an environmental sustainability factor area whereby pavement preservation and maintenance treatments are evaluated on their noise impacts (CEE 2010a).
- Air Quality/Emissions examine six principal air pollutants, namely carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter and sulfur dioxide (CEE 2010b). The intent of this factor is to assess each pavement preservation and maintenance treatment in terms of these pollutants. This would involve both calculations for the air quality/emissions for the equipment and materials. Also considered would be the associated impact the treatments have on the travelling public in terms of emissions associated with traffic delays due to the treatment placement, Part of the calculation of this factor would be the preventive maintenance treatment's service life.
- Water Quality evaluates the effects of transportation-related impacts associated with alternative maintenance strategies and materials. Regulatory requirements relate to the operation and maintenance of municipal storm sewer systems, storm water discharge associated with construction activities, and effluent standards related to the total maximum daily effluent discharge standards. Treatments and programs should be evaluated for their individual and collective effect on these resources (CEE 2010c).
- Energy Usage relates to the quantification of cumulative energy usage of the pavement preservation and maintenance treatment throughout the life cycle. Energy usage is important in its correlation to emissions of greenhouse gases and their relationship to climate change.

14.4 Pavement Preservation and Maintenance Treatments

A variety of different treatments are available to transportation agencies, and their use is determined according to factors of traffic, climate, available materials, etc. Criteria of environmental criteria do not currently play a part in treatment selection. Table 14.1 summarizes responses from a survey conducted in 2010 regarding which pavement preservation and maintenance practices are most commonly used by state

Table 14.1 Summary of pavement preservation and maintenance techniques in survey

Surface type	Technique most often cited	→			Technique least often cited
Gravel	Regrading	Regravel	Dust palliative	Otta seal	Other
Surface treated	Chip seal hot patches	Slurry seal cold patches	Microsurfacing Asphalt level-up	Fog seal thin hot mix overlay	Crack seal other
Asphalt	Chip seal hot patches	Slurry seal cold patches	Microsurfacing Asphalt level-up	Fog seal thin hot mix overlay	Crack seal other
Concrete	Diamond grinding shotblasting	Milling mud jacking	Thin PCC overlay Dowel bar retrofit	Joint sealing	Crack seal other
Composite	Chip seal hot patches	Slurry seal cold patches	Microsurfacing Asphalt level-up	Fog seal thin hot mix overlay	Crack seal other

and provincial DOT's for gravel, surface treated, asphalt, concrete and composite pavements (Tighe and Gransberg 2011). The survey was directed to pavement maintenance practitioners in state, provincial, federal and selected transportation agencies in the US and Canada and it provided 49 responses from 42 U.S. state DOTs and 7 Canadian provincial ministries of transportation (Tighe and Gransberg 2011).

14.4.1 Treatment Selection and Usage

Normally the agency will consider many factors when determining which treatments should be used. These factors may include: cost of treatment, type and extent of distress, traffic type and volume, climate, existing pavement type, expected life, availability of qualified contractors, availability of quality materials, time of year, pavement noise, facility downtime (user delays) surface friction, anticipated level of service and other project specific conditions (Moulthrop 2007). As noted this list is extensive but does not include environmental sustainability. Training and information that quantifies the importance of preservation and maintenance treatments in respect to environmental sustainability impact factor areas is needed to furnish an opportunity to evaluate environmental sustainability and the associated agency will use its established procedures, guidelines and specifications to select the appropriate treatment (Hicks et al. 1997).

A variety of program and technical guidance is available for support and training of personnel involved in preventive maintenance treatment selection, placement, inspection, etc. For example, the California DOT (Caltrans) Maintenance Technical Advisory Guides for Flexible Pavements and Rigid Pavements guidelines serve as good documents for evaluating materials and treatment selection (Caltrans 2008a, b). In addition, there are several FHWA Manuals of Practice on various preventive maintenance techniques as summarized in Table 14.2. Other documents include: Materials and Crack Seal Application (FHWA 2001), Joint Sealing in Portland Cement Concrete Pavements (FHWA 2002), Gravel Roads Maintenance and Design Manual (FHWA 2000), NCHRP studies, 20-07 on Pavement Preservation, Practices, Research Plans and Initiatives (Peshkin and Hoerner 2005) and NCHRP 342, Chip Seal Best Practices also provide valuable state-of-the-art information (Gransberg 2005). While these documents provide an excellent basis for the planning, design and construction of the treatment, there is no specific reference to environmental sustainability and how it relates to the identified environmental sustainability impact factor areas.

Furthermore there are several studies which discuss pavement preservation treatments and performance but environmental sustainability is not evaluated or considered in the decision-making process (Galehouse 2005). In addition, previous NCHRP studies, 20-07 on Pavement Preservation, Practices, Research Plans and Initiatives (Peshkin 2005) and NCHRP 342, Chip Seal Best Practices also provide valuable state-of-the-art information (Gransberg 2005).

Table 14.2 Pavement preservation checklist series (Newman 2010)

Publication title	Publication number	Series number
Crack seal application	FHWA-IF-02-005	1
Chip seal application	FHWA-IF-02-046	2
Thin hot mix Asphalt overlay	FHWA-IF-02-049	3
Fog seal application	FHWA-IF-03-001	4
Microsurfacing application	FHWA-IF-03-002	5
Joint sealing PCC pavements	FHWA-IF-03-003	6
Diamond grinding of Portland cement concrete pavements	FHWA-IF-03-040	7
Dowel-bar retrofit for Portland cement concrete pavements	FHWA-IF-03-041	8
Partial-depth repair of Portland cement concrete pavements	FHWA-IF-02-042	9
Full-depth repair of Portland cement concrete pavements	FHWA-IF-03-043	10
Hot in-place Asphalt recycling application checklist	FHWA-IF-06-011	11
Cold in-place Asphalt recycling application checklist	FHWA-IF-06-012	12
Slurry seal application checklist	FHWA-IF-06-014	13

14.4.2 Evaluating Preservation Treatment Sustainability

There are various aspects that must be considered when evaluating pavement preservation and maintenance practices for a respective pavement. Generally the expected service life of the treatment is a function of the traffic loading, subgrade soil and design thickness. Many factors can be considered including the pavement condition, roughness, skid number, structural adequacy and the associated impact on the level of service. Another important performance measure would be the calculation of the environmental sustainability impact factors of each treatment and the subsequent overall environmental sustainability impact of the treatment.

A very environmentally efficient pavement preservation measure is the use of shotblasting on asphalt and concrete pavements that have lost their skid resistance over time (Transport Canada 2003). This process consumes no materials as it recycles the steel abrasives used to restore macrotexture and microtexture on the pavement surface. On the other hand, microsurfacing is often used to restore skid resistance to sound asphalt pavements with polished aggregate. When it is compared to thin (less than 2" or 5 cm) hot-mix overlays, it consumes half the energy and virgin materials, emits about 60 % of the CO_2, and reduces the potential for occupational illnesses and accidents by 63 % (Uhlman 2010). For example, another aspect which could be considered in environmental sustainability is the examination of photo chemical ozone creation calculations and associated reductions in CO_2 and NO_2 emissions with respect to treatments such as microsurfacing (ISSA 2010).

Uhlman (2010) found that using microsurfacing as a pavement preservation treatment leaves a much smaller ecological “fingerprint” than the hot-mix overlay. The ecological fingerprint concept involves comparing various ecological factors related to a product or process how it impacts the environment. Stakeholders select the factors that impact future generations and show it as a three-dimensional figure. Although this concept is still somewhat developmental, it provides a methodology for looking at multiple factors and how they impact the environment (Schmidt 2004). Many factors determine which preservation and maintenance treated is best suited for each agency, some of these factors include: traffic, climate, available materials, cost of treatment, type and extent of distress, expected life, time of year, etc.

14.5 Opportunities to Improve Sustainability in Pavement Preservation and Maintenance

The literature is rich with information on practices that can improve sustainability that can and have been applied to highway design and construction. Each study represents an opportunity for maintenance engineers to potentially adopt aspects of the practices that can improve sustainability in maintenance and preservation. In other cases, the identified practices that can improve sustainability will likely need to be adapted or altered prior to their usage in pavement preservation and maintenance applications. Table 14.3 consolidates the information found in the literature and extends each study’s result to possible pavement preservation and maintenance applications. In most cases, the possible application was mentioned in the cited report or paper and, the mention took the form of a recommendation for additional research to validate the concept. The report by Denevillers (2010) detailed actual field testing of vegetable-based carbon emulsions.

One of the principles of environmental sustainability is to minimize the use of non-renewable resources. For example, the use of a renewable bio-fluxing agent as a prime coat was successfully demonstrated in Morocco, and also tested and used in chip seals on Route 960 in Saumur, France. The same is true for the bio-binder which has been successfully applied in Canada and 7 European countries. Though it is not in the table, it should be noted that it has successfully been used in road marking paints in France and England. It should also be noted, that many of these treatments should be evaluated in the broader environmental sustainability context as details in the literature were limited.

Table 14.3 illustrates that while fundamental research has been done on enhancing highway environmental sustainability through the use of recycled materials, alternative materials, and green construction technologies, the information necessary to extend these promising opportunities to pavement preservation and maintenance must still be developed through future research and field testing. Additionally the economic analyses contained in the above reports are very

Table 14.3 Alternative, Recycled and Renewable Highway Design/Construction Literature Review Results

Material/ technique	Literature cite	Possible preservation uses	Possible maintenance uses	Remarks
Bio-fluxing Agent	Denevillers 2010	Prime coat Chip seals Microsurfacing	Overlay tack coat Cold mix Warm mix	Trade name is Vegeflux ®
Bio-binder	Denevillers 2010	Chip seals Microsurfacing	Cold in-place recycling Chip seals	Trade name is Vege-col ®
Recycled concrete aggregate (RCA)	Gardner and Greenwood 2008	Whitetopping	Full-depth patching Partial-depth patching	RCA acts to sequester CO2 in addition to recycling
Recycled glass gravel	Melton and Morgan 1996	Untried	Unbound base courses	Potential use on gravel roads
Fly ash	MnDOT 2005	Microsurfacing filler Slurry seal filler	Concrete maintenance mixes Microsurfacing	Widely used in a variety of products
Bottom ash	Carpenter and Gardner 2007	Microsurfacing mineral filler	Subase under gravel surface	
Flue gas desulpherization gypsum	Benson and Edil 2009	Microsurfacing filler Slurry seal filler	Concrete maintenance mixes	
Kiln dust	MnDOT 2005	Prime coat Microsurfacing	Prime coat Microsurfacing	
Baghouse fines	ISSA 2010	Microsurfacing mineral filler Slurry seal filler	Untried	
Crushed slag	Chappat and Bilal 2003	Chip seal aggregate	Special binder road mix	
Ultra-high pressure water cutter	Pidwerbesky and Waters 2007	Restore macrotexture on chip seals	Retexture chip sealed roads prior to resealing.	Uses no virgin material and the sludge can be recycled as precoating for chip seal aggregates
Shotblasting	Transport Canada 2003	Restore microtexture on polished hot-mix Asphalt (HMA) and Portland cement concrete (PCC) pavements	Restore skid resistance on resealed PCC bridge decks	Uses no virgin material and the steel shot is recycled for reuse in the process

(continued)

Table 14.3 (continued)

Material/ technique	Literature cite	Possible preservation uses	Possible maintenance uses	Remarks
Recycled motor oil	Waters 2009	Dust palliative Otta seals	Otta seal as surface course	Motor oil is refined before use
Recycled tire rubber	Beatty et al. 2002	Chip seals Thin overlays	Chip seals Thin overlays	Also found to reduce road noise.

rudimentary. A recent study found that the standard FHWA-approved life cycle cost analysis method for new construction is not easily applied to pavement preservation projects (Pittinger 2010). As a result, rigorous research would be needed in order to apply a life cycle cost analysis algorithm which goes beyond merely looking at treatment construction costs and provides a rigorous methodology to assign a value to such things as carbon sequestration and resource renewability.

14.6 State-of-the Practice in Sustainable Pavement Preservation and Maintenance

The Transportation Research Board (TRB) of the US National Academies sponsored a study by the authors of this chapter to benchmark the state-of-the-practice in sustainable pavement preservation and maintenance practices in North America (Tighe and Gransberg 2011). As part of the study a survey was issued to all US state departments of transportation (DOT) and Canadian ministries of transportation (MOT). Responses were received from 42 US DOTs and 7 Canadian provincial MOTs, yielding a response rate of 84 and 70 % respectively. The survey was aimed at finding out three primary factors:

- Did the agencies have formal plans or policies to incorporate sustainability into the design and/or construction of pavement preservation treatments?
- What treatments were in use and how did the agencies view the level of sustainability of each treatment?
- How widespread was the use of the most sustainable treatments?

This section presents the environmental sustainability impact factor areas and the extent to which the TRB survey responses used them in their construction and maintenance decisions. Environmental stewardship considers the **use of renewable resources** at *below their rates of regeneration* and **nonrenewable resources** *below rates of development of substitutes* as noted by the first two environmental sustainability impact factor areas. In addition, the need to provide a clean environment from both an air quality and water quality perspective should be included in an environmental monitoring plan, as well as, including pollution prevention, climate protection, habitat preservation and aesthetics (Ramani et al.2009).

14.6.1 Recycling, Reusing, and Reclaiming of Existing Materials

Recycling, reusing, and reclaiming of existing materials is crucial to advance sustainable development (Carpenter 2007). Construction materials can be expensive and some resources already have limited supply, making it important to make good utilization of available materials. One of the concerns with recycled material usage is potential uncertainty regarding the actual composition of a recycled material when compared to the virgin material it would replace. As a result, some agencies have withheld permission to use recycled materials while others have limited the amount of recycled material that can be incorporated into the pavement structure (Melton 1996; Smith 2009). Several successful uses of Recycled Asphalt Pavement (RAP), and Recycled Concrete Aggregate (RCA) are available in the literature and it can be noted that in addition to providing technical benefits, they improve the performance of the pavement (Scholz 2010; Smith 2009; Alkins et al. 2008; Tighe 2008; Beatty et al. 2002; Hansen and Copeland 2013). Further, both hot and cold in-place recycling are used by agencies for maintenance and rehabilitation of pavements, minimizing the amount of new materials for the work and reducing energy requirements for transporting materials to the jobsite. Table 14.4 shows that roughly 70 % of the responding agencies permit the use of recycled materials in their pavement preservation and maintenance programs.

14.6.2 Alternative Materials

Alternative materials also hold promise to be able to enhance environmental sustainability in pavement preservation and maintenance. Research has shown that materials such as RAS, recycled rubber tire, recycled glass, and reclaimed carbon from copier toner can be successfully incorporated into new pavements (Chan 2010). The incorporation of innovative materials can also potentially enhance pavement performance and reduce the demand for virgin materials (Horvath 2004). Thus, the survey sought to find the level of alternative material usage in agency pavement preservation and maintenance programs in Canada and the US. Table 14.9 shows that alternative materials have a lower level of use than recycled pavement materials, probably awaiting further research into their long-term performance in maintenance applications. Table 14.5 reflects the relatively widespread use of fly ash in concrete, as well as asphalt shingles and recycled rubber tires in HMA pavements. However, use of other alternative materials remains relatively uncommon. These results suggest that future research into applications and performance of alternative materials could be of value.

Table 14.4 Summary of recycled and alternative materials authorization in pavement maintenance program

	Are recycled materials allowed in your current program?		Are alternative materials allowed in your current program?	
	No	Yes	No	Yes
Canada	0	7	2	5
USA	14	28	18	24
Total	14	35	20	29
Percentage (%)	28.6	71.4	40.8	59.2

Table 14.5 Summary of recycled and alternative material usage by pavement type

Recycled/alt material	Gravel		Surface treated		Asphalt	
	Canada	USA	Canada	USA	Canada	USA
Fly ash	0	0	0	1	1	0
Shingles	0	1	0	1	2	13
Tire rubber	0	1	0	1	2	13
Glass	0	2	0	0	0	3
Foundry sand	0	0	0	0	0	1
Carbon	0	0	0	0	0	1
Recycled/alt material	*Concrete*		*Composite*		*Total*	*Percentage (%)*
	Canada	*USA*	*Canada*	*USA*		
Fly ash	4	21	0	1	28	57.1
Shingles	0	0	0	0	17	34.7
Tire rubber	0	0	0	0	17	34.7
Glass	0	1	0	0	6	12.2
Foundry sand	0	2	0	0	3	6.1
Carbon	0	0	0	0	1	2.0

14.6.3 Noise Pollution

Minimizing or eliminating noise pollution is another element of a sustainable design and construction program, and it follows that standards imposed on construction may also be applicable to maintenance operations. Table 14.6 shows the results of that portion of the survey. It shows that only about 21 % of the respondents felt that noise pollution is an important/very important issue in their agencies. Only 7 % were aware of noise standards for their agencies' pavement maintenance operations; whereas over one third of the survey respondents did not

Table 14.6 Summary of noise pollution measures

	How important is noise distribution during pavement maintenance operations in your agency?						Agency noise standards in effect				
	Very important	Important	Neutral	Not important	Not even considered	No opinion	Construction noise	Maintenance noise	Traffic noise	No noise standard	Don't know
Canada	0	1	3	0	2	1	2	1	0	4	0
US	4	4	12	0	4	11	7	2	3	11	15
Total	4	5	15	0	6	12	9	3	3	15	15
Percentage (%)	9.5	11.9	35.7	0.0	14.3	28.6	21.4	7.1	7.1	35.7	35.7

Table 14.7 Summary of water quality policies

	Water quality considered?			Agency water quality guidelines?		
	No	Yes	Don't know	No	Yes	Don't know
Canada	4	2	1	3	3	1
USA	8	17	12	5	17	15
Total	12	19	13	8	20	16
Percentage (%)	27.3	43.2	29.5	18.2	45.5	36.4

have any noise standards for maintenance operations. Relevant future research could help establish appropriate noise standards for construction and maintenance operations, and provide a tool for using noise considerations as part of treatment selection. As noted by the high "no opinion" or "don't know" category, it would be suggested that education and training could be provided in this environmental sustainability impact factor area for maintenance personnel.

14.6.4 Water Quality

For the environmental sustainability factor of water quality, there is a similar unfamiliarity among the survey respondents about how agency policies applied to maintenance activities. Based on this evaluation, there are no current measures available which quantify the effects of pavement maintenance and preservation on water quality. The data in Table 14.7 indicates that the pavement preservation and maintenance treatment's impact on water quality is considered less than half the time. That is probably because less than half the responding agencies indicated that they have agency water quality guidelines. The fact that roughly a third of all respondents did not know if their agency considered water quality or had water quality guidelines validates the conclusion that coupling programmatic environmental sustainability with pavement preservation and maintenance programs has not yet happened in North America. Again, this would reinforce both the need to develop measures in this area for quantification.

14.6.5 Air Quality and Energy Use

Table 14.8 shows that the news with regard to air quality is better. A little over 60 % of the agencies reported that they monitor air quality in the course of their pavement maintenance operations. However, only 25 % of the agencies consider energy usage when selecting pavement preservation and maintenance treatments. Both of these are areas where the use of preventive maintenance treatments in a pavement preservation program can have noticeable effect. Many of the treatments

Table 14.8 Summary of air quality monitoring and energy usage

	Air quality monitoring?			Energy usage considered?		
	No	Yes	Don't know	No	Yes	Don't know
Canada	0	7	0	3	3	1
USA	2	20	15	15	8	14
Total	2	27	15	18	11	15
Percentage (%)	4.5	61.4	34.1	40.9	25.0	34.1

are emulsion-based, with comparatively low emissions during construction, although the emissions during bitumen manufacture can be significant. Similarly, providing quantitative measures for differences among energy use among the various treatments would be a valuable tool in treatment selection.

The recycled and alternative materials authorization is the most prevalent. Although it is not explicitly stated, the role of pavement in-service monitoring and pavement management is also common. If implemented properly, a pavement management program that improves sustainability emerges because the pavement monitoring system triggers pavement preservation activities, which in turn extend the service life of the pavement and reduce the impact to the environment in all categories. In short, keeping good roads good is the most effective way to sustain the service life of a road while reducing the consumption of energy, virgin materials, and nonrenewable resources, which automatically reduces air, water, and noise pollution.

A study of the Georgia DOT network-level pavement management system (Wang 2010) demonstrated that such a system also makes economic sense. The report found that a robust in-service pavement monitoring system "will help decision makers address the question of paying for roadway preservation now at a lower cost or later at a much higher cost" (Wang 2010). Further examination and quantification of this impact is required as the direct policies and practices to pavement preservation and maintenance treatments should be explicitly reviewed for these environmental sustainability impact factor areas. In terms of noise pollution, water quality and air quality, there is clearly an opportunity to incorporate these environmental sustainability impact factor areas into preservation and maintenance operations.

14.7 Rated Performance Versus Practices

The final portion of the survey sought to quantify the perceptions of pavement preservation and maintenance practitioners with regard to the environmental sustainability of their current practices. The analysis had two parts. First, the survey asked how they considered the contribution to overall environmental sustainability of commonly used practices. The study found that the Canadian and US practitioners agree that the two practices that contribute the greatest degree toward

Table 14.9 Rated sustainability of common treatments

Pavement type	Percentage usage (%)	Rated sustainability		
		1 = very sustainable to 4 = not sustainable		
Asphalt		Combined	Canada	US
Chip seal	87.5	1.8	2.0	1.7
Thin overlay	93.8	2.0	2.3	1.9
Microsurfacing	84.4	2.1	2.0	2.1
Crack seal	53.1	2.2	2.0	2.2
Hot patches	87.5	2.4	2.2	2.5
Slurry seal	50.0	2.4	2.5	2.4
Fog seal	43.8	2.6	2.5	2.6
Cold patches	68.8	2.7	2.4	2.7
Concrete		*Combined*	*Canada*	*US*
Diamond grinding	92.6	2.0	2.3	2.0
Joint sealing	88.9	2.2	2.0	2.2
Crack seal	59.3	2.3	2.0	2.3
White topping	29.6	2.4	2.0	2.4
Shotblasting	22.2	2.4	2.0	2.5

promoting environmental sustainability are material quality and selection and maintenance timing.

Next the respondents were asked to rate the environmental sustainability of several common pavement preservation and maintenance treatments from an overall holistic approach based on their engineering judgment. Note the respondents all had extensive pavement maintenance experience and their experience was deemed to be key to the analysis. Table 14.9 shows the outcome of that exercise. The combined perception is that chip seals are the most sustainable treatment for asphalt pavements while diamond grinding is more sustainable for concrete pavements.

It is interesting to note that when the actual usage of each treatment is compared with its environmental sustainability ranking, a trend regarding fundamental practice of sustainable pavement preservation and maintenance programs can be found. Those trends for asphalt and concrete pavements are shown in Figs. 14.3 and 14.4. In both figures the trend is clear. The rated environmental sustainability of the treatment is directly proportional to its use. Therefore, even though the responding agencies did not indicate that formal environmental sustainability considerations or programs were a significant part of their program, it appears that they believe that treatments that they use most often are sustainable. When the asphalt overlay is compared to the chip sealing and microsurfacing, the focus is on expected service life rather than energy usage or virgin material usage.

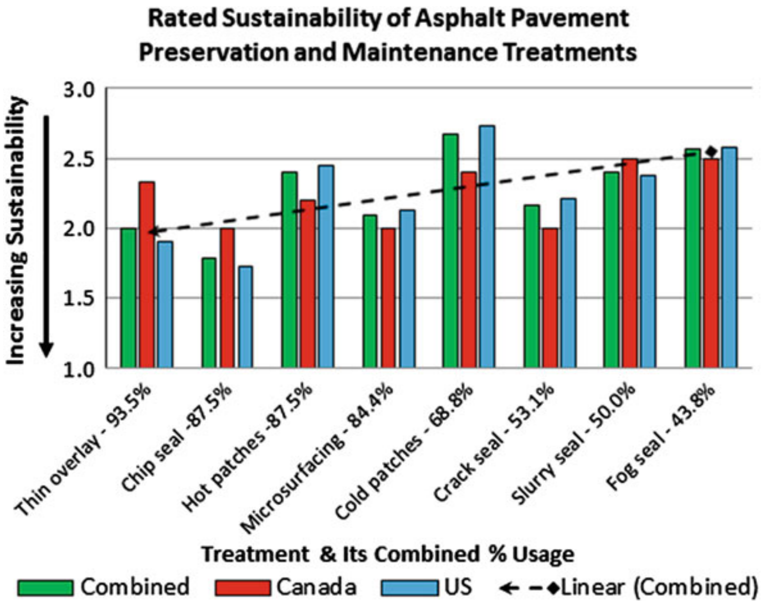

Fig. 14.3 Asphalt pavement trend in usage versus rated sustainability

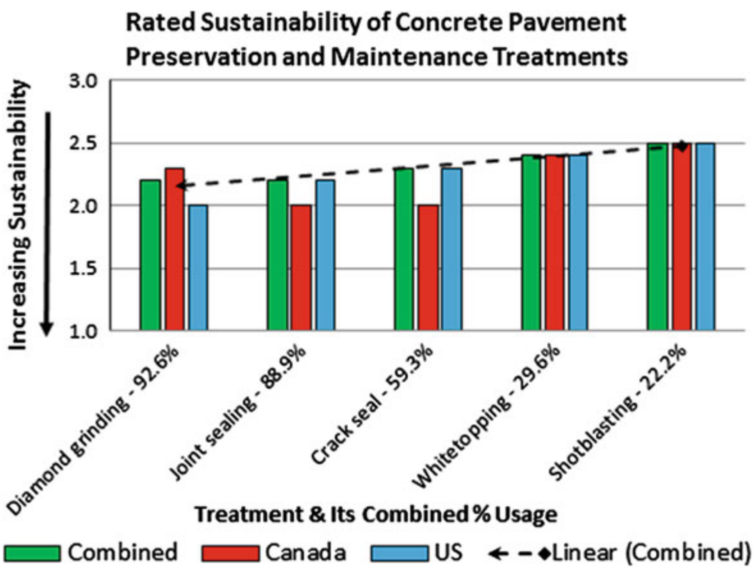

Fig. 14.4 Concrete pavement trend in usage versus rated sustainability

Furthermore, because agency maintenance budgets are usually fixed amounts that do not directly reflect the actual amount of maintenance needs, then using service life as the primary factor for sustainability may be a good approach. For example, in a life cycle assessment where a longer service life can compensate for the incremental increase in the amount of energy and virgin materials usage, and from the perspective of an agency pavement manager, it means that road will not need attention for an extended amount of time. Therefore, the observation that the perception of a treatment in terms of the environmental sustainability impact factor areas is directly proportional to its usage is validated.

14.8 Industry Initiatives to Measure Sustainability in Highways

As the concept of environmental sustainability becomes more important to highway agencies, they have become aware of the need to quantify their actions and programs in environmental terms. A number of different environmental sustainability measurement initiatives have been developed, providing rating systems or "scorecards" for agencies' use. Four examples of environmental sustainability initiatives for highway pavements are Greenroads (Muench 2010), GreenLITES (NYDOT 2009), Green Guide for Road Task Force (TAC 2010), and GreenPave (MTO 2010). The study found that while these rating systems had some reference to pavement maintenance, the real focus was on new construction and that limited its utility for quantifying sustainability in pavement preservation treatments. Two other initiatives were found that have been developed by the private sector and are worth noting as they promise to provide a foundation for the future advancement of this topic. For more detailed information on pavement LCA, mostly applied to estimate GHG emissions, the readers are directed to the following chapters in this book:

- The Product Process Service Life Cycle Assessment Framework to Estimate GHG Emissions for Highways (Mukherjee and Cass)
- Pavement Life-Cycle Assessment (Parry and Huang)
- Application of LCA Results to Network-level Highway Pavement Management (Harvey, Wang and Lea)

Many commonly used preventive maintenance treatments are "greener" than major rehabilitation or reconstruction, conserving energy, virgin materials, and reducing greenhouse gases by keeping good roads good (Chehovitz 2010). Figure 14.5 shows of the type of comparative analysis that can be done if the information for each possible maintenance treatment was available. In this example, microsurfacing's environmental footprint is shown to be among the lowest of three commonly used alternatives (Takamura 2001). The study developed "eco-efficiency" indices for the five categories shown as shown in the figure.

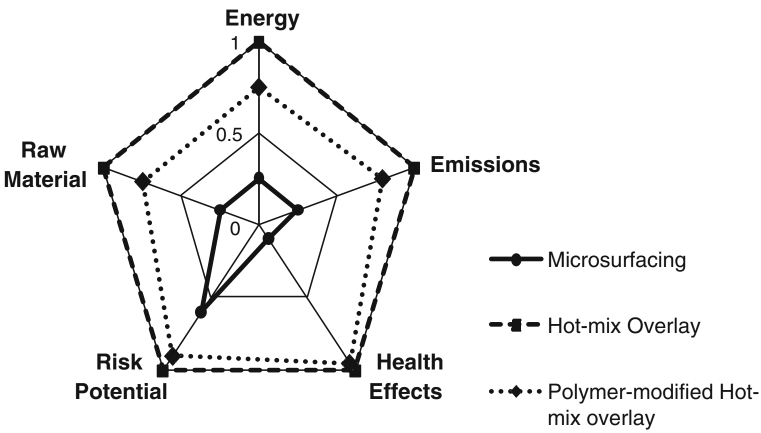

Fig. 14.5 Microsurfacing ecological fingerprint compared to three types of pavement preservation overlays (after Takamura 2001)

Another factor that could have been included in the calculation is the reduced gas emissions due to microsurfacing's ability to greatly reduce traffic delays in work zones (Johnson et al. 2007). Additionally, the "risk potential" and "health effects" categories did not include the reduction in work zone accident risk inherent to a fast curing treatment like microsurfacing because the primary focus of the study was on accident reduction (Erwin and Tighe 2008). A benefit of having quantified environmental sustainability data is it provides the engineer with necessary information for justification to offset any marginal increase in construction cost of one treatment versus other lower priced alternatives.

It must be noted that all of the three treatments in Fig. 14.5 would be considered as part of a pavement preservation program (FHWA 2005). Therefore, if environmental sustainability was the primary decision factor and if the engineer could establish that performance was otherwise comparable, the radar diagram shows that microsurfacing would be the more sustainable option. Data are lacking to apply this analysis to the full suite of potential rehabilitation and maintenance treatments. Subsequent research could provide applicable values for all possible treatments in all seven environmental sustainability impact factor areas

14.9 Summary

Currently, public agencies in the US and Canada have done very little to extend the knowledge gained from research and practice in sustainable highway project delivery beyond construction completion and into the pavement preservation and maintenance phase of a road's life cycle. Thus, there are many opportunities for future research and enormous potential for agencies to accrue benefits in this area of practice. These potential benefits are diverse and of strategic importance as they encompass improvements to virgin material usage, alternative material usage, pavement in-service monitoring and management, noise, air quality, water quality and energy usage. Treatments identified in this chapter are primarily related to preservation and maintenance. However, these are not exclusive to preservation and maintenance and can be used in pavement rehabilitation.

Optimization of pavement preservation practices and keeping them adequately funded can potentially improve pavement sustainability. Therefore, the bright light in this analysis is that North American transportation agencies are committed to the concept of preserving the network and have shown a willingness to invest in preservation as evidenced by the FHWA policy to permit federal-aid highway funding for preservation projects. Thus, the next step is to invest in the treatment types themselves and take pavement preservation and maintenance to an even higher level of sustainability by selecting treatments that minimize the impact to the environment.

References

Alkins, A., Lane, B., & Kazmierowski. T. (2008). *Sustainable pavements environmental, economic, and social benefits of in situ pavement recycling* (pp. 100–103). Transportation Research Record No. 2084. Washington, DC: National Academy of Sciences.

Amekudzi, A., & Jeon, C. M. (2007). Evaluating transport systems sustainability: Atlanta metropolitan region, *Presented at 86th Annual Meeting of the Transportation Research Board*, Washington, D.C.

Ball, G. F. A., Harrington, P. R., & Patrick, J. E. (2008). *Environmental effects of emulsions, land transport New Zealand research Report 343* (p. 47). New Zealand Transport Agency: Wellington, NZ.

Beatty, T. L. et al. (2002). *Pavement preservation technology in France, South Africa, and Australia*, Report FHWA-PL-3-001 (p. 56). Office of International Programs, Federal Highway Administration, American Trade Initiatives, Alexandria, Va: Washington, D.C.

Benson, C., & Edil, T. (2009). *Quantifying the benefits of using coal combustion products in sustainable construction* (p. 45). EPRI: Palo Alto, CA.

Bruntdland Commission. (1987). *World commission on environment and development. our common future*. Oxford England: Oxford University Press.

California Department of Transportation. (2008a). Maintenance technical advisory guide *(MTAG)*, *Flexible Pavement Preservations* (Vol. 1, 2nd ed.). Training Modules, California Department of Transportation, Office of Pavement Preservation, Division of Maintenance. Access: http://www.dot.ca.gov/hq/maint/PavePres/ppindex.htm

California Department of Transportation. (2008b). *Maintenance technical advisory guide (MTAG)*, *Rigid Pavement Preservation* (Vol. 2, 2nd ed.). California Department of Transportation, Office of Pavement Preservation, Division of Maintenance. Access: http://www.dot.ca.gov/hq/maint/MTA_GuideVolume2Rigid.html

Carpenter, A. C., & Gardner, K. H. (2007). Recycled material highway construction environmental assessment: life cycle based risk assessment of recycled materials in roadway construction. *Final Report for RMRC Research Project, 43*, 12.

Center for Environmental Excellence (CEE) (2010a) "Noise," American Association of State Highway and transportation, (AASHTO). Access: http://www.environment.transportation.org/tools/print.aspx

Center for Environmental Excellence (CEE) (2010b) “Air Quality,” (AASHTO). Access: http://www.environment.transportation.org/tools/print.aspx

Center for Environmental Excellence (CEE) (2010c) “Water Quality/Wetlands,” (AASHTO). Access: http://www.environment.transportation.org/tools/print.aspx

Center for Environmental Excellence (CEE) (2010d) “Sustainability,” (AASHTO). Access: http://www.environment.transportation.org/environmental_issues/sustainability

Chaignon, F., & Mueller, S. (2009). *Calculating CO_2e emissions?*. Scottdale, AZ: A discussion with the PPETG.

Chan, P., & Tighe, S. (2010). *Quantifying pavement sustainability* (p. 5). Ontario: Ministry of Transportation of Ontario.

Chappat, M., & Bilal, J. (2003). *Sustainable development, the environmental road of the future: Life cycle analysis*. Colas: The Road Forward.

Chehovitz, J., & Galehouse, L. (2010). *Energy usage and greenhouse gas emissions of pavement preservation processed for Asphalt concrete pavements: Proceedings on the 1st International Conference of Pavement Preservation* (pp. 27–42). Newport Beach: California, April.

Deneviller, C. (2010). *Renewable carbon-based binders for pavement preservation: Proceedings ISSA Annual Conference* (p. 31). Florida: Sunny Isles.

Erwin, T., & Tighe, S. L. (2008). Safety effect of preventive maintenance: A case study of microsurfacing. transportation research record. *Journal of the Transportation Research Board 2044*, 79–86.

Federal Highway Administration (FHWA). (2005). *Action pavement preservation definitions, Federal Highway Administration*. Access http://www.fhwa.dot.gov/pavement/preservation/091205.cfm

Federal Highway Administration (FHWA). (2001) *Crack seal application, Pavement preservation checklist series* (Vol. 1), Publication No. FHWA-IF-02-005, p. 16.

Federal Highway Administration (FHWA). *Joint sealing in Portland cement concrete pavements, Pavement preservation checklist series* (Vol. 6), Publication No. FHWA-IF-03-003, p. 34.

Federal Highway Association (FHWA). (2000) *Gravel roads: Maintenance and design manual, Federal Highway Administration, South Dakota Local Transportation Assistance Program (SD LTAP)*, November 2000.

Galehouse, L., King, H., Leach, D., Moulthrop, J. & Ballou, B. (2005). *Preservation maintenance treatment performance at 14 years*. Transportation Research Board.

Gardner, K., & Greenwood, S. (2008). Sustainable highways through the use of carbon sequestering construction materials. *Final Report for RMRC Research Project, 35*, 43.

Gransberg, D. D., & James, D. M. B. (2005). *Chip seal best practices, national cooperative highway research program synthesis* (Vol. 342, p. 124), ISBN 0-309-09744-4. Washington, D. C: Transportation Research Board, National Academies.

Hansen, K. R., & Copeland, A. (2013). Annual Asphalt pavement industry survey on recycled materials and warm-mix asphalt usage: 2009–2012. *NAPA Information Series (IS)* (Vol. 138). MD: Lanham.

Harmon, T. (2010). *Sustainable transportation* (p. 9). International Sustainable Pavements Workshop: Virginia Tech/Nottingham Transportation Engineering Center, Washington DC, Januray.

Hicks, R. G., Dunn, K., & Moulthrop, J. S. (1997). Framework for *selecting effective preventive maintenance treatments for flexible pavements, transportation research record 1597* (pp. 1–10). Washington D.C: TRB, National Research Council.

Horvath, A., Pidwerbesky, B. & Waters, J. (2004). *Sustainable Innovative Surfacing Treatments for Low Volume Roads*, Transportation Research Record 1989, TRB, National Research Council, Washington, D.C, 2007, pp. 1–10.

Horvath, A. (2009). Pavement life-cycle assessment tool for environmental and economic effects. Retrieved April 2, 2009 from http://www.ce.berkeley.edu/~horvath/palate.html

Infraguide. (2005). *Reuse and recycling of road construction and maintenance materials* (Vol. 11), Federation of Canadian Municipalities and National Research Council.

International Organization for Standardization (ISO). (2006). *Environmental management—Life cycle assessment—principles and framework* (2nd ed.). International Standard ISO 14040, September 2006.

International Slurry Surfacing Association (ISSA). (2010). *Inspector's manual for slurry systems* (p. 106). Annapolis, MD: International Slurry Surfacing Association.

James, A. (2006). *"Overview of Asphalt emulsion", transportation research circular E-C102* (pp. 1–6). Washington, D.C: Transportation Research Board of the National Academies.

Jeon, C., & Amekudzi, A. (2005). Addressing sustainability in transportation systems: Definitions, indicators, and metrics, *Journal of Infrastructure Systems,11*, 31–50.

Johnson, N., Wood, T. J. & Olson, R. C. (2007). *Flexible slurry-microsurfacing system of overlay preparation, transportation research record: journal of the transportation research board* (Vol. 1989, pp. 18–26). Washington, D.C: Transportation Research Board of the National Academies.

Kober, W.W. (2009). The road to environmental stewardship via in-place pavement recycling, Midwestern States regional in-place recycling conference Bloomington, Minnesota, August 2009.

Melton, J. S. & Morgan, T. (1996). Evaluation of tests for recycled material aggregates for use in unbound application. *Final Report of RMRC Project* (Vol. 6, p. 18).

Ministry of Transportation (MTO). (2010). *Ontario's transportation technology transfer digest, ministry of transportation* (Vol 16, Issue 1). Winter 2010.

Minnesota Department of Transportation (MnDOT). (2005). *Standard specifications for construction, minnesota* (p. 776). St. Paul, Minnesota: Department of Transportation.

Moulthrop, J. S. & Smith, R. E. (2007). *State of the art and state of the practice in pavement maintenance*, Transportation Research Board.

Muench, S. (2010). *Greenroads v1.0 Rating System*. Washington: University of Washington.

New York Department Of Transportation. (2009). *NYDOT*. NY: GreenLITES Project Design Certificate Program, New York State Department of, Transportation (NYSDOT).

Newman, C. (2010). *Pavement preservation checklist series*, Personal Communication.

Peshkin, D. G., & Hoerner, T. E. (2005). *Pavement preservation: Practices, research plans, and initiatives*. Washington, D.C: National Cooperative Highway Research Program, Transportation ResearchBoard, National Research Council.

Pidwerbesky, B., & Waters, J. (2007). *Sustainable innovative surfacing treatments for low volume roads* (pp. 1–10). Washington, D.C: Transportation Research Record 1989, TRB, National Research Council.

Pittenger, D. M. (2010). *Life cycle cost-based pavement preservation treatment design* (p. 67). Master's Thesis. Norman, Oklahoma: University of Oklahoma.

Ramani, T., Zietsman, J., Eisele, W., Rosa, E., Spillane, D., & Bochner, B. (2009). *Developing sustainable transportation performance measures for TXDOT's strategic plan: Technical Report*. Austin: Texas Department of Transportation.

Schmidt, I., Meurer, M., Saling, P., Kicherer, A., Reuter, W., & Gensch, C. O. (2004). SEEbalance® managing sustainability of products and processes with the socio-eco-efficiency analysis by BASF. *Green Management International, 45*, 79–94.

Scholz, T. V. (2010). Preliminary investigation of RAP and RAS in HMAC, Oregon Department of Transportation, February 2010.

Smith, J., & Tighe, S. (2009). *Recycled concrete aggregate coefficient of thermal expansion: Characterization, variability and impacts on pavement performance* (Vol. 2113, pp. 53–61). Washington, D.C: National Academy of Sciences, Transportation Research Record.

Stephanos, P. (2009). Focus: Strategic, safe, and sustainable: Today's vision for pavements, Federal Highway Administration, December 2009.

Takamura, K., Lok, K. P., & Wittlingerb, R. (2001). *Microsurfacing for preventive maintenance: eco-efficient strategy* (p. 5). Maui, Hawaii: International Slurry Seal Association Annual Meeting.

Tighe, S, Hanasoge, N., Eyers, B., Essex, R., & Damp, S. (2008). *Who thought recycled asphalt shingles (ras) needed to be landfilled: Why not build a road?*. Toronto: Transportation Association of Canada Conference Proceedings.

Tighe, S. L. & Gransberg, D. (2011). *Sustainable pavement maintenance practices* (Vol. 365). Washington, D.C: NCHRP Research Results Digest.

Transport Canada. (2003). *Runaway rubber removal and retexturing by shotblasting*, Pavement Maintenance Specification, Section PMS-5540, Civil Aviation International Aviation and Technical Programs, Ottawa, Ontario, Canada, May 2003, p. 3.

Transportation Association of Canada (TAC). (2010). Green guide for roads, transportation association of Canada. Retrieved March 3, 2010 from www.tac-atc.ca/english/projects/greenguide.cfm

Uhlman, B. (2010). Eco-efficiency of microsurfacing, proceedings, AEMA-ARRA-ISSA annual meeting, sunny Florida: Isles, p. 56.

United States Green Building Council USGBC. (2010). Green building by the numbers, US green building council (USGBC). Access: http://usgbc.org/ShowFile/aspx?DocumentID=3340

Wang, Z., Tsai, Y., & Pitts, E. (2010). Pavement preservation: pay now or pay big later, compendium of papers from the First International Conference on Pavement Preservation. Newport Beach, California, April 2010, pp. 85–102.

Waters, J. (2009). *Long-term dust suppression using the otta seal technique, New Zealand Transport Agency Research Report 368* (p. 5199). NZTA: Wellington, New Zealand.