5-2017

A tool to evaluate sustainability of pavement maintenance projects.

Yibo Zhang
University of Louisville

A TOOL TO EVALUATE SUSTAINABILITY OF PAVEMENT MAINTENANCE PROJECTS

By

Yibo Zhang
B.S., Zhengzhou University, China, 2008
M.S., Chongqing Jiaotong University, China, 2012

A Dissertation
Submitted to the Faculty of the
J.B. Speed School of Engineering of the University of Louisville
in Partial Fulfillment of the Requirements
for the Degree of

Doctor of Philosophy
in Civil Engineering

Department of Civil and Environmental Engineering
University of Louisville
Louisville, Kentucky

May, 2017

A TOOL TO EVALUATE SUSTAINABILITY OF PAVEMENT MAINTENANCE PROJECTS

By

Yibo Zhang
B.S., Zhengzhou University, China, 2008
M.S., Chongqing Jiaotong University, China, 2012

A Dissertation Approved on
December 12, 2016

by the following Dissertation Committee:

____
Dissertation Director
Dr. J.P. Mohsen

____
Dr. Zhihui Sun

____
Dr. T.D. Rockaway

____
Dr. Lihui Bai

DEDICATION

This dissertation is dedicated to my girlfriend

Yiming Zhong

As the third author

Also to my parents

Ms. Suxiang Yang

and

Mr. Guangli Zhang

For their love

ACKNOWLEDGEMENTS

I always remember the day I met my advisor, Dr. J.P. Mohsen, for the first time in Chongqing, I have received a lot of support and encouragement from him since then. I miss our discussions on my research as well as the wonderful trips in Washington D.C. and China. I would like to express the deepest appreciation to him for his patience, kindness, and immense knowledge.

I would like to thank the rest of my dissertation committee: Dr. Zhihui Sun, Dr. Thomas D. Rockaway, and Dr. Lihui Bai for their thoughtful ideas and insightful comments about my research, but also for the hard questions which incented me to improve my research from various perspectives. My sincere thanks also go to Ms. Sarah Lynn Cunningham, for enlightening me to recognize the relevance of sustainability in pavement maintenance engineering.

Many thanks to the professionals I have met and spoke with during my field investigations. They are the experts in the field and provided valuable advice to my investigations.

I am grateful to the faculty and staff in our CEE Department, especially Dr. Young Hoon Kim, Mr. M. Brandon Shelley, and Ms. Gail Graves, for their help and assistance during my Ph.D. program. It was fantastic to have the opportunity to work with the talented people in our CEE Department: Li Yang, Ying Zhang, Fengjuan Liu, Shanshan Li, Song Wang, Austin Connor, Mohammad Ghavami, and Mahyar Ramezani.

With a special mention to Wenqi Liu, Zhenzhen Xie, Zhichao Lu, Qi Li, and Ran Tian, the members of "Louisville Hotpot Group", as well as Xiaohui Zhang, Tao Tang and Long Li. When I needed help, they were always there, and gave me the best memories in Louisville.

To my parents. I must express my very profound gratitude to them for all the opportunities they have offered, all the moral and emotional support they have provided, and all the forgiveness they have given in my life. They are amazing individuals and best examples of giving, perseverance, courage, and responsibility.

To Yiming Zhong. From the preparation of proposal to the finalization of dissertation, she spent countless hours listening to my ideas, proofreading the drafts, and cheering me up, even when she was already busy with her own study and work. Without her companionship and persistent help it would not have been possible for me to finish my research on schedule.

I also place on record, my sense of gratitude to one and all, who directly or indirectly, have lent their hands in this venture.

To this journey, to the days and nights I spent at University of Louisville.

"You fought battles, overcame obstacles.

You had a goal, gave it your soul.

You worked hard, went the extra yard.

You gave it your all, today you stand tall."

----Anonymous

ABSTRACT

A TOOL TO EVALUATE SUSTAINABILITY OF PAVEMENT MAINTENANCE PROJECTS

Yibo Zhang

December 12, 2016

Pavement maintenance activities are widely regarded to be critical elements during pavement life cycle, different maintenance techniques have been used to restore or extend the service lives of pavements. However, the existing maintenance practices on pavement system have problems that impair the economic benefits, disturb the natural environment, and somewhat ignore the needs from stakeholders. To minimize these negative impacts, sustainability is an ideal way because it addresses the problems under Triple Bottom Line (TBL, refers to economy, environment, and society). Sustainability analysis within transportation or pavement industry has been studied in different countries, but the concept of sustainable pavement maintenance is relatively new and has not been defined well yet. In this research, the concept of sustainable pavement maintenance has been proposed and defined to help benefit the current pavement industry.

Rating tool has its advantages measuring sustainability activities. There are many rating tools designed for sustainable infrastructure, transportation, or pavement, but

maintenance has its own characteristics and yet never had its own rating tool. To link the theoretical concept of sustainable pavement maintenance with actual projects, a sustainability rating tool for pavement maintenance (Pavement Sustainability Index for Maintenance, PSIM) has been developed by a so-called 5-step methodology. Step one and two are to determine the rating categories and indicators; step three is to determine the priority of each category by the Analytic Hierarchy Process (AHP); step four is to determine points distribution under each indicator by reviewing the sustainability practices of 8 State DOTs; final step is to propose the certification methodology according to the Pavement Sustainability Index (PSI) earned by the maintenance project.

To prove the usability value of PSIM, four common maintenance activities have been discussed as case studies, including rejuvenation, utility cut restoration (UCR), overlay, as well as mill and overlay. The projects selected were located in or adjacent to Louisville, KY. Among the nine projects being evaluated by PSIM framework, UCR projects were not sustainable; rejuvenation project, overlay projects, and one of the mill and overlay projects earned one PSIM star; two PSIM stars were awarded to two of the mill and overlay projects.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Pavement is one of the most important components of infrastructure. However, pavements and their ancillary facilities continue to deteriorate since they were built, therefore they have to be maintained properly to perform well and serve users well. Traditional pavement maintenance has different types of problems encountered by the stakeholders which will negatively affect either the maintenance itself or the maintaining results. In order to minimize those negative effects, a new concept should be brought to the pavement maintenance industry. This chapter describes the background, objective, significance, and scope of this research.

1.1 Background

1.1.1 Highway Transportation in the U.S.

Transportation infrastructure construction is the cornerstone to support economic development. Highway transportation is the dominant transportation mode used in the United States to move people and goods according to the data provided by U.S. Department of Transportation and Bureau of Transportation Statistics as shown in Table 1.1~1.3 (BTS, 2015). Besides, as can be seen from Fig. 1.1, travel demands from people and freight on pavement keep at a high level and have been still growing over the years (BTS, 2015).

Table 1.1 System Mileage within the United States in 2011 (Statute miles)

Highway (paved and unpaved)	Rail	Amtrak	Transit	Channels
4,077,756	95,387	21,225	10,933	25,000

Table 1.2 U.S. Vehicle-Miles in 2012 (Millions)

Air	Highway	Transit	Train
5,965	2,968,815	3,961	538

Table 1.3 Fuel Consumption by Mode of Transportation in 2012

Air	Highway	Transit	Rail	Amtrak	Water
11,950 MG	167,906 MG	6,506 MkWh; 839 MG	3,600 MG	549 MkWh; 63 MG	7,681 MG
jet fuel and aviation gasoline	gasoline, diesel and other fuels	electricity; motor fuel	distillate/ diesel fuel	electricity; distillate/ diesel fuel	residual fuel oil, distillate/ diesel fuel, and gasoline

Note: MG – Million Gallons; MkWh – million kWh

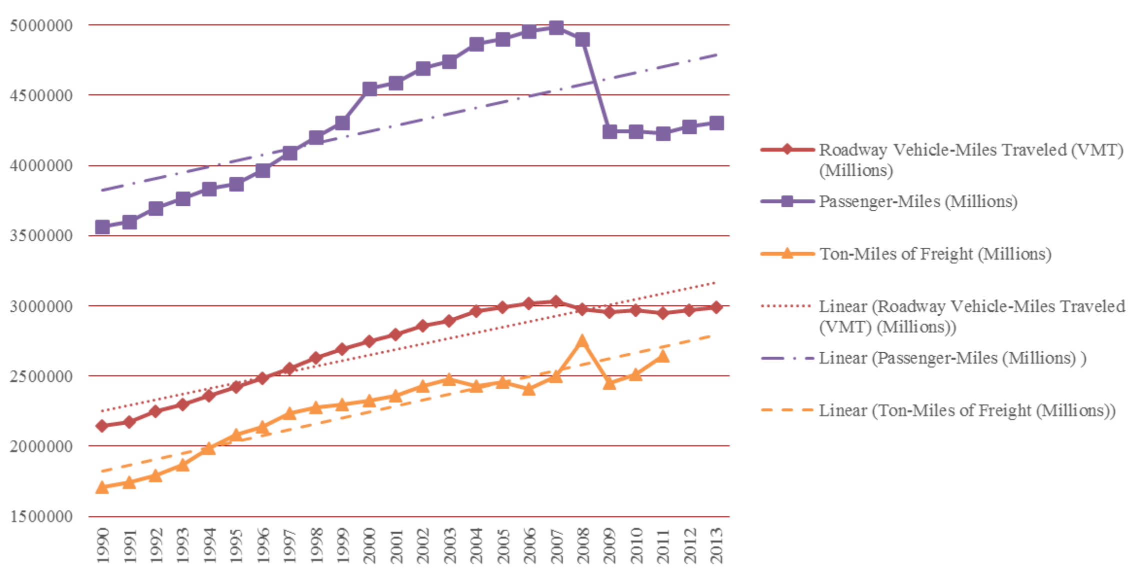


Fig. 1.1. Travel demands on highways during 1990-2013

Pavement has influences on people/community and natural environment as well. On average, an American spends 4.3 years driving a car and 3 months in traffic during the 78.6 years of life expectancy (Distractify Staff, 2015). Pavement is the agent to bring people, people bring changes to the area such as development, which can be responsible for either benefits or damages to the existing balance between economy development, natural environment, and people themselves (Tsunokawa & Hoban, 1997).

Construction and operation of pavement have ecological disturbances to the environment including destruction, fragmentation, degradation, and other cumulative impacts to ecological system (Southerland, 1994). Specifically speaking, if improperly handled, pavement construction activities might bring noise, vibration, soil erosion, water/air pollution, and interference with animal and plant life, especially in the previously undeveloped areas.

1.1.2 Pavement Deterioration

According to the reports from USDOT, the performance of the pavement system has not kept pace with the growth in travel and commerce simultaneously, the current physical condition of the pavements is unsatisfactory.

FHWA uses International Roughness Index (IRI) and Present Serviceability Rating (PSR) as main indicators for pavement condition (other indicators including rutting, cracking, and faulting to be released soon) (FHWA & FTA, 2013), and published the investigation results of the pavement condition as shown in Table 1.4.

As can be seen from Table 1.4, only 58% of those pavements reported have a good physical performance, and 9.5% of the pavements on average should be repaired or their performance should be improved in the near future.

Table 1.4 Investigation Results of Pavement Roughness, All Systems by Length

(Modified From Original Tables from FHWA (FHWA, 2013a))

Functional System		Ride Quality (inches per mile)			Total Reported (miles)
		Good, IRI＜95	Others, 95≤IRI≤170	Unacceptable, IRI＞170	
Urban	Interstate	12,214	4,467	950	17,630
	Other Freeways & Expressways	6,420	3,957	888	11,266
	Other Principal Arterial	19,973	24,625	16789	61,386
Rural	Interstate	24,166	4,631	588	29,385
	Other Freeways & Expressways	3,782	917	108	4,809
	Other Principal Arterial	61,583	23,535	3434	88,550
	Minor Arterial	65,951	46,180	8966	121,097
Total		194,089	108,312	31,723	334,123

Notes: International Roughness Index objectively measures the cumulative deviation from a smooth surface in inches per mile.

Table 1.5 Investigation Results of Pavement Roughness of Federal-aid highways

Ride Quality (inches per mile)	Federal-Aid Highways	
	VMT Percentage	Mileage Percentage
Unacceptable (IRI＞170 or PSR＜2.5)	0.18	0.2
Fair (95≤IRI≤170 or 2.5≤PSR＜3.5)	0.314	0.449
Good (IRI＜95 or PSR≥3.5)	0.506	0.351

Notes: International Roughness Index objectively measures the cumulative deviation from a smooth surface in inches per mile; Present Serviceability Rating is a subjective rating system based on a scale of 0 to 5.

FHWA also published the IRI data for Federal-aid highways as shown in Table 1.5 (FHWA & FTA, 2013), which make up a quarter of the nation's mileage and carry 85% of the total VMT (vehicle-miles traveled). Approximately 20% of the Federal-aid highways should be improved soon.

Table 1.6 Typical distresses on paved and unpaved pavements (Miller & Bellinger, 2003; Hall et al., 2001; CPYRWMA, 2000)

Surface Type		Common Distresses	
Paved Surface	Asphalt Surface	Cracking	Fatigue Cracking Block Cracking Edge Cracking Longitudinal Cracking Reflection Cracking at Joints Transverse Cracking
		Patching and Potholes	Patch Deterioration Potholes
		Surface Deformation	Rutting Shoving
		Surface Defects	Bleeding Polished Aggregate Raveling
		Miscellaneous	Lane-to-Shoulder Dropoff Water Bleeding and Pumping
	Concrete Surface	Cracking	Corner Breaks Durability Cracking (“D” Cracking) Longitudinal Cracking Transverse Cracking
		Joint Deficiencies	Joint Seal Damage Spalling of Longitudinal Joints Spalling of Transverse Joints
		Surface Defects	Map Cracking Scaling Polished Aggregate Popouts
		Miscellaneous	Blowups Faulting of Transverse Joints and Cracks Lane-to-Shoulder Dropoff Lane-to-Shoulder Separation Patch/Patch Deterioration Water Bleeding and Pumping Punchouts
Unpaved Surface	Dirt and gravel Surface	Surface deteriorations	Dust Raveling Slipperiness
		Surface deformation	Rutting Corrugating/”Washboarding” Depressions Potholes Softspots
	Others	-	

When people are looking at individual pavement sections, it is the pavement distresses that negatively affect the ride quality. Distresses are part of the pavement deterioration. Typical distresses on pavements are shown as in Table 1.6 according to the surface types of pavement structure. The paved pavement also includes the composite pavement, but only dirt and gravel pavement is considered under the category of unpaved pavement because most of unpaved pavements have dirt and gravel surface.

There are also other problems associated with deteriorating pavement condition, such as the deterioration of roadway and roadside facilities, litter on pavement, snow/ice in the pavement area, landscape deterioration, etc. They are not directly affecting the pavement structure, but must be considered to improve pavement performance, driving comfort, and safety features.

1.1.3 Pavement Maintenance Activities

Being different from new construction, expansion, and reconstruction, preservation, maintenance, and rehabilitation are the commonly used terminologies to describe the activities to improve pavement performance. The activities used to prevent, mitigate, or stop the pavement deteriorations will be discussed and classified in this section for the following research.

Relationships: superordinate or subordinate?

There is no regulatory differentiation between pavement preservation and pavement maintenance within Canadian agencies' preservation practices (Gopalakrishnan et al., 2014). However, in the U.S., FHWA does differentiate between preservation and maintenance and uses the differences to allocate federal funds accordingly.

Both preservation and maintenance are able to delay reconstruction and prolong the time between major rehabilitation and reconstruction. Preservation and maintenance treatments usually provide the least expensive pavement management strategy available on a life cycle cost basis (Geiger, 2005).

FHWA considers preservation as a "proactive" approach to maintain pavements (Geiger, 2005), which means preservation is part of maintenance. Therefore, maintenance activities can be divided into two parts, one is preservation which is proactive, and the other one is reactive treatments. For convenience, those two part will be called as proactive preservation (PP) and reactive repair (RR).

PP restores "pavements while still in good condition and extending their service life", and it is an effective way to conserve energy, virgin materials, and to reduce greenhouse gases by "keeping good roads good" (Gopalakrishnan et al., 2014).

RR, such as routine and corrective maintenance, is a conventional way used by many agencies to repair or treat existing distresses.

Rehabilitation is another conventional approach that most agencies use to manage their pavements. "Rehabilitation is typically programmed following the 'worst first' principle, in which pavements are allowed to deteriorate until the worst one rises to the top of the capital projects list" (NCPTC, 2014).

Alan O. King has done a massive job on the relationship between PP and RR. The two most important conclusions were 1) reconstruction does not belong to maintenance, and 2) preservation belongs to maintenance (King, 2006).

In FHWA's 2005 Memorandum (Geiger, 2005), preservation, maintenance, and rehabilitation activities were discussed in details together with their corresponding functions, which can be seen from Table 1.7.

Table 1.7 Different types of pavement maintenance activities

Type of Activity		Increase Capacity	Increase Strength	Reduce Aging	Restore Serviceability
	Major (Heavy) Rehabilitation		√	√	√
	Structural Overlay		√	√	√
Preservation	Minor (Light) Rehabilitation			√	√
	Preventive Maintenance			√	√
	Routine Maintenance				√
	Corrective (Reactive) Maintenance				√
	Catastrophic Maintenance				√

Some conclusions can be drawn according to this Memorandum:

- Preservation and rehabilitation are part of maintenance activities.
- Maintenance activities include: preventive maintenance, routine maintenance, corrective maintenance, catastrophic maintenance, rehabilitation.
- Rehabilitation techniques include restoration treatments and structural overlays, and have two sub-categories as minor and major rehabilitation.
- Preservation program consists of preventive maintenance, minor rehabilitation, and some of the routine maintenance activities.

Pavement Deterioration Timeline

Also based on the FHWA's 2005 Memorandum (Geiger, 2005):

- Preservation, preventive maintenance, rehabilitation, routine maintenance are all included in the section of "definitions for pavement maintenance terminology" of the Memorandum. Corrective maintenance and catastrophic maintenance are the other two types of maintenance activities.

- Preventive Maintenance is "typically applied to pavements in good condition".

- Preservation covers both preventive maintenance and minor rehabilitation. "An effective pavement preservation program will address pavements while they are still in good condition", which implies that preservation could be used on the pavement for the initial stage of FAIR, and preservation will not be practical beyond that point. Therefore, preservation can used a little beyond the GOOD stage of the pavement condition, and minor rehabilitation is the one that covers the gap between preservation and preventive maintenance.

- Rehabilitation is used to "extend the service life of an existing pavement and/or improve its load carrying capacity", it can be used in any stage of the pavement condition. The dividing points between minor and major rehabilitation should be the ending point of preservation.

- Routine maintenance is scheduled to "to maintain and preserve the condition of the highway system at a satisfactory level of service", so it is not used when pavement fails to offer service.

- Corrective maintenance are "performed to restore a pavement to an acceptable level of service…"

- Catastrophic maintenance returns "a roadway facility back to a minimum level of service…" It is a temporary action to offer minimum performance and need other permanent restorations to follow up.

- After catastrophic maintenance is done, pavement offers a minimum performance and continues to deteriorate. Since a permanent restoration is able to repair the pavement while the pavement is below minimum performance, rehabilitation should cover the initial stage of FAIL of the pavement condition.

Generally, different types of treatments are applied at different stages of pavement life. If the pavement condition is benchmarked as four levels, good, fair, acceptable, and fail, as deteriorating, the relationship between preservation, maintenance, and rehabilitation can be easily found from Fig. 1.2.

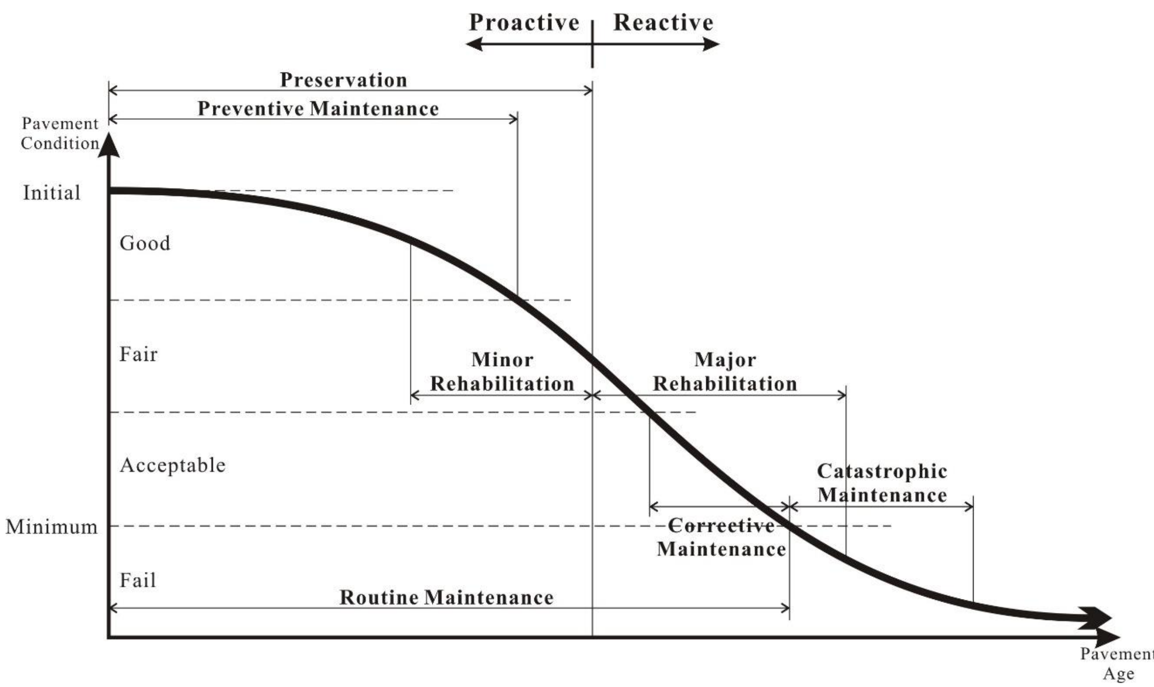


Fig. 1.2. Maintenance activities throughout the pavement deterioration timeline

In this research, preservation, maintenance, and rehabilitation are all considered as pavement maintenance activities. All the maintenance activities that extend pavement life but do not increase pavement capacity will be discussed. Pavement life can be extended by either increasing strength, reducing aging, or restoring serviceability of pavement and its ancillary facilities.

1.2 Research Significance

1.2.1 Problems within Existing Pavement Maintenance Practices

Since human activities and social development are very dependent on highway transportation, its deterioration need to be prevented or mitigated by maintenance activities. Unfortunately, some problems already exist within the traditional maintenance activities, and they will negatively affect either the maintenance process or results.

Budget

The revenues for pavement expenditure have fallen short since 2008 (CRFB, 2015), and pavement maintenance is often treated as a low priority compared to other general pavement construction. Therefore, most of the current pavement maintenance practices have tight budgets, they will be only reactive treatments to remove deteriorated sections of the pavement. However, maintenance should not be conducted to just fix the distress, it is better to look beneath the deteriorating pavements to find the actual reason of the deterioration; otherwise, maintenance will only restore the pavement performance but will not be able to actually fix the initial cause of the distress, which will create a need for repetitive maintenance. In the long run, the expenditure on operation and maintenance will gradually drop, if the pavement performance can be maintained at a reasonable level.

Nature

Second, pavement maintenance project also affects the surrounding environment by, for instance, energy consumption and emissions. People are focusing on energy consumption and greenhouse gas emission of vehicles by coming up with high efficient engine or alternative fuels. However, within the transportation sector, pavement construction is a big consumer to use energy and a big source of emission as well. Also, a lot of maintenance activities involve small-scale or short-term projects, such as pothole repair and crack sealing, the environmental impacts from smaller or shorter construction projects are likely to be ignored due to the lack of guidelines or onsite inspection. Another example is the existing landscape along the pavement route; as a part of the ecological environment, the landscape might be disturbed by pavement maintenance activities.

People

Third, highway transportation involves not only pavement and its ancillary facilities, but also the users and the neighborhood. It was reported that 3,545,693 miles of pavements in the U.S. were built before 1960 (BTS, 2015). Although some of them have been rehabilitated or reconstructed, a large quantity of pavements have been in service for tens of years. The neighborhood of the pavement probably have been changing over such a long time as well, and the needs of the neighborhood have been changing accordingly. In either case, maintenance could take a step further to offer better service, such as safety and comfort, to the users and the neighborhood by considering their specific needs. Maintenance itself can bring safety and comfort issues as well. For example, motorists do not like glare while driving because they cannot see what they want to see against the glare. Glare could come from vehicles in the opposite direction or the night lighting of maintenance projects, and it could lead to serious safety problems especially at night.

In general, traditional pavement maintenance considers little other than the distresses on the pavement and the techniques needed to fix those distresses. Sustainability, which reflects the need from economy, environment, and society, can be used to discuss the three categories of problems mentioned above, so sustainable pavement maintenance will be a good solution to minimize those negative affections mentioned above and benefit the pavement maintenance industry.

1.2.2 Suggestions from NCHRP and FHWA

There have been growing recognitions that pavement maintenance have economic, environmental, and social impacts. Here are two examples.

FHWA is active in studying the sustainability of highway transportation. In one of its documents published in 2015 (Van Dam, et al., 2015), FHWA expresses its interests in studying the sustainability features of maintenance: the document has one section discussing sustainable design of rehabilitation, and has one chapter for possible sustainable improvements of preservation/maintenance techniques. Technique is just one part of pavement maintenance project. To better determine the items that should be considered for a sustainable maintenance project, the concept, or definition, of sustainable pavement maintenance should be stated clearly first.

The NCHRP, which was established under TRB and has been studying the issues related to the planning, design, construction, operation, and maintenance of pavements in the U.S., declared that "**an assessment tool to properly quantify environmental sustainability in the pavement preservation and maintenance context is both missing and required**" in one of its report in 2011 (Tighe & Gransberg, 2011). Sustainability considers environmental issues as well as economic and social ones. A comprehensive sustainability rating tool for pavement maintenance will not only be able to follow NCHRP's suggestion but also serves as the bridge between the concept and the practices of sustainable pavement maintenance.

1.3 Research Objectives

In order to address the problems with existing pavement maintenance activities and to supplement the sustainability research of infrastructure, the new concept of sustainable pavement maintenance will be defined and a sustainability rating tool to evaluate pavement maintenance projects will be developed. To achieve the research goals, specific research objectives are shown below:

- Review the sustainability research of pavement/transportation, including existing definitions and rating tools, to understand the appropriate considerations for sustainable pavement
- Define the concept of sustainable pavement maintenance
- Create the developing procedure for the new sustainability rating tool and develop the rating tool
- Evaluate pavement maintenance projects to test the applicability of the new rating tool

1.4 Research Scope

Maintenance, as a critical element during the life cycle of the pavement, keeps pavement system in a good shape. A new concept should be introduced to minimize the problems within traditional pavement maintenance practices.

Since pavement maintenance project is to be evaluated, the definition of maintenance will be studied first. Preservation, maintenance, rehabilitation are the most commonly used words to describe those activities that mitigate pavement distresses or extend pavement life. The differences and relationships among them will be discussed to determine what activities can be considered as maintenance.

In order to evaluate pavement maintenance projects in term of sustainability, sustainable pavement maintenance should be defined. The definition will serve as a guideline for the stakeholders to determine what counts as sustainable activities during a pavement maintenance project so as to differentiate traditional pavement maintenance and sustainable pavement maintenance. Any technique or practice can be considered as sustainable if its features agree with this theoretical result.

To comprehensively evaluate the sustainability of pavement maintenance projects, a rating tool will be developed based on a statistical framework. The developing procedure and products will be shown. By using this rating tool, stakeholders will be able to check what to consider and how to consider for a sustainable pavement maintenance project.

Case studies will be provided to demonstrate the evaluation of the developed rating tool. The evaluation results will be introduced.

Finally, conclusions of this research and recommendations for the rating tool are provided.

CHAPTER II

LITERATURE REVIEW

Existing studies of sustainable pavement maintenance and sustainability rating tools for pavement or transportation will be reviewed in this chapter.

2.1 Sustainability Related to Pavement Maintenance

Maintenance plays critical roles in pavement industry. The three types of existing problems with pavement maintenance mentioned in Section 1.2.1 reflect its needs from economy, environment, and society, which exactly agree with the requirements of Triple Bottom Line (TBL) (see Fig. 2.1) that had been widely used to describe sustainability since its debut by John Elkington in 1994. Therefore, sustainable pavement maintenance will be a good way to cut the maintenance cost in the long run, to conserve energy and resources while mitigate environmental impacts at project level, and to consider the needs of different groups.

A definition of sustainable pavement maintenance is required to provide a systematic concept and to set a standard explaining what can be counted as sustainable practice for a pavement maintenance project. The defining process will start from the meaning of sustainability itself.

Fig. 2.1. The relationships between Triple Bottom Line (CorpCROP, n.d.)

2.1.1 Sustainability

Sustainability was first introduced in the *Report of the World Commission on Environment and Development: Our Common Future* in 1987, the Brundtland Commission defined sustainable development as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This initial definition only emphasized needs which were excessively broad although both present and future were considered. However, this definition was always the start of any sustainable development.

2.1.2 Sustainable Transportation or Sustainable Pavement

Definitions from FHWA

People who are not familiar with sustainable pavement maintenance could start with the concept of sustainable pavement or sustainable transportation. FHWA is authoritative about pavement research and has played a leading role on promoting sustainable pavement/transportation in recent years at national level, since it has to consider the situations in different regions to find appropriate sustainable pavements for the whole nation.

In 2001, FHWA gave the definition of sustainable transportation as “is safe, high quality, and accessible to all; ecologically sound; economical; and a positive contributor to regional development” based on the visits to Sweden, Germany, the Netherlands and the United Kingdom (Petty, et al., 2001). Although FHWA also explained the definition by some specific goals, it was merely an extraction from triple bottom line; transportation needs more than that to be sustainable.

In response to the sustainability promise of green highways, FHWA stated in 2009 that today’s pavement initiatives should “aim to advance the vision of meeting drivers’ needs while building and maintaining a safe, long lasting, and cost-effective highway system” (Stephanos, 2009).

FHWA expanded the definition of sustainable transportation in 2010 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). This definition modified the Brundtland’s sustainability and gave more details about what is sustainable transportation system.

FHWA did not give a specific definition for sustainable transportation in its 2011 sustainability guidebook (Amekudzi, et al., 2011). After reviewing the definitions from five agencies, the guidebook stated that all kinds of transportation “contributing to the sustainable development of the community that owns and uses the system” should be considered as sustainable. This was a general description of sustainable transportation, which indicated that there is no "one size fits all" sustainable solution under different circumstances of transportation.

According to a report from FHWA and FTA published in 2013 (FHWA & FTA, 2013), sustainability of transportation emphasizes "the natural environment, the economic efficiency of the transportation system, and societal needs (e.g., mobility, accessibility, and safety)"; the sustainability initiatives from different transportation agencies include "Intelligent Transportation Systems, linking transportation and land use decision-making, linking planning and environment, and addressing requirements of the NEPA (The National Environmental Policy Act)". Still, this definition was making a simple connection to the triple bottom line for transportation.

FHWA introduced the concept of sustainability particularly to pavements in 2014 (Muench & Van Dam, 2014). "A sustainable pavement is one that achieves its specific engineering goals, while, on a broader scale, 1) meets basic human needs, 2) uses resources effectively, and 3) preserves/restores surrounding ecosystems". This was a signal that pavement became an independent topic in the sustainable research projects at national level. It still needed improvement but was a good start.

In 2015, FHWA restated that sustainable pavement refers to "system characteristics that encompasses a pavement's ability to 1) achieve the engineering goals for which it was constructed, 2) preserve and (ideally) restore surrounding ecosystems, 3) use financial, human, and environmental resources economically, and 4) meet basic human needs such as health, safety, equity, employment, comfort, and happiness" (Van Dam, et al., 2015). This sentence went beyond a definition of sustainable pavement. It involved different but related disciplines and provided four principles that any pavement should follow to be sustainable.

Definitions from rating tools for sustainable transportation or pavement

Each rating tool has its own understanding of sustainable transportation or pavement. Definitions from nine rating tools are listed below.

INVEST by FHWA

A sustainable highway should “satisfy lifecycle functional requirements of societal development and economic growth while striving to enhance the natural environment and reduce consumption of natural resources”. INVEST declares that highways should be considered as one part of transportation infrastructure to address sustainability in them. The sustainable highway should “focus on access (not just mobility), moving people and goods (not just vehicles), and providing people with transportation choices, such as safe and comfortable routes for walking, cycling, and transit” (Reid, et al., 2015).

Greenroads

Greenroads use the term “Greenroad” as an equivalent for sustainable pavement. A "Greenroad" is a transportation project that is designed and constructed to a level of sustainability substantially higher than current common practice. Greenroads Projects efficiently use resources and renewable materials, help reduce emissions, manage waste, enable multimodal transport, and are designed to be accessible by all (Anderson, et al., 2011).

GreenLITES

GreenLITES is an internal rating tool at NYSDOT. Transportation sustainability at NYSDOT is “a philosophy that 1) allows individual and societal transportation needs to be met in a manner consistent with human and ecosystem health with equity within and between generations; 2) is safe, affordable, accessible, operates efficiently, offers choice of transport mode and supports a vibrant economy; 3) protects and preserves the environment by limiting transportation emissions and wastes, minimizes the consumption of resources and enhances the existing environment as practicable” (NYSDOT, n.d.).

The concept can be explained as six principles (NYSDOT, n.d.):

- Protect and enhance the environment.
- Conserve energy and natural resources.
- Preserve or enhance the historic, scenic, and aesthetic project setting characteristics.
- Encourage public involvement in the transportation planning process.
- Integrate smart growth and other sound land-use practices.
- Encourage new and innovative approaches to sustainable design, and how we operate and maintain our facilities.

I-LAST

I-LAST states that the “sustainable features in the design and construction of highway projects are to (IDOT & IJSG, 2012):

- Minimize impacts to environmental resources
- Minimize consumption of material resources
- Minimize energy consumption
- Preserve or enhance the historic, scenic and aesthetic context of a highway project

- Integrate highway projects into the community in a way that helps to preserve and enhance community life
- Encourage community involvement in the transportation planning process
- Encourage integration of non-motorized means of transportation into a highway project
- Find a balance between what is important:
  - to the transportation function of the facility
  - to the community
  - to the natural environment, and
  - is economically sound
- Encourage the use of new and innovative approaches in achieving these goals."

BE^{2}ST

BE^{2}ST Manual cited the definition of sustainable development from U.N. Department of Economic and Social Affairs in 1987, which is the ability to "meet the needs and aspirations of the present without compromising the ability to meet those of the future" (RMRC, 2010).

INVEST by VicRoads

Sustainable transport is "the ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future" (VicRoads, 2011).

STARS

STARS-PLAN cites the definition from the Centre for Sustainable Transportation as sustainable transportation (STC & PBOT, 2012):

- Allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.
- Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy.

Limits emissions and waste within the planet's ability to absorb them, minimizes consumption of nonrenewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.

STAR

Sustainable transport projects have "positive net economic, social, and environmental impacts. They make efficient use of resources, and are within or strengthen the financial and institutional capacity of the local institutions to deliver such projects. Such projects may have limited and acceptable trade-offs between the dimensions of sustainability" (Véron-Okamoto & Sakamoto, 2014).

GreenPave

Sustainable pavement considers the "life cycle cost, the impact of noise on human health, the impact of construction on the natural hydrologic cycle, and the impact of pavement heat absorption on surrounding areas" (MTO, 2014).

Other definitions

Except FHWA and sustainability rating tools mentioned above, there are also some valuable studies on sustainable transportation from other organizations or individuals. Table 2.1 gives a list of the wide-accepted definitions of sustainable transportation from other agencies or other countries.

Table 2.1 Definitions of sustainable transportation

Date	Focus	Definition	Document	Organization/Author
Nov 2008	transport	"… a sustainable transport system" can be defined as one that "1) allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations; 2) is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development; 3) limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes while minimising the impact on the use of land and the generation of noise."	Sustainable Transportation Indicators: A Recommended Research Program For Developing Sustainable Transportation Indicators and Data	Sustainable Transportation Indicators Subcommittee of the Transportation Research Board, from EU
Aug 2011			Guide To Sustainable Transportation Performance Measures	Environmental Protection Agency, from TRB
Apr 2001			Minutes of the 2340th meeting of the Council of Ministers, Luxembourg	European Union cited from Canada CST
May 2009	transportation	A sustainable transportation system is one that 1) allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations; 2) is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; 3) limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.	Transportation and Sustainability Best Practices Background	Center for Environmental Excellence by AASHTO
1997			Defining Sustainable Transportation	Centre for Sustainable Transportation, Canada
2004	Mobility	improve "the needs of society to move freely, gain access, communicate, trade and establish relationships" "without sacrificing other essential human or ecological requirements now or in the future"	Mobility 2030: Meeting the challenges to sustainability	World Business Council on Sustainable Development

2004	Transport	Sustainable transport is the "transport that achieves the primary purpose of movement of people and goods, while simultaneously contributing to achieving environmental, economic and social sustainability".	World report on road traffic injury prevention	World Health Organization
Apr 2012	Transport	Sustainable transport is best defined as a system that allows the basic access and development needs to be met safely, promises equity for successive generations, operates fairly and efficiently, offers choice of transport mode, limits emissions and waste, and is affordable.	Sustainable Transportation in the Middle East	Karim Elgendy and Wissam Yassine
May 2011	transportation	A more sustainable transportation system is one that: - Allows the basic access and development needs of people to be met safely and promotes equity within and between successive generations. (Social dimension) - Is affordable within the limits imposed by internalization of external costs, operates fairly and efficiently, and fosters a balanced regional development. (Economic dimension) - Limits emissions of air pollution and GHGs as well as waste and minimises the impact on the use of land and the generation of noise. (Environmental dimension) - Is designed in a participatory process, which involves relevant stakeholders in all parts of the society (Degree of participation).	Developing Practical Tools for Evaluation in the Context of the CSD Process	United Nations/Daniel Bongardt, Dominik Schmid, Cornie Huizenga, Todd Litman

2.1.3 Sustainable Pavement Maintenance

Sustainable pavement maintenance can be seen as a subset of sustainable transportation or sustainable pavement where the impacts of the maintenance treatments on the economy, environment and social equity will be defined and evaluated. In this section, the definition of sustainable pavement maintenance will be discussed.

Most of the existing studies on sustainable pavement maintenance focused on the environmentally sustainable features of different maintenance techniques, such as energy consumption and materials involved. Takamura et al. analyzed the environmental footprint of three preservation techniques considering 5 different indicators in 2001(Takamura, et al., 2001). In 2012, Kazmierowski conducted a similar research, he compared the energy consumption and emissions of 4 groups of pavement preservation techniques and tried to find out the best one (Kazmierowski, 2012). Their research provided a good solution of using different environmentally sustainable indicators to evaluate different pavement maintenance techniques, but both of them used limited impact factors to search best techniques and did not consider social sustainability.

NCHRP, Gransberg et al., and FHWA focused on the environmental sustainability of maintenance activities, and all tried to relate the sustainability impact factors to the features of techniques and materials.

NCHRP emphasized the importance of preservation in pavement maintenance program, and recommended committing resources to preservation as the foundation of sustainable maintenance (Tighe & Gransberg, 2011). By conducting a survey issued to maintenance engineers from U.S. and Canada, thin asphalt overlay, diamond grinding, and regrading/regraveling are found as the most commonly used treatments for asphalt surface, concrete surface, and graveled pavements, respectively. NCHRP encouraged sustainability research on post-construction operations, and declared that "**an assessment tool to properly quantify environmental sustainability in the pavement preservation and maintenance context is both missing and required**".

Gransberg et al. separated preservation from maintenance activities (Gopalakrishnan, et al., 2014). Sustainability for preservation and maintenance was defined as "promoting environmentally friendly practices that also provide technical and economic benefits". They discussed the environmental impacts of preservation and maintenance under 7 factors:

- Virgin material usage;
- Alternative material usage;
- Program for pavement in-service monitoring and management;
- Noise;
- Air quality/emissions;
- Water quality and energy usage.

Different preservation and maintenance treatments could be recommended for projects based on the corresponding relationships among the 7 factors, as well as cost and technical features.

A list of alternative, recycled, and renewable design/construction was provided to show the opportunities to improve environmental sustainability of preservation and maintenance.

Although the discussion of this document focused on preservation and maintenance, it was stated that the discussions could also be applied to rehabilitation activities, which means the three types of treatments do share similar considerations pursuing sustainability.

TRB and the U.S. National Academies have sponsored a survey for the transportation agencies of U.S. and Canada (Gopalakrishnan, et al., 2014). The transportation agencies believed that the two most important factors for environmentally sustainable maintenance are material quality/selection and maintenance timing. The transportation agencies were also asked to rate the environmental sustainability of common maintenance treatments, the results are shown as in Table 2.2.

Table 2.2 Rated sustainability of common maintenance treatments

Pavement type	Treatments	Percentage usage (%)	Rated sustainability 1 (very sustainable) to 4 (not sustainable)		
			Combined	Canada	U.S.
Asphalt	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	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

As can be seen from Table 2.2, the rated environmental sustainability of the treatments are positively correlated to their percentage of use, which means the transportation agencies believe their most frequently used treatments are the most environmentally sustainable ones. Therefore, this survey results were mostly subjective judgments, and only focused on environmental sustainability of maintenance treatments.

FHWA published a document about its research achievement in 2015. Chapter 4 focused on sustainability of pavement design and discussed little about rehabilitation procedure except accelerated construction and single-lane rehabilitation. In Chapter 7, FHWA also promoted preservation strategies to improve sustainability of maintenance. Besides, pavement management systems were recommended for maintenance projects. Various maintenance and preservation treatments for asphalt surface and concrete surface pavements were evaluated. Construction quality was believed to be a way to guarantee higher sustainability achievements in addition to the selection of techniques and materials. FHWA also evaluated commonly used maintenance treatments. The costs and societal impacts of treatments were also considered in addition to functional advantages, treatment lives, and environmental impacts. However, the quantification of sustainability was not provided (Van Dam, et al., 2015).

2.2 Existing Sustainability Rating Tools

2.2.1 Functions and Advantages of Sustainability Rating Tool

Exploring the meaning and benefits of sustainable pavement maintenance only tells the industry that it is necessary and feasible, it also must be considered how to measure the sustainability of pavement maintenance projects so that different projects can be comparable on a standard scale. Rating (Assessment) tool is able to serve the evaluation purpose and has other advantages as well. Generally, a rating tool has a list of every situation with sustainable features that a project or organization might encounter, and evaluates the project or organization performance under each situation, the project or organization then receives a score as an indication of its sustainability level.

A sustainability rating tool is able to:

- Serve as a checklist of sustainable activities to show what activity counts as sustainable practices;
- Determine the priority of different sustainable options;
- Evaluate a project in terms of sustainability;
- Explain the benefits of a sustainable project;
- Give project details under strong and weak sustainability indicators which can be considered as instructions for future projects;

- Compare the sustainability achieved by different projects; and
- Promote sustainability to other projects and the public.

2.2.2 Sustainability Rating Tools for Infrastructure

The most popular rating tool for sustainable infrastructure is Leadership in Energy & Environmental Design (LEED) from the U.S. Green Building Council. The latest version of LEED (v4) has 5 modules that can be used to evaluate different infrastructure construction. Module ND (Neighborhood Development) being used for new land development projects or redevelopment projects has some credits related to pavement construction issues (USGBC, 2016a), such as design and restoration of habitat or wetland and water bodies, minimize site disturbance. Being designed for existing buildings that are undergoing improvement work or little to no construction, LEED Module O+M (Building Operations and Maintenance) considers something about infrastructure maintenance (USGBC, 2016b), such as existing building commissioning, occupant comfort survey. Both modules can be helpful for the considerations of sustainable pavement maintenance.

Some of the existing rating tools for infrastructure are show in Table 2.3.

Table 2.3 List of sustainability rating tools for infrastructure

Name	Country	Website
LEED	USA	http://leed.usgbc.org/
ENVISION	USA	http://sustainableinfrastructure.org/
SITES	USA	http://www.sustainablesites.org/
CEEQUAL	UK	http://www.ceequal.com/
BREEAM	Europe	http://www.breeam.org/
IS	Australia	http://www.isca.org.au/
Green Star	Australia	https://www.gbca.org.au/green-star/

2.2.3 Sustainability Rating Tools for Transportation or Pavement

There are also many sustainability rating tools used to evaluate sustainable pavement or transportation. In order to check if the existing rating tools cover pavement maintenance activities or not, 9 sustainability rating tools for transportation or pavement are selected. The rating tool will be selected if its detailed manual and/or application on real projects are published online. All of the 9 rating tools are reviewed in following sections.

INVEST by FHWA

INVEST was developed by FHWA. It has been applied on more than 1600 projects or programs since its releasing in October 2012. It is the only rating tool covering the full transportation life-cycle, from planning, design, construction, operations and maintenance (FHWA, n.d.a). Some information of INVEST by FHWA can be found in Table 2.4.

Under its latest version 1.2, INVEST by FHWA has four modules including one as Operation and Maintenance. The OM module is to evaluate the sustainability within an agency's operations and maintenance policies, processes, procedures and programs. This module focuses on system-level operations and maintenance activities, and can be used under 4 scenarios as follows (FHWA, n.d.b):

- Retrospectively evaluating the sustainability of one or part of one completed program.
- Proactively setting goals, providing guidance, and measuring the sustainability of a developing program.

- Assisting owners, stakeholders and program teams with understanding new technologies and best practices in sustainability and helping them anticipate new, related requirements that may emerge.

- Estimating the sustainability of an OM program to facilitate the decision-making process.

Table 2.4 Information of INVEST by FHWA

Sustainability rating tool	INVEST, Infrastructure Voluntary Evaluation Sustainability Tool
Developer	FHWA
Website	https://www.sustainablehighways.org/
Release date	V1.0, Oct 2012
Last update	V1.2, Sep 2015
Application scope, as of Aug 2016	15 State DOTs, 16 MPOs, 23 Federal Lands Units, 5 Other transport agencies in US, 1 foreign government. >1600 projects or programs evaluated.

11 out of 14 indicators under OM module involve pavement maintenance (as shown in Table 2.5 below), but the indicators are designed to meet transportation agencies' needs, so that pavement maintenance are evaluated for its management and plan at agency-level, not for the activities and impacts at project-level. In other words, INVEST by FHWA should be used together with other rating tools to evaluate pavement maintenance projects.

Table 2.5 Indicators that are related to maintenance under OM module of INVEST by FHWA

Focused area	Item	Criteria (Indicators)	What is involved in maintenance?
Internal operations	OM-01	Internal Sustainability Plan	employee engagement and training; commuting options
	OM-02	Electrical Energy Efficiency and Use	employee awareness
	OM-03	Vehicle Fuel Efficiency and Use	development a fleet management plan
	OM-04	Reduce, Reuse and Recycle	develop a reduce, reuse, and recycle plan

Maintenance and operations of the highway system	OM-05	Safety Management	assess current safety performance; develop and implement a plan including goals and targets; measure progress and monitor performance
	OM-06	Environmental Commitments Tracking System	develop an environmental compliance tracking system (ECTS); require and integrate key functions of ECTS; GIS based ECTS; measure progress and monitor performance
	OM-09	Maintenance Management System	maintenance quality assurance
	OM-10	Highway Infrastructure Preservation and Maintenance	develop a road maintenance plan; sustainable maintenance and operations; include performance measures, monitor, and demonstrate progress
	OM-11	Traffic Control Infrastructure Maintenance	develop a traffic control maintenance plan
	OM-12	Road Weather Management Program	implement the standards of practice or standard operating procedures for snow and ice control; implement materials management plan
	OM-14	Work Zone Traffic Control	leverage contracting innovations; coordinate with the public; promote public awareness

Greenroads

Greenroads was designed to evaluate pavement projects (Anderson, et al., 2011). According to its V1.5 manual, Greenroads can be used for all types and sizes of pavement projects, including new, rehabilitation, reconstruction, preservation, overlay, and bridge projects. Some information of Greenroads can be found in Table 2.6.

However, under its latest version (V2), only 15 out of 61 of its indicators clearly involve maintenance (as shown in Table 2.7 below) and take 11% of the total available points (Greenroads Foundation, n.d.). Most of the 15 indicators focused on construction activities.

Table 2.6 Information of Greenroads

Sustainability rating tool	Greenroads
Developers	University of Washington, CH2M HILL, etc.
Website	https://www.greenroads.org/
Release date	V0.95, 2009. Research started in 2007
Last update, as of August 2016	V2, July 2015
Application scope, as of Nov 12 2015	9 countries, 65 organization members, 120 testing projects, 80 application projects

Table 2.7 Indicators that are related to maintenance under Greenroads

Category	Credit/Indicator
Project Requirements	PR-2 Energy & Carbon Footprint
	PR-7 Quality Control
	PR-8 Pollution Prevention
	PR-9 Waste Management
	PR-10 Noise & Glare Control
	PR-12 Asset Management
Construction Activities	CA-3 Quality Process
	CA-4 Equipment Fuel Efficiency
	CA-5 Workzone Air Emissions
	CA-6 Workzone Water Use
	CA-7 Accelerated Construction
	CA-9 Communications & Outreach
Utilities & Controls	UC-7 Traffic Emissions Reduction
	UC-8 Travel Time Reduction
Access & Livability	AL-2 Safety Enhancements

As for pavement maintenance, Greenroads is applicable to rehabilitation, preservation, and overlay. However, it can only be applied to maintenance construction projects that preserve the lives of roadways, not on those activities that are part of the site maintenance plan (usually performed by Public Agencies and their contractors). Some of its credits reflect maintenance and preservation activities and require related future plans. However, since Greenroads assumes those future plans will be performed as promised, this rating tool cannot effectively monitor those activities in the long run (Anderson, et al., 2011).

Furthermore, Greenroads requires responsible organizations, standards, schedule, and methods only for limited maintenance activities, such as some maintenance activities on pavement structure (such as patching, repair, crack sealing, shoulder/sidewalk maintenance and repair), stormwater system cleaning and repair, vegetation, snow/ice control, pavement cleaning, and other maintenance activities related to traffic control infrastructure (such as marking, sign, safety device, traffic signal, lighting, and ITS).

In conclusion, Greenroads can be applied on selected pavement maintenance projects, but it 1) limits the scope of maintenance, 2) just relies on a plan to guarantee sustainability, and 3) just discusses the basic information about those maintenance activities.

GreenLITES

To "recognize transportation project designs, operations and maintenance practices that incorporate a high level of environmental sustainability", NYSDOT works with MPOs to align GreenLITES practices into the transportation planning process (NYSDOT, n.d.), but GreenLITES considers more than just environmental indicators. Some information of GreenLITES can be found in Table 2.8.

GreenLITES has four tools to incorporate sustainability into programs, projects, and practices (Nelson, et al., 2011; Nelson & Krekeler, 2012), as shown in Table 2.9 below.

Table 2.8 Information of GreenLITES

Sustainability rating tool	GreenLITES, Green Leadership In Transportation Environmental Sustainability
Developer	NYSDOT
Website	https://www.dot.ny.gov/programs/greenlites
Release date	Sep 2008 Project Design Program; Apr 2009 Maintenance/Operations Plan Spreadsheet; Mar 2010 Regional Pilot Program
Last update	V2.1.0, Apr 2010
Application scope, as of Jan 19 2016	All "let" projects except standby, where-and-when, or job order contracts, and projects with plans, specifications and estimates submitted to NYSDOT after Sep 25, 2008

Table 2.9 Four tools under GreenLITES

Tool	Level	Function
Project Design Scorecard	Operational	Distinguish transportation projects and operations based on the extent to which they incorporate sustainable choices, and works for "operational" type decisions
Operations Spreadsheet		
Project Solicitation Tool	Tactical	Determine how consistent a project is with sustainability goals, and decide what project to include in long term capital infrastructure program submissions
Regional Sustainability Assessment Table, Regional Infrastructure Sustainability Elements (RISE) Table	Strategic	Develop and assess regional long term sustainability goals holistically and across program areas using the triple bottom line

Although GreenLITES considers all pavement maintenance projects, either with plan sheets or only with proposal, only one indicator clearly mentions pavement maintenance, which is Hazardous Materials Minimization within Category Materials and Resources. When giving certification, typically there are no higher level certifications ("higher" than "certified", means "silver, gold, evergreen") for maintenance projects, but "if the maintenance project scores more than 29 points, it may be certified as silver, gold, or evergreen using the standard GreenLITES rating system" (NYSDOT, n.d.).

I-LAST

I-LAST is not exactly a rating tool because it has no indicators; instead, it gives project requirements under each category to make project sustainability measureable and gives practices that can result in sustainable outcomes at project level (IDOT & IJSG, 2012). Some information of I-LAST can be found in Table 2.10.

3 out of 15 indicators within I-LAST clearly involve maintenance activities (as shown in Table 2.11 below).

Table 2.10 Information of I-LAST

Sustainability rating tool	I-LAST, Illinois – Livable and Sustainable Transportation Rating System and Guide
Developer	Illinois Department of Transportation, American Council of Engineering Companies - Illinois, Illinois Road and Transportation Builders Association, and other organizations
Website	http://www.idot.illinois.gov/assets/uploads/files/transportation-system/reports/desenv/enviromental/i-last%20v%202%2002.pdf
Release date	V1.0, Jan 2010
Last update	V2.02, Sep 2012
Application scope, as of Feb 13 2016	None

Table 2.11 Indicators that are related to maintenance under I-LAST

Category	Indicator	ID	Description	Sub-ID	Explanation
Environmental	E-1 Protect, Enhance or Restore Wildlife and its Habitat	E-1j	Provide mowing markers	-	-
Transportation	T-1 Traffic Operations	T-1c	Expansion of or connection to a Traffic Management Center (TMC)	-	-
Materials	M-1 Materials	M-1m	Extended long life pavement; design and rehabilitation strategies	M-1m-4	Specify the use of perpetual (30 yr) HMA pavement design
				M-1m-5	Specify the use of 30 year design life concrete pavement
				M-1m-6	Specify the use of 40 year design life concrete pavement

BE^{2}ST

BE^{2}ST system is an Excel based program that is linked to other open sources. For example, BE^{2}ST uses PaLATE and the Life Cycle Cost Analysis (LCCA) RealCost software program for Environmental and Economic Effects, it uses Mechanistic-Empirical Pavement Design Guide (MEPDG) to measure service life, it uses Traffic Noise Model LookUp (TNM-Look) to assess traffic noise, and it uses International

Roughness Index (IRI) simulation to determine life of pavement. Some information of BE^2ST can be found in Table 2.12.

Table 2.12 Information of BE^2ST

Sustainability rating tool	BE^2ST-in-highways, Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways
Developer	RMRC (Recycled Materials Resource Center) at University of Wisconsin-Madison
Website	http://rmrc.wisc.edu/be2st-in-highways/
Release date	July 2010
Last update	Nov 2010
Application scope, as of Mar 14, 2016	Wisconsin

With BE^2ST, real projects are evaluated in term of sustainability compared to a "reference design". The reference design meets statutory, social, and project specific requirements but has none sustainable features (Edil, n.d.), and the real project may involve some sustainable designs. The rating score is presented as percentage compared to the reference design and then prorated to an equivalent score based on the weight for each rating category.

BE^2ST can be used for highway projects during the planning and designing phase. One of its purposes is to encourage wider adoption of recycled materials in roadway construction and rehabilitation, so all its indicators are restricted to issues related to quantifiable construction materials and processes.

There are two layers of indicators: mandatory screening and judgment indicators. Regulatory/social and project specific indicators are considered as mandatory screening, while environmental and economic indicators belong to judgement. Half of the 14 indicators at judgement layer can be directly applied on rehabilitation projects (as shown in Table 2.13 below), none of them involves preservation.

Table 2.13 Indicators that are related to maintenance under BE^{2}ST

Category	Indicators	Target Value
Environmental Indicator Economic Indicator	Energy Consumption	20% reduction
	Global Warming Potential	20% reduction
	In Situ Recycling Rate	20% recycling of construction and demolition waste
	Water Consumption	10% reduction
	Life Cycle Cost	10% reduction
Voluntary Indicator	energy efficient lighting and communication	measurement of these criteria should be based on actual performance
	safety improvement	

INVEST, VicRoads

Either design and per-construction, construction, or post construction of a pavement project can be evaluated by INVEST developed by VicRoads in Australia, and it can be applied on new construction, maintenance, and reconstruction of pavement (VicRoads, 2011). Some information of INVEST by VicRoads can be found in Table 2.14.

However, only 9 out of 48 clearly consider evaluating pavement maintenance activities (as shown in Table 2.15 below).

Table 2.14 Information of INVEST by VicRoads

Sustainability rating tool	INVEST, Integrated VicRoads Environmental Sustainability Tool
Developer	VicRoads, Roads Corporation of Victoria
Website	https://www.vicroads.vic.gov.au/~/media/files/documents/planning%20and%20projects/sustainabilityandclimatechangestrategy20102015.ashx
Release date	V1.0, Mar 2011
Last update	V1.0, Mar 2011
Application scope, as of Mar 29 2016	VicRoads projects only, including D&C projects and regional projects

Table 2.15 Indicators that are related to maintenance under INVEST by VicRoads

Category	Indicator
Energy	Installation of road energy systems
Noise Management	Temporary noise attenuation measures during construction
Resource Management	Use of products and materials with greater environmental benefits
	Reuse contaminated fill material (including biosolids)
Road Design	Coordination of construction works with other public infrastructure works
	Incorporating future maintenance requirements
Urban Design	Provision of aesthetic views and community infrastructure
Water and Waterway Management	Use of non-potable water
	Incorporate water sensitive road design

STARS

STARS considers the future use of a transportation project by evaluating transportation investments rather than just evaluates its design and construction, which indicates the idea of "the use of a transportation project often has bigger impacts that its construction". STARS helps users to focus on improving access instead of just improving mobility because "mobility is a means to accessing places, not an end in itself" (STC & PBOT, 2012; STC, et al., 2011; STC, et al., 2012). Some information of STARS can be found in Table 2.16.

Table 2.16 Information of STARS

Sustainability rating tool	STARS, Sustainable Transportation Analysis & Rating System
Developer	The North American Sustainable Transportation Council (STC), the Portland (OR) Bureau of Transportation, the Santa Cruz County Regional Transportation Commission, and other private sector firms
Website	http://www.transportationcouncil.org/about-stars
Release date	STARS-Project, Nov 2010
Last update	STARS-Plan, V1.0, Jan 2012 STARS-Project, V1.2, Apr 2013 STARS for Safety, Health, and Equity, Mar 2012
Application scope, as of Nov 2 2015	10 pilot projects in CA, WA, and OR

STARS uses a “backcasting” approach from “The Natural Step” helping users find better strategies to meet their goals. “Backcasting involves setting a vision and goals for the future, and then identifying the strategies and steps to take in order to reach those goals”. So it “asks users to evaluate strategies to help them achieve their goals” rather than just “comply with a list of standards” (STC & PBOT, 2012; STC, et al., 2011; STC, et al., 2012).

There are three manuals: STARS-Plan (for transportation plans), STARS-Project (transportation projects) and STARS for Safety, Health, and Equity. STARS-Plan and STARS-Project allow users to earn points under different categories. Only 3 out of 21 indicators in STARS-Plan and 1 out of 12 indicators in STARS-Project are directly related to maintenance activities (as shown in Table 2.17 below).

Table 2.17 Indicators that are related to maintenance under STARS

Manual	Category	Indicator
Plan	Integrated Process	Acquire baseline data
	Cost Effectiveness	Optimize benefits over the life-cycle of the project
		To prioritize the enhancement and maintenance of the existing system over system expansion
Project	Cost Effective Analysis	Cost Estimation and Cost-Effective Calculations

STAR

STAR adds a fourth part into sustainability, which is the risk to the sustainability of a project’s outcomes. It refers to the risk that expected outcomes may not be realized or sustained. It may also relate to the uncertainty of the evaluation itself, as STAR is meant to be carried out before a project is implemented (Véron-Okamoto & Sakamoto, 2014). Some information of STAR can be found in Table 2.18.

Table 2.18 Information of STAR

Sustainability rating tool	STAR, Sustainable Transport Appraisal Rating
Developer	ADB, Asian Development Bank
Website	http://www.adb.org/publications/toward-sustainability-appraisal-framework-transport
Release date	Jan 2014
Last update	Jan 2014
Application scope, as of Mar 31 2016	ADB's transport projects

Only 6 out of 18 STAR indicators directly involve maintenance (as shown in Table 2.19 below).

Table 2.19 Indicators that are related to maintenance under STAR

Dimension/Core Criteria		Area/Indicator	Objective
Sustainable Transportation Objectives	Economic	Fiscal burden	Reduce the cost of transport systems for the taxpayer
	Poverty and Social	Employment	Generate or provide access to quality employment opportunities for the poor
		Safety	Improve the safety and security of transport users and local communities
	Environmental	Climate resilience	Improve the resilience of the transport system to impacts of climate change, including climate variability and extreme weather events
Risk to Sustainability		Design and evaluation risk	Risk of cost overruns and below-expectation traffic demand, risks that negative impacts are above expectations, or risks that positive outcomes are below expectations, because of evaluation uncertainty
		Operation risk	Risk that the level of service provided by the project cannot be sustained at its expected level

GreenPave

GreenPave focuses specifically on the pavement component and pavement related items (MTO, 2014), such as pavement structure, rehabilitation strategies, use of material, pavement performance, and type of vehicles and equipment used during construction, rather than the entire road. GreenPave can be applied at design stage and as-constructed stage of a project. Some information of GreenPave can be found in Table 2.20.

Table 2.20 Information of GreenPave

Sustainability rating tool	GreenPave, Green Pavement Design Rating System
Developer	Ontario Ministry of Transportation
Website	http://conf.tac-atc.ca/english/annualconference/tac2012/docs/session29/chan.pdf
Release date	V1.0, Mar 2012
Last update	V2.0, Mar 2014
Application scope, as of Nov 2 2015	New, reconstruction and rehabilitation of Ontario pavement structures

One of GreenPave's goals is to enhance the sustainability of Ontario's transportation infrastructure through designing and selecting sustainable pavement treatment alternatives (Chan, et al., 2012).

Table 2.21 Indicators that are related to maintenance under GreenPave

Category	Sub-Category/Indicator
Pavement Technologies	Noise mitigation Cool pavements
Materials & Resources	Recycled content Undisturbed pavement structure Local materials Construction quality
Energy & Atmosphere	Reduced energy consumption GHG emissions reduction Pollution reduction
Innovation & Design Process	Innovation in design Exemplary process

11 out of 14 GreenPave indicators are directly related to maintenance (as shown in Table 2.21). Although GreenPave declared that it can be used for new construction and rehabilitation projects, none of the indicators reflects the needs from preservation and other maintenance projects.

In conclusion, compared to general pavement construction activities and existing sustainability rating tools for transportation or pavement, a number of content areas are substantially different for a project with a maintenance focus. The rating tools discussed above do have categories or indicators directly considering pavement maintenance activities, and so do some other popular sustainability rating tools for transportation or pavement such as Sustainable Sites Initiative (developed by American Society of Landscape Architects in 2009), Green Guide for Road Task Force (developed by Transportation Association of Canada in 2010), and Greenways (developed by Jackson State University in 2012) (Hirsch, 2012). However, these rating tools do not consider the maintenance activities as much as design and new construction throughout the life cycle of transportation infrastructure, which limits their applicability on quantifying sustainability in maintenance activities.

Literature review in this section also proves the reasonability of NCHRP's suggestion that a sustainability rating tool exclusively designed for pavement maintenance is needed. Such tool is necessary to both supplement the theory of sustainable pavement and to benefit the pavement maintenance industry.

CHAPTER III

CONCEPT OF SUSTAINABLE PAVEMENT MAINTENANCE

The results of literature review in Section 2.1 shows that sustainable pavement maintenance is receiving more attention, but the existing studies mainly focused on how to improve sustainability via techniques and materials. In order to consider all the reasonable impacts from economy, environment, and society, a comprehensive definition of sustainable pavement maintenance is needed.

3.1 Theory and Definition of Sustainable Pavement Maintenance

In response to the problems that appeared after pavements were built, some transportation agencies or pavement owners take action when the pavements fall to poor condition, and some agencies would use preservation when the pavements are still in good condition. Generally, pavement maintenance is used primarily to maintain the pavements performance at a reasonably serviceable level and to delay the costly reconstruction.

Sustainable pavement maintenance considers more for maintenance practices than traditional maintenance does, it encourages the project team to do a little more than just fixing the distresses or restore the performance for pavements.

Based on the idea of sustainable pavement or transportation and the consideration of improving pavement performance for all of the stakeholders, the definition of sustainable pavement maintenance should be a guideline rather than a detailed description, and should decide what to be considered and what can be considered as sustainable practices during maintenance projects. 6 principles that should be included in a complete and reasonable definition are:

- Triple Bottom Line (TBL). The "three pillars of sustainability" - economy, environment, society - should be covered in the discussion of sustainable pavement maintenance.

- Balance. To date, there's no single solution to keep the three gears moving together. The improvement of one aspect may be at the cost of other aspects under a specific project. Also, among the variables of the project collaboration that affect the decision-making, a balance can be reached by taking concerns from stakeholders standing for varies aspects.

- System. The pavement maintenance project should be considered as a system, and the maintenance should be planned in the whole transportation system. The project system can be discussed from two perspectives.

  First, all the activities throughout a pavement maintenance project should be considered, as shown in Table 3.1.

Table 3.1 Examples of activities throughout the pavement maintenance project

Stages	Pre-construction activities	Activities during construction	Post-construction activities
Examples	• Planning and preparation; • Crew training; • Collaboration among stakeholders; etc.	• Construction materials collection; • Maintenance process; • Inspection and acceptance; etc.	• Observation; • Monitoring; • Documentation; etc.

Second, sustainable pavement maintenance will be introduced at project level, but each maintenance project should be also considered in the whole transportation system if applicable. Sustainable pavement maintenance will be able to efficiently distribute the resources, optimize the maintenance practices, and eventually enhance the overall pavement system. The components within the pavement system are shown as Fig. 3.1.

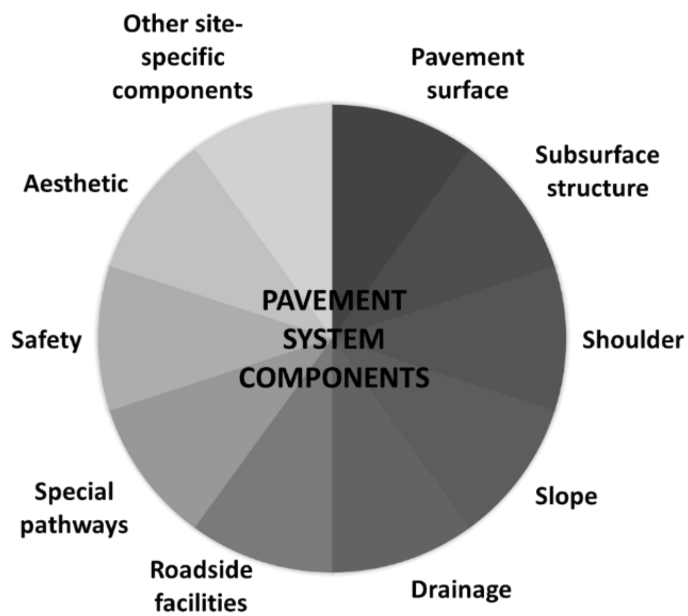


Fig. 3.1. Components of pavement system

- Context-Sensitive Solution. Each project of pavement maintenance has its own features. Context Sensitive Solution (CSS) is "a collaborative, interdisciplinary approach that involves all stakeholders in providing a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure conditions" (FHWA, n.d.c). The solution of one project might not be able to be modified to apply to another even if they have similar distresses to fix. Some practices considered as context-sensitive solutions include: 1) Strategy and evaluation methodology for certain weather, season, and climate; 2) Adoption on different locations, for different classifications, and with different traffic volumes; 3) Interaction with adjacent infrastructure or other maintenance project.

- Evolvement. Since elements like stakeholders' perceptions, adjacent infrastructure and technology change over time, sustainable solutions should be evolved consistently to match those changes.

- Collaboration. Sustainability affects the system as a whole. Therefore, the development of sustainability requires involvement and collaboration of all the stakeholders. Sustainable pavement maintenance is aimed to imbedding all kinds of stakeholders' opinions into the projects/programs and providing guidance toward sustainability at all levels of the organization. Only if all the stakeholders work together can sustainability be truly achieved.

The 6 principles are not considered and executed at the same level, their relations can be found from Fig. 3.2.

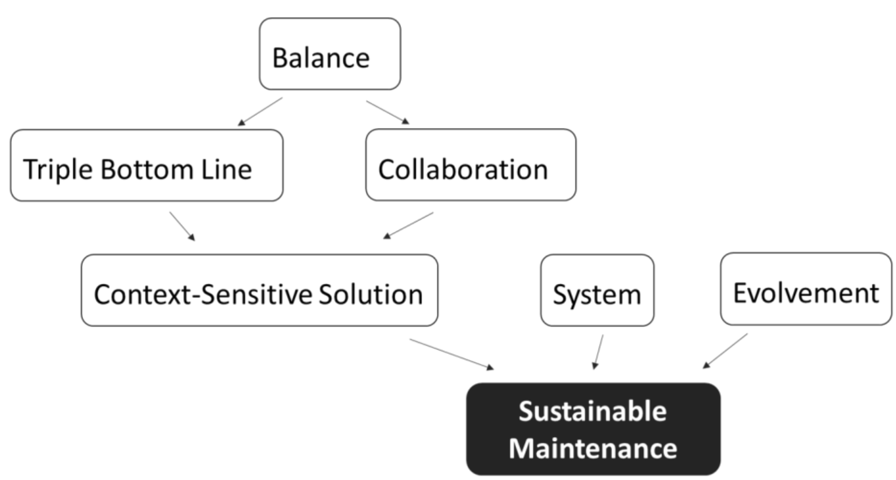


Fig. 3.2. Relationships among the 6 principles of sustainable pavement maintenance

In summary, **sustainable pavement maintenance** is a systematic, project-based collaboration that 1) reasonably allocates the labor, capital, and natural resources, 2) reduces negative impacts on surrounding environment, and 3) considers stakeholders' preference about preserving pavement structure or restoring the pavement performance; it 4) should be conducted as a component of the whole transportation system, 5) should comply with regulations at any level, and 6) should be evolved over time.

Sustainable pavement maintenance defined here is a more integrated concept in the industry compared to the existing studies. Traditional maintenance repairs pavement structure, while sustainable maintenance improves pavement system.

3.2 Benefits from Sustainable Pavement Maintenance

Sustainable activities throughout pavement maintenance projects, if conducted successfully, will greatly remove the negative impacts on or even benefit economy, environment, and society. The environment can be benefited from potential reductions in GHG and air pollutants emissions, hazardous material exposure, and soil erosion and sediment. Society can be benefited from less traffic disruption, and improved safety both in work zone and traffic flow. Economy can be benefited from fuel savings resulted from less user delay and better traffic control, the reduction in the use of virgin materials and energy, the reduced needs of repetitive maintenance, and the extended pavement lives to save costs in the long run.

3.3 Stakeholders Involved in a Sustainable Pavement Maintenance Project

Any "individual, group, or organization, who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome" (McDonald, n.d.) of a maintenance project can be considered as a stakeholder, including but not limited to:

- Road owners
- Funding sources
- Contractors/working crew
- Inspectors
- Administrative departments/regulatory agencies
- Pavement users
- Nearby communities (property or business owners, residents or workers)
- Public
- Material suppliers, if applicable
- Equipment suppliers, if applicable
- Research organizations, if applicable

The opinions of all the stakeholders mentioned above should be considered to make the final decision for a sustainable maintenance project, so that the project could benefit all of the stakeholders. Stakeholders' involvement should start as early as the project preparation. For large-scale or long-term project, the project team should take advice from the representative of each group of stakeholders, so the concerns from different stakeholders can be considered and assessed by the project team at early stage. The project team should regularly contact (such as meetings or emails) with the representative of each group of stakeholders, and track their opinions throughout the project. For small-scale or short-term project, similar stakeholder involvement is also recommended.

Sometimes the stakeholders might not be able to participate in the process of the decision making, or their opinions might be difficult to collect, in these cases, the project team may come up with a solution (such as website or questionnaire) for collecting opinions or feedback from stakeholders, so that all the interested individuals could express their concerns and contribute to the project. The collected data can be used as references for similar projects in the future.

CHAPTER IV

DEVELOPMENT OF A SUSTAINABILITY RATING TOOL FOR PAVEMENT MAINTENANCE

Compared to existing sustainability rating tools for transportation or pavement discussed in Section 2.2.3, a number of content areas are substantially different for a project with a pavement maintenance focus. It is necessary to develop a sustainability rating tool that is exclusively designed for pavement maintenance. The new rating tool to be developed can be used to:

- Provide the bridge between concept and practice of sustainable pavement maintenance;
- List and define those sustainable and practical solutions in pavement maintenance industry;
- Evaluate and quantify sustainability of individual pavement maintenance projects reasonably;
- Provide index for users to conveniently look up sustainability activities and compare sustainability among different activities or projects;
- Award certification according to the level of achieved sustainability;
- Track and quantify the sustainability goals over time;
- Involve all stakeholders as early as possible for maintenance projects;

- Raise public awareness about making maintenance activities sustainable.

The new-developed rating tool is named as Pavement Sustainability Index for Maintenance (PSIM), green clover is used as its logo as shown in Fig. 4.1. PSIM will be developed in five steps (Zhang & Mohsen, 2016):

- Determine the rating categories;
- Determine the rating indicators under each category;
- Determine the priority of each category;
- Determine the points under each indicator;
- Propose a certification methodology.

Fig. 4.1. PSIM logo (designed by Yibo Zhang)

4.1 Determination of Rating Categories

The first step to develop a sustainability rating tool is to determine the rating categories, each category will focus certain sustainability topics named indicators. The categories of PSIM was determined as shown in Table 4.1.

Table 4.1 Rating categories of PSIM

Pavement Maintenance Project			
Input		Output	Others
Abstract Inputs	Concrete Inputs		
Management, Technique	Material, Energy&Water	Environment, Safety, Community	Innovation

8 categories determined for PSIM are described as below.

- Management (Mn). It is a reflection that pavement maintenance project should be a system not only at the project level but also as a part of the whole pavement system.
- Technique (T). It discusses the sustainability topics associated with pavement maintenance techniques.
- Material (Mt). It is always one of the top concerns of sustainable infrastructure, because materials take a lot of energy to produce, transport, store, and dispose, and materials themselves are precious resources as well.
- Energy&Water (EW). It considers energy conservation and emissions reduction of using electricity and fuel, and also considers protecting water resources.
- Environment (E). It is directly dealing with any kind of pollution to environment and people resulted from pavement maintenance activities, and attempts to remove the negative impacts of pavement maintenance activities on surrounding nature and community as much as possible.
- Safety (S). It addresses the importance of safety during pavement maintenance project, such as pavement users, working crew, and people living or working in nearby communities.

- Community (C). It focuses on the community near the pavement maintenance project; the people living or working nearby, cultural environment, and anyone who will be benefited from sustainable pavement maintenance project in either direct or indirect way are also considered.
- Innovation (I). It evaluates any creative and practical idea to improve the sustainability of pavement maintenance, and recommends adding the experience from other sustainable projects into pavement maintenance.

4.2 Determination of Sustainability Indicators

Indicators enrich the details of the rating categories. PSIM indicators were designed based on the objects affected by pavement maintenance activities, including:

- The human. There are different stakeholders involved in maintenance activities, and they can be specified as three groups: 1) Pavement users (motorists, pedestrians, bicyclists, etc.); 2) Working crew who conduct maintenance activities; 3) Other stakeholders.
- The vehicle. The element of vehicle includes vehicles in the traffic flow, vehicles/equipment driven by the working crew, and vehicles for transporting materials/wastes.
- The pavement. This element not only considers pavement structure itself, but also takes other components of transportation system and surrounding environment into account.

In general, the design of PSIM indicators considers the safety and comfort of human, the operation and management of vehicle, as well as the techniques and materials used to maintain pavement.

Jeon and Amekudzi had reviewed 16 frameworks of sustainable transportation and listed 177 rating indicators to evaluate any sustainable progress on transportation (Jeon & Amekudzi, 2005). Litman also did a comprehensive research on indicators for sustainable transport planning (Litman, 2007). Besides, the indicators distribution of LEED modules (Neighborhood Development and Operation & Maintenance) and 9 rating tools discussed in section 2.2.3 for transportation or pavement are also used as references to determine indicators under each category.

The indicators are carefully designed to avoid overlapping. The final list of sustainability indicators for pavement maintenance are shown in Fig. 4.2. The PSIM Scorecard provides the purpose of each indicator, which can be found in Appendix A.

Management	Technique	Material	Energy&Water	Environment	Safety	Community	Innovation
Project Team	Technique Selection	Quality Certification	Efficient Lighting	Wastes	Traffic Control	Report the Problem	Creative Idea
Budget Plan	Distress Reason	Material Production	Energy Consumption I, Construction	Air Quality	Construction Safety	Landscape Maintenance	Sustainability Representative
Quality Management	Standard Procedure	Local Material	Energy Consumption II, Transport	Noise Control	Pavement Marking	Aesthetic Design	Certified Sustainable Pavement
Emergencies	Disturbance and Repair	Material Storage	Energy Consumption III, Asphalt Mixture	Vibration Control	Appurtenances	Culture Conservation	
Maintenance Schedule	Uneven Surface	Recycle Material	Water Consumption	Erosion and Sediment Control	Pedestrian and Bicyclists	Notification	
Project Record	Preservation	Alternative Material	Heat Island Alleviation	Ecology Conservation	Drainage	Ease of Use	
Work Zone Management		Earthwork			Glare Control	Community Adaption	
Crew Training					Snow and Ice Removal	Sustainability Promotion	
Project Interaction							

The eight icons for rating categories are designed by Freepik and Yibo Zhang.

Fig. 4.2. Categories and Indicators of PSIM

4.3 Determination of Category Priority

Analytic Hierarchy Process (AHP) was used here to determine the weighting (priority) of each category of PSIM. AHP, which was developed by Thomas Saaty in the early 1980s, is subjective method to rank different elements and make decisions. AHP has been accepted as an industry standard and widely used in different fields (Jawad, 2013; Oswald & McNeil, 2010; Ali & Al Nsairat, 2009; Triantaphyllou & Mann, 1995). It uses pairwise comparison to generate ratio data so that the result can show how much more important one item is prioritized than another rather than an order list of importance. It decomposes the decision problem into a hierarchy of a set of sub-problems first, and then considers the judgement from professionals or stakeholders for the priority of each sub-problem, finally gives numerical weights for the whole hierarchy.

4.3.1 Introduction of Analytic Hierarchy Process

AHP is a multi-criteria decision making approach in which factors are arranged in a hierarchic structure by generating relative ratio scales of measurement (Saaty, 1990). It has many advantages such as:

- AHP is a systematic analytic method. The decomposition, comparison, judgment, and integration of those different elements affecting decision are involved, so that the relationships between different elements and final decision result are maintained and quantified in the AHP process.
- AHP successfully combines qualitative and quantitative methods during its process, but also reasonably emphasizes qualitative analysis. The required input data are easy to obtain.
- AHP is able to transform decision making with multiple targets and

multiple criteria into simple problems of single target at different levels. The calculations are straightforward and relatively simple.

Therefore, this methodology is suitable for engineering applications of determining the relative importance of alternatives if the final decision is based on the evaluation of alternatives in terms of corresponding criteria (Triantaphyllou & Mann, 1995), especially the criteria are indicated in different ways or are difficult to be quantified. Pairwise comparisons are used to obtain the weights of importance of criteria. The consistencies of completed comparisons can be improved by a certain mechanism with AHP.

This section focused on the AHP weighting process for criteria (determining the relative importance of each criterion), since this process will be mainly used for the development of new sustainability rating tool for pavement maintenance. The process is shown as below in four steps.

Step 1: Determine criteria

Assuming there are a number (n) of decision criteria, each alternative can be evaluated by criteria. wi is assumed to be the weight of the criterion Ci. All criteria are assumed to be indicated by the same unit (AHP can be also used if criteria are indicated by different units).

Step 2: Input data – pairwise comparison and "importance matrix"

Pairwise comparisons are conducted between each two of the criteria. Table 4.2 is used to describe the relative importance between two criteria.

Table 4.2 Scale of relative importances

Value of Relative Importance	Definition	Explanation (Triantaphyllou & Mann, 1995)
1	Equal importance	Two activities contribute equally to the objective
2	Equal to moderate importance	When compromise is needed between the values of odd number
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate to strong importance	When compromise is needed between the values of odd number
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong to very strong importance	When compromise is needed between the values of odd number
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
8	Very strong to extreme importance	When compromise is needed between the values of odd number
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above nonzero values	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

The results of relative importances then can be organized into "importance matrix A".

$$A = \left[a_{ij}\right] = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \end{array} \quad (4.1)$$

If aij > 1, then the ith criterion is more important than the jth criterion;

If aij < 1, then the ith criterion is less important than the jth criterion;

If aij = 1, then two criteria have the same importance;

aij and aji are reciprocals, aij · aji = 1

Step 3: Compute the vector of criteria weights

The normalized "importance matrix" can be obtained by

$$A_{norm} = \left[\bar{a}_{ij}\right] = \left[\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}\right] \quad (4.2)$$

Then, the criteria weight vector, an n-dimensional column vector, can be calculated by averaging the entries on each row of the normalized "importance matrix" as

$$w_i = \frac{\sum_{k=1}^{n} \bar{a}_{ik}}{n} \quad (4.3)$$

The elements of the obtained vector are the weights of each criterion.

Step 4: Check consistency

If criterion 1 is strongly more important than criterion 2, and criterion 2 is moderately more important than criterion 3, then criterion 1 obviously will be more important than criterion 3. An inconsistency occurs if the decision maker evaluates criterion 1 is less important than criterion 3.

An eigenvalue can be calculated: $\lambda_{\max} = \sum_{i=1}^{n} \frac{(Aw)_i}{nw_i}$ (4.4)

Then the Consistency Index: $CI = \frac{\lambda_{\max} - n}{n-1}$ (4.5)

If CI = 0, then judgments are perfectly consistent. The inconsistency becomes higher with a higher CI value.

A maximum value of 0.10 of consistency ratio $CR = \frac{CI}{RI}$ (4.6) may be accepted for typical use. Random Index (RI) is the consistency index when the entries of "importance matrix" are completely random, and can be picked from the Table 4.3.

Table 4.3 Typical values of Random Index (RI) (Jingdongwf, 2013)

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

4.3.2 Determination of Category Priority Using Analytic Hierarchy Process

The procedure to determine the category priority is shown as in Fig. 4.3.

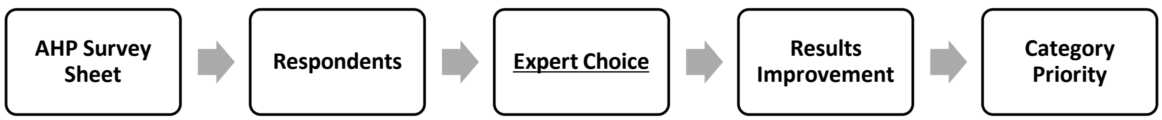


Fig. 4.3. Flow chart of determining the category priority of PSIM using AHP method

The AHP survey form is prepared as shown in Appendix B. The PSIM Scorecard (without points distribution results) is provided together with AHP survey sheet to the respondents. The respondents were asked to review the Scorecard to get familiar with what will be evaluated under each category, then were asked to compare the importance of any two of the categories based on a "1 to 9 scale" shown in Table 4.2. For example, if the respondent strongly agrees with that Category Management is more important than Category Technique, then he/she should circle the number of "5" closer to Management in the first row of the right form on the AHP survey sheet.

During PSIM inspector's field visits, randomly selected people were invited to review the PSIM Scorecard and fill the AHP survey sheet, including 6 groups:

- Employees (including officers and inspectors) from Public Works or transportation agencies, 3 respondents;
- Working crew members (including engineers and technicians) of

maintenance projects, 9 respondents;

- Traffic control specialists working on maintenance projects, 3 respondents;
- Motorists, pedestrians, and bicyclists passing by maintenance projects, 6 respondents;
- Residents and workers in the community close to maintenance projects or deteriorated pavements, 6 respondents;
- Teachers and students of Civil Engineering who were involved in at least one course related to sustainable design, 4 respondents;

	Mn	T	Mt	EW	E	S	C	I
Mn		4.0	7.0	8.0	6.0	7.0	8.0	6.0
T			4.0	5.0	3.0	4.0	5.0	3.0
Mt				2.0	2.0	1.0	2.0	2.0
EW					3.0	2.0	1.0	3.0
E						2.0	3.0	1.0
S							2.0	2.0
C								3.0
I	Incon: 0.02							

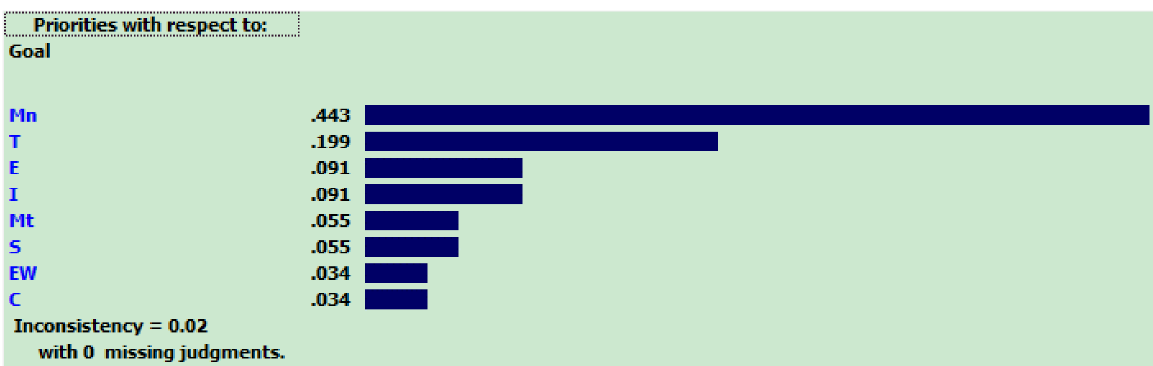


Fig. 4.4. Interface of Expert Choice

34 individuals were invited, 31 of them finished the survey and returned the survey sheet. The survey results are then given to an AHP software named Expert Choice to calculate the priorities of the 8 categories. The interface of Expert Choice is shown as in Fig. 4.4.

AHP allows inconsistency and provided the inconsistency result for each set of judgments. Usually an inconsistency of no more than 0.10 is acceptable (Barfod, 2014). If the inconsistency for any set of judgments is more than 0.10, that set of judgments will be improved (Cash flow Valuation Online, n.d.) until the inconstancy is no more than 0.10 following the steps:

- Select the "Inconsistency" command and "1st" on its dropdown menu, the cell of most inconsistent judgment will be highlighted.
- Select the "Inconsistency" command and "Best Fit" on its dropdown menu to have the "best judgment" for the highlighted cell displayed.
- Modify the highlighted judgment as recommended.
- Repeat the first three steps until the inconstancy is no more than 0.10.

The detailed results of AHP survey can be found in Appendix C.

Table 4.4 Category priority result of PSIM

Item	Category	Normalized Priority	Ranking
Mn	Management	0.138	2
T	Technique	0.101	5
Mt	Material	0.101	4
EW	Energy&Water	0.061	8
E	Environment	0.129	3
S	Safety	0.310	1
C	Community	0.090	6
I	Innovation	0.070	7

The means of the 31 sets of results were then calculated and normalized to obtain the final priorities. As can be seen from Table 4.4, Safety was ranked first followed by Environment, Community, Material, Energy&Water, Management, Technique, and finally Innovation.

4.4 Determination of Points Distribution

Most of the existing sustainability rating tools for transportation or pavement distribute points under each indicator (also known as indicator weighting) by subjective judgement of rating tool developers. INVEST by FHWA completely uses subjective judgement of rating tool developers. Greenroads uses subjective judgement of rating tool developers with limited data support for weighting some indicators). BE^{2}ST considers three different weighting categories: 1) equally assigned weighting; 2) weighting assigned by consensus of a stakeholder group; and 3) project specific weighting assignment.

Table 4.5 Points Distribution under PSIM Rating Categories

Item	Category	Normalized Priority	Points Distribution
Mn	Management	0.138	28
T	Technique	0.101	20
Mt	Material	0.101	20
EW	Energy&Water	0.061	12
E	Environment	0.129	26
S	Safety	0.310	62
C	Community	0.090	18
I	Innovation	0.070	14
	Total Points		200

PSIM will use a statistical approach as objective weighting method to distribute points under each indicator. The maximum possible points that can be earned from PSIM are set to be 200. The possible points under each category were calculated in proportion according to the category priorities obtained from section 4.3 as shown in Table 4.5.

Points under indicators will be distributed by reviewing State DOT's practices under PSIM indicators. The following State DOTs have the best sustainability practices across the U.S.: Caltrans, CDOT, FDOT, MnDOT, NYSDOT, ODOT-Oregon, and

WSDOT (Zietsman & Ramani, 2011). Also, KYTC is effectively improving the sustainability of transportation infrastructure (McCormack, et al., 2014), the practices of KYTC will be included as well. The practices of 8 state DOTs mentioned above will be reviewed as can be seen in Appendix D. 350 manuals or websites were reviewed, which can also serve as reference documents for each PSIM Indicator.

The final result of points distribution is shown in Table 4.6.

Table 4.6 Points Distribution under PSIM Rating Indicators

Category	Indicators	Maximum Pts
Management	Project Team	2
	Budget Plan	3
	Quality Management	4
	Emergencies	3
	Maintenance Schedule	3
	Project Record	4
	Work Zone Management	3
	Crew Training	4
	Project Interaction	2
Technique	Technique Selection	2
	Distress Reason	4
	Standard Procedure	8
	Disturbance and Repair	2
	Uneven Surface	2
	Preservation	2
Material	Quality Certification	5
	Material Production	4
	Local Material	2
	Material Storage	2
	Recycle Material	4
	Alternative Material	1
	Earthwork	2
Energy&Water	Efficient Lighting	3
	Energy Consumption I, Construction	3
	Energy Consumption II, Transport	2
	Energy Consumption III, Asphalt Mixture	2
	Water Consumption	1
	Heat Island Alleviation	1
Environment	Wastes	6
	Air Quality	4

	Noise Control	4
	Vibration Control	2
	Erosion and Sediment Control	4
	Ecology Conservation	6
Safety	Traffic Control	10
	Construction Safety	10
	Pavement Marking	7
	Appurtenances	10
	Pedestrian and Bicyclists	8
	Drainage	10
	Glare Control	2
	Snow and Ice Removal	5
Community	Report the Problem	1
	Landscape Maintenance	4
	Aesthetic Design	2
	Culture Conservation	3
	Notification	2
	Ease of Use	1
	Community Adaption	4
	Sustainability Promotion	1
Innovation	Creative Idea	8
	Sustainability Representative	4
	Certified Sustainable Pavement	2

4.5 Proposal of Certification Level

After a pavement maintenance project has been evaluated within PSIM framework, a score called Pavement Sustainability Index (PSI) will be awarded to the project to reflect its sustainability achievements.

Those existing sustainability rating tools for pavement/transportation calculate the total points earned by projects/programs under each indicator as the basis for certification. However, for PSIM and pavement maintenance project, it is possible that one pavement maintenance project does not cover all the indicators, since each project has its unique background as well as the scale of each project might vary considerably.

PSI should be a reflection of the evaluation under those involved indicators by considering both indicators covered and points earned.

A typical PSI is a combination of two parts: the quantity of indicators involved, and the percentage of points earned under involved indicators. For instance, if the PSI of one project is 20/50%, it means the project has involved 20 PSIM indicators, and has earned half of the maximum points that can be earned under those 20 indicators.

Large-scale, more extensive project usually involves more indicators than small-scale, less extensive one does, so that it has more chances to make itself sustainable and earn PSIM points. However, it does not mean that small-scale project will never become more sustainable than large-scale one, it will receive a high certification as long as it has earned enough points under those indicators involved.

In order to demonstrate the sustainability achievements of different pavement maintenance projects, reasonable certification level should be granted for the project after evaluation and PSI calculation.

Table 4.7 PSIM Certification Levels

		Quantity of Indicators		
		20~29	30~39	40~53
Percentage of Points	40.0%~59.9%	-	★	★★
	60.0%~79.9%	★	★★	★★★
	80.0%~100.0%	★★	★★★	★★★(Demonstration Project)

There are three certification levels based on the indicator quantity and approximate scoring rate as shown in Table 4.7. One to three PSIM stars will be awarded to the project according to its PSI. If the project involves 36 indicators or more and earned at least 80% of maximum possible points, the project will be a PSIM demonstration project. The PSIM stars are also the reflection of sustainability achievements of a pavement maintenance project. For instance, if a PSI of 30/60% has been calculated, two stars will be granted.

In conclusion, the procedure of PSIM certification is:

- Count the indicators involved in the project (I) and calculate the maximum possible points that can be earned (Pm);
- Evaluate the sustainability practices of the project under each involved indicator, and calculate the sum of earned points (Pe);
- Determine the PSI as (I)/(Pe/Pm×100%) (4.7);
- Grant PSIM stars according to Table 4.8.

4.6 Introduction of PSIM

PSIM has some unique **features** compared to other rating tools for transportation or pavement:

- Exclusively designed for pavement maintenance
- Make maintenance projects of different sizes easily comparable
- Self-evaluation or third-party certification
- Brand new method of certification
- Coefficient ranking of pavement maintenance contractor and manager
- Emphasize the involvement of all stakeholders for pavement maintenance

As a sustainability rating tool designed for pavement maintenance projects, PSIM can be used under various **circumstances**:

- All types of maintenance activities, including preservation and rehabilitation activities to restore pavement structure, enhance ride quality, extend service life of existing facilities, improve safety, or make pavement system easy to use;

- Maintenance activities on different components of pavement system;
- Maintenance on all three types of pavement surfaces: asphalt, concrete, and unpaved (mostly dirt and gravel). The distresses, techniques, and materials used to maintain different types of pavement surfaces are different, but the economic, environmental, and social impacts of maintenance activities can be considered under the same indicators; therefore, PSIM will be a uniform tool for asphalt, concrete, and unpaved surfaces;
- Pavements for different purposes, such as parking lot;
- Pavements in different areas: urban, suburban, rural, and eco-sensitive areas (such as national parks and wetlands);
- Pavement with different traffic volumes;
- Proceeding, or finished maintenance projects.

However, PSIM is not design for new construction, reconstruction, or expansion of pavement.

There are two **products** developed for PSIM. One is Scorecard, which shows rating categories and indicators with points distribution. The other is Users' Manual, which shows purpose and details of each rating indicator.

PSIM **inspector** plays the role of reviewing any documents submitted from project teams and conducting third party certification. Since PSIM evaluates what is being done and what has been done during pavement maintenance project, it is necessary for PSIM inspector to be in the construction field observing actual pavement maintenance activities. The requirements for being PSIM inspector include:

- Being familiar with the concept of sustainability;
- Being familiar with PSIM rating tool;
- Being independent of pavement owners and project contractors;
- Being able to communicate with stakeholders to collect information;
- Being on construction site to observe maintenance activities and to interview stakeholders every day throughout the project.

To **promote** the concept of sustainable pavement maintenance as well as PSIM rating tool to the professionals and public, Contractor Coefficient Ranking and Manager Coefficient Ranking are proposed.

The contractor coefficient rankings (CR_c) take into account the PSIM results of each contractor in the pavement maintenance industry and are used to determine a contractor's priority during bidding. The contractor with a higher PSIM coefficient ranking shows its strength in promoting sustainability and might have a bigger chance to win the bidding.

There also will be manager coefficient ranks (CR_m) for those who served as team leader in a qualified (at least one PSIM star) sustainable pavement maintenance project. CR_m take into account the PSIM results of each project manager and are used to determine a manager's priority when a project team leader is needed. The manager with a higher PSIM coefficient ranking shows his/her strength in promoting sustainability and might have a bigger chance to be assigned as the project team leader of the future projects. CR_c and CR_m can be calculated as below:

$$CR_c \ or \ CR_m = \sum_{i=0}^{3} N_i * i \quad (4.8)$$

in which,

i----the amount of stars that the contractor/manager earned in one project, $i = 0 \sim 3$;

N_i----the amount of projects earning i star(s) which the contractor/manager has been involved in.

As one of the final products of PSIM development, *PSIM Manual* explains each rating indicators and gives rating strategy for each indicator. Anyone being interested in sustainable pavement maintenance is highly recommended to review *PSIM Manual* as shown in Appendix B. Each indicator will include the following information:

- Name
- Benefits according to TBL
- Application: can this indicator be used on asphalt pavement, concrete pavement, or unpaved pavement?
- Explanation
- Example from actual maintenance practices (if applicable)
- Related Indicators
- How To Measure: the information needed for evaluation
- Possible points
- Rating Strategy: how to award points under different scenarios;
- Resources (if applicable): reading materials for the indicator.

CHAPTER V

CASE STUDIES

The project being evaluated by PSIM must be either in progress or already finished, so that the actual activities during maintenance can be evaluated. PSIM can be used as self-assessment or third-party evaluation.

Project team should follow the steps if it is a self-assessment:

1. Obtain copies of and get familiar with the PSIM Scorecard and Manual;
2. Confirm the scoping for the project and determine the SIL (sustainability indicators list) based on which indicators are involved (the amount of involved indicators is N) in the project;
3. Determine the maximum points (MAX) under each indicator within SIL based on the project context;
4. Submit the evaluation report to PSIM inspector for review when the indicator I-1 is involved;
5. Calculate the PSI as $(N)/(\frac{ACT}{MAX} \times 100\%)$ (5.1);
6. Provide evidence for earned points if PSIM certification is needed.

PSIM inspector should follow the steps if it is a third-party evaluation:

1. Observe the maintenance activities and interview stakeholders;

2. Confirm the scoping for the project and determine the SIL (sustainability indicator list) based on which indicators are involved (the amount of involved indicators is N) in the project;

3. Determine the maximum points (MAX) under SIL;

4. Evaluate the project practices and determine the actual points (ACT) earned by the project;

5. Calculate the PSI as $(N)/(\frac{ACT}{MAX} \times 100\%)$ (5.2);

6. Provide PSIM evaluation report to inform project team of their performance, and award PSIM certification if PSI meets certain requirements.

To check the applicability of PSIM on pavement maintenance projects, four types of maintenance activities were selected to demonstrate the PSIM evaluation process. The application of PSIM on real pavement maintenance project, and the PSIM report (as the evaluation results) will be introduced in this section. The contents of PSIM report include:

- Sustainability indicators list (SIL), which is the indicators involved throughout the project
- Maximum (achievable) and actual (awarded) points under each indicator
- PSI and certification (if applicable)
- Indicator-by-indicator explanation
- Strengths (sustainability achievements) and weaknesses (potential improvements)
- Specify the activities that deserve Innovation points (if applicable)

If the information needed under certain indicator was not available, a decision will be made based on the observation of PSIM inspector or no points will be granted under that indicator.

5.1 Case Study 1, Rejuvenation in Corydon, IN

Harrison County, IN adopted a rejuvenator to preserve multiple pavement sections in the county. This rejuvenator (WD 2000 ™) was produced by Lone Star Specialties, LLC located in Texas. WD 2000 is a type of penetrating sealer for asphalt surface. Coal tar oils in the product will lower the viscosity and increase the ductility of existing asphalt, while top tars in the product seal the asphalt surface as a shield of protection. VOC content in WD 2000 is less than 2.8 lb/gal. According to its introduction, "certificates of analysis are supplied for each shipment of WD 2000 to confirm specification requirement".

Different resources were used to obtain the information of the projects, including project list from contractor and County Highway Department, field visits, working crew (foreman and equipment operators) interviews, emails with contractor employees, and using Google Map.

The application of WD 2000 on Heidelberg Road (from Hillgrove Road to State Road 135) in Corydon, IN was selected as a case study for PSIM evaluation. This project covered a pavement section of approximately 5.3 mile, and was part of the County's rejuvenating fog seal project (with a total of 117 miles of County roads treated).

PSIM inspector was on site on Sep 12, 2014 and Sep 17, 2016 (project date) to observe pavement condition and contractor's (a local commercial paving company) work. The pavement condition was fair to good (according the PASER rating data provided by the contractor). The rejuvenating application needed the pavement surface to be free of debris and dry. Then WD 2000 was applied by spray machine in large areas or by paint rollers in small and hard to reach areas. Small amount of traffic was allowed when spraying WD 2000, and the pavement can be opened to traffic after 5 hours of curing and drying. The rejuvenation operation and result are shown in Fig. 5.1.

Fig. 5.1. Field view of rejuvenation on Heidelberg Road in Corydon, IN

The PSIM evaluation results are shown as in the Table 5.1 below.

Table 5.1 PSIM evaluation results of case study 1

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	Contractor has a project team to apply the rejuvenator
	Budget Plan	3	1	Budget is available

	Quality Management	4	2	Visual inspection; Manufacturer has strict quality guidelines; inspector from the County was not observed during construction
	Emergencies	3	0	N/A
	Maintenance Schedule	3	2	Schedule was tight and was available to County Highway Department
	Project Record	4	3	ADT, Initial paving year, PASER rating, length and width are in the project record
	Work Zone Management	3	2	The working routes of hauling truck and sprayer are planned ahead but the parking of equipment and vehicles on adjacent roads sometimes blocked the traffic
	Crew Training	4	4	Working crew are trained and experienced, but sustainability is not involved
Technique	Technique Selection	2	2	WD-2000 is selected rather than traditional fog seal according to economic, environmental, and social benefits
	Standard Procedure	8	8	Manufacturer has its own standard application procedure
	Preservation	2	2	WD-2000 was used as preservation for pavements that were 4 to 14 years old
Material	Quality Certification	5	5	Certificates of analysis are supplied for each shipment of WD-2000
	Local Material	2	0	WD-2000 was shipped from Texas
Energy& Water	Energy Consumption I, Construction	3	0	N/A
	Energy Consumption II, Transport	2	1	Carpool observed
	Heat Island Alleviation	1	0	N/A
Environment	Noise Control	2	1	Sprayer generates low noise
	Ecology Conservation	6	2	Rejuvenator was non hazardous material approved by EPA, OSHA, IARC, FDA, and FAA; some rejuvenator was sprayed on the turf along the road
Safety	Traffic Control	10	10	Flaggers were onsite using signs and flashing devices
	Construction Safety	10	8	Some of the working crew do not wear safety vest
	Pavement Marking	7	2	Pavement marking is painted by trained technician
Community	Notification	2	0	N/A
	Community Adaption	4	2	The needs of neighbors were not inspected before preservation, and were not considered during preservation, but neighbors were able to travel with little disruption
	Sustainability Promotion	1	1	Rejuvenator and its successful applications were promoted by manufacturer and contractor, brochure was available, information can be found on both websites
Innovation	Sustainability Representative	4	0	N/A

Certified Sustainable Pavement	2	0	N/A
Indicators Amount	26		N/A: Information not available
Total Pts	99	60	
Percentage Earned	60.6%		
Certification Level	★		

The project earned a total of 60 points under 26 PSIM Indicators, so the project's PSI is 26/60.6%, which means this pavement maintenance project was sustainable and achieved one PSIM star.

Strengths:

- Consistent schedule from County and contractor
- Preservation project
- Basic information about the pavement and project are on record
- Information and document are available for sustainability promotion

Weaknesses:

- Turf along the pavement was not protected

5.2 Utility Cut Restoration in Louisville, KY

The primary function of the pavement system is for transportation, but it also serves as corridors for infrastructure providing water, gas, electric, sewer, and other kinds of utilities to businesses and residents. Performing installation, repair, or modification on these infrastructure systems often requires road cuts to access the buried assets, which adversely affects the life expectancy of the pavement. The infrastructure owners strive to and the pavement users hope to restore the pavement back to the original condition at higher construction efficiency and stakeholders' satisfaction.

As of 2014, Louisville Metro Public Works Department managed approximately 8,000 miles of paved pavements in Louisville, KY (Roberts, et al., 2015). However, 99% of the underground utility work was performed by either the Louisville Water Company (LWC), Louisville Gas & Electric (LG&E), or the Metropolitan Sewer District (MSD).

Different resources were used to obtain the information of the projects, including daily work assignment reports from LWC, field visits, working crew interviews, communications (emails and periodic meetings) with the officials of LWC, and using Google Map.

5.2.1 Case Study 2

A UCR project on asphalt pavement at Fern Valley Road & Shepherdsville Road in Louisville, KY was selected as the case study. LWC scheduled a pavement digging due to a water main break on June 17, 2015, and asked the contractor to conduct the asphalt pavement restoration due to the utility cut on the following day. The construction site was located on the northwest corner of the intersection of Fern Valley Road and Shepherdsville Road, there is a big parking lot along the road. After the pavement was dug, the main break was repaired, and the trench was backfilled, one local contractor (a highway street and bridge construction company) conducted a thin HMA overlay at an approximate size of 74×15 square feet to restore the pavement cutting area on June 18, 2015, and finished the work on the same day. It was sunny on June 18, and there was a heavy rain at dusk on June 19, 2015. Some field observations during and after restoration are shown in Fig. 5.2.

Fig. 5.2. Field view of utility cut restoration on Fern Valley Road in Louisville, KY

The PSIM evaluation results are shown as in the Table 5.2 below.

Table 5.2 PSIM evaluation results of case study 2

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	People at the three utility agencies were designated to be in charge of utility cut restorations, and they have relationships with contractors
	Budget Plan	3	0	N/A
	Quality Management	4	1	Both backfilling and pavement restoration were visually checked
	Emergencies	3	0	N/A
	Maintenance Schedule	3	2	Tight schedule. Digging started one day before the pavement restoration. Pavement was restored within one day and was completed before the raining
	Project Record	4	2	Only project log from LWC was available, project log from contractor is not available; LWC projects data base exists but project information is limited
	Work Zone Management	3	2	Equipment, vehicles, and tools were well organized at the nearby parking lot, but there was no guidelines about work zone management

	Crew Training	4	3	Experienced working crew was working on site but did not know about sustainable pavement maintenance
Technique	Standard Procedure	8	6	Separate contractors were involved for trench backfilling and pavement restoration; pavement restoration followed the standard procedure from contractor, but neither did trench backfilling. Louisville Metro is seeking standard procedures for trench backfilling, and the project is under progress
Material	Quality Certification	5	0	N/A
	Material Production	4	0	N/A
	Local Material	2	2	HMA is ordered in Louisville
	Earthwork	2	0	Backfilling was not observed
Energy& Water	Energy Consumption I, Construction	3	0	Traditional construction equipment was used
	Energy Consumption II, Transport	2	1	Carpool was observed
	Heat Island Alleviation	1	0	No such treatment was applied
Environment	Wastes	6	2	Pavement surface and the shoulder between lanes and curb was clean, but not all of asphalt wastes were removed from site. The destination of wastes was unknown
	Air Quality	4	0	Dust was not controlled during restoration
	Noise Control	2	0	N/A
	Ecology Conservation	6	1	The existing plant was not disturbed, but some wastes of asphalt mixture was left on the lawn along the pavement
Safety	Traffic Control	10	7	Well designed and effective. Traffic controlled was initiated before digging. The traffic cones were removed from pavement after construction but were not removed from the site. No guideline for traffic control was observed
	Construction Safety	10	6	No accident, but working crew did not wear reflective safety vest. No guideline for construction was observed
	Pavement Marking	7	2	All traffic marking that were destroyed during construction were restored, but the resource of marking material was unknown
Community	Report the Problem	1	1	LWC has "Report a Water Main Break"; Louisville Public Works has “Report a Pothole or other city services issue”; Louisville MetroCall 311 and 311 app
	Notification	2	0	N/A
	Community Adaption	4	2	Asphalt pavement for different uses all followed the same restoration procedure; People entering or existing the parking lot were not affected
	Sustainability Promotion	1	0	N/A
Innovation	Sustainability Representative	4	0	N/A

Certified Sustainable Pavement	2	0	N/A
Indicators Amount	29		N/A: Information not available
Total Pts	112	42	
Percentage Earned	37.5%		
Certification Level	-		

The project earned a total of 42 points under 29 PSIM Indicators, so the project's PSI is 29/37.5%, which means this pavement maintenance project was not sustainable defined by PSIM.

Strength:

- Tight schedule
- Good traffic control
- Reasonable parking of construction equipment

Weakness:

- Collecting and disposing solid waste
- Setting notification about the finishing date on site
- Lack of quality management

5.2.2 Case Study 3

A UCR project on asphalt pavement at 8111 Preston Highway in Louisville, KY was selected as the second case study. LWC scheduled a pavement digging due to a water main break on June 16, 2015, and asked the contractor to conduct the asphalt pavement restoration due to the utility cut on June 18, 2015. The construction areas include the pavement located in front of a local business as part of its parking lot and a smaller area on Preston Hwy (north bound). After the pavement was dug, the main break was repaired, and the trench was backfilled, one local contractor (a highway street and bridge construction company) conducted a thin HMA overlay at approximate sizes of 26×20 square feet plus 6×3 square feet to restore the pavement cutting area on June 18, 2016, and finished the work on the same day. It was sunny on June 18, and it was raining before the restoration. Some field observations during and after restoration are shown in Fig. 5.3.

Fig. 5.3. Field view of utility cut restoration on Preston Highway in Louisville, KY

The PSIM evaluation results are shown as in the Table 5-3 below.

Table 5.3 PSIM evaluation results of case study 3

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	People at the three utility agencies were designated to be in charge of utility cut restorations, and they have relationships with contractors
	Budget Plan	3	0	N/A

	Quality Management	4	1	Both backfilling and pavement restoration were visually checked
	Emergencies	3	0	N/A
	Maintenance Schedule	3	0	Tight schedule. Digging started two days before the pavement restoration. Working crew had another project before this one. Pavement restoration was finished in the early afternoon. The sidewalk was still in non-repaired condition on the following day
	Project Record	4	2	Only project log from LWC was available, project log from contractor is not available; LWC projects data base exists but project information is limited
	Work Zone Management	3	2	Equipment, vehicles, and tools were stored appropriately at adjacent areas. Warning lines were set up around construction area. There was no guidelines about work zone management
	Crew Training	4	3	Experienced working crew was working on site but did not know about sustainable pavement maintenance
Technique	Standard Procedure	8	4	Separate contractors were involved for trench backfilling and pavement restoration; contractor had its restoration procedure, but the working crew did not remove all the water and mud due to the previous rains on site and did not wait until the soil was dry enough
	Uneven Surface	1	1	One gas pipe, one water pump, and one sewer are located within the construction area, working crew were able to make the surface smooth
Material	Quality Certification	5	0	N/A
	Material Production	4	0	N/A
	Local Material	2	0	N/A
	Earthwork	2	0	Compaction of backfill was not observed
Energy& Water	Energy Consumption I, Construction	3	0	Traditional construction equipment was used
	Energy Consumption II, Transport	2	1	Carpool was observed
	Heat Island Alleviation	1	0	No such treatment was applied
Environment	Wastes	6	2	Construction area was clean, but not all of asphalt wastes were removed from site. The destination of wastes was unknown
	Air Quality	4	0	Dust was not controlled during restoration
	Noise Control	2	0	N/A
	Vibration Control	2	0	N/A
Safety	Traffic Control	10	5	Traffic from/to an intersection and a local business were affected, but the distribution of traffic barricades at the intersection was a little confusing to the drivers. Barricades and cones were removed after restoration was done.
	Construction Safety	10	6	No accident, but working crew did not wear reflective safety vest. No guideline for construction was observed

	Pavement Marking	7	2	New lane markers were painted after paving, but the resource of marking material was unknown
	Pedestrian and Bicyclists	2	0	Sidewalk was not restored together with the pavement
	Drainage	4	4	Appropriate grade was made toward the sewer
Community	Report the Problem	1	1	LWC has "Report a Water Main Break"; Louisville Public Works has “Report a Pothole or other city services issue”; Louisville MetroCall 311 and 311 app
	Notification	2	0	N/A
	Community Adaption	4	0	The business next to the parking lot was affected, and no mitigation planned for the people entering or existing the parking lot was observed; asphalt pavement for different uses all followed the same restoration procedure
	Sustainability Promotion	1	0	N/A
Innovation	Sustainability Representative	4	0	N/A
	Certified Sustainable Pavement	2	0	N/A
Indicators Amount		32		N/A: Information not available
Total Pts		115	36	
Percentage Earned		31.3%		
Certification Level		-		

The project earned a total of 36 points under 32 PSIM Indicators, so the project’s PSI is 32/31.3%, which means this pavement maintenance project was not sustainable defined by PSIM.

Strength:

- Tight schedule
- Good work zone management
- All wastes were removed

Weakness:

- Confusing traffic control
- Setting notification about the finishing date on site
- Enhancing stakeholders’ involvement

- Lack of quality management (such as inspection during and after construction)

5.3 Overlay in Pleasureville, KY

Overlay is a common pavement maintenance method if existing pavement materials are still OK, additional structure is necessary, and there is no vertical limitation (Rettner, n.d.). The overlay projects in Pleasureville, KY are parts of State road maintenance project, so the asphalt mixture design follows KYTC specifications (CL2 Asph Surf 0.38D PG 64-22). The general procedure of overlay include 5 steps: cleaning grass and debris on the pavement; spraying tack coat; paving and compacting to produce a 1¼ inches HMA overlay; cleaning any unwanted asphalt and debris.

Different resources were used to obtain the information of the projects, including field visits, community (residents) interviews, working crew (superintendent and foreman) interviews, County inspector interviews, emails with supervisor of County Road Department, County website, and using Google Map.

5.3.1 Case Study 4

Overlay on Maddox-Onan Road in Pleasureville, KY was selected as a case study. The pavement section was approximately 4550 ft long and 12~14 ft wide. The neighborhood includes residential houses and crop farms. Main distresses on the pavement include cracking (transverse, longitudinal, and alligator), potholes, patching settlement due to drainage pipe cut, and grass on the shoulder as well as in the cracking.

PSIM inspector was on site on Sep 12, 2016 (project date) and Oct 1, 2016 to observe the condition of old pavement, contractor's (a paving company located at

Frankfort, KY) work, and finishing status. Field observations of overlay are shown in Fig. 5.4.

Fig. 5.4. Field view of overlay on Maddox-Onan Road in Pleasureville, KY

The PSIM evaluation results are shown as in the Table 5.4 below.

Table 5.4 PSIM evaluation results of case study 4

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	County Road Department, KYTC, main contractor, and subcontractors were involved
	Budget Plan	3	1	Bidding documents were submitted by main contractor
	Quality Management	4	3	County inspector was in the field every day, and State inspector checked in upon completion
	Emergencies	3	1	Backup paving machine was available; no specific emergency reaction plan

	Maintenance Schedule	3	2	Main contractor decided the schedule based on the maintenance timeline provided by County, and the schedules from main contractor and County were almost the same
	Project Record	4	2	Inspection reports were submitted by inspectors; Projects list was published on Shelby County website
	Work Zone Management	3	2	Construction equipment were parking either at the small parking lot at the intersection of Main St and Marcus St or on the gravel or turf areas along the route; the hauling trucks were well organized
	Crew Training	4	4	Superintendent, inspectors, and working crew were well trained, but sustainability awareness was little involved
Technique	Distress Reason	4	0	Same overlay on the previous utility cut restoration area
	Standard Procedure	8	7	Overlay procedure followed the State standard; water puddle was not removed when paving
Material	Quality Certification	5	5	Main contractor has a quality control lab at its plant
	Material Production	4	0	N/A
	Local Material	2	2	HMA was hauled from Frankfort, approximately 20 miles away; tack coat was ordered from a company in South Carolina that is approximately 280 miles away
	Recycle Material	2	1	25% of the HMA was recycled asphalt mixture
Energy& Water	Energy Consumption I, Construction	3	2	Idling of construction equipment was observed
	Energy Consumption II, Transport	2	1	Carpool was observed
	Water Consumption	1	0	N/A
Environment	Wastes	6	5	Little was left on the turf along the route
	Air Quality	4	1	No dust control while cleaning debris
	Noise Control	2	0	N/A
	Vibration Control	2	0	N/A
	Ecology Conservation	6	1	Equipment and vehicles parked on lawn along the route
Safety	Traffic Control	10	4	Only roll-up flagger sign was observed; manual traffic control was observed
	Construction Safety	10	10	Working crew were trained under OSHA and other requirements, all working crew were wearing safety vests
	Drainage	4	4	Crown (1 in) was made when paving
Community	Report the Problem	1	0	N/A
	Notification	2	1	Approximate starting and finishing date were published on local newspaper and Facebook, but the residents were not aware of the dates

	Community Adaption	4	0	N/A
	Sustainability Promotion	1	0	N/A
Innovation	Sustainability Representative	4	1	Superintendent considers and is responsible for environmental and social issues
	Certified Sustainable Pavement	2	0	N/A
Indicators Amount		31		N/A: Information not available
Total Pts		115	62	
Percentage Earned		53.9%		
Certification Level		★		

The project earned a total of 62 points under 31 PSIM Indicators, so the project's PSI is 31/53.9%, which means this pavement maintenance project was sustainable and achieved one PSIM star.

Strength:

- Sustainability was considered by the project team
- 25% of HMA was recycled materials
- Schedule from contractor matched the one from County
- Inspectors from County Road Department were on site every day

Weakness:

- Insufficient notification to the neighbors
- Insufficient traffic control

5.3.2 Case Study 5

Overlay on Cropper School Road in Pleasureville, KY was selected as a case study, this project involved a little milling effort at the intersection of Cropper School Road and Cropper Road in order to create a smooth edge. The overlay area was approximately 530 ft long and 11~14 ft wide. The neighborhood was mainly residential houses and lawn. Main distresses on the pavement are cracking (transverse, longitudinal, and alligator) and potholes.

PSIM inspector was on site on Sep 13, 2016 (project date) and Oct 1, 2016 to observe the condition of old pavement, contractor's (a paving company located at Frankfort, KY) work, and finishing status. Field observations of overlay are shown in Fig. 5.5.

Fig. 5.5. Field view of overlay on Cropper School Road in Pleasureville, KY

The PSIM evaluation results are shown as in the Table 5.5 below.

Table 5.5 PSIM evaluation results of case study 5

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	County Road Department, KYTC, main contractor, and subcontractors were involved
	Budget Plan	3	1	Bidding documents were submitted by main contractor
	Quality Management	4	3	County inspector was in the field every day, and State inspector checked in upon completion
	Emergencies	3	1	Backup paving machine was available; no specific emergency reaction plan
	Maintenance Schedule	3	2	Main contractor decided the schedule based on the maintenance timeline provided by County, and the schedules from main contractor and County were almost the same
	Project Record	4	2	Inspection reports were submitted by inspectors; Projects list was published on Shelby County website

	Work Zone Management	3	2	Construction equipment were parking either at the parking lot at Cropper Alternative School or at the parking lot across the Cropper Rd
	Crew Training	4	4	Superintendent, inspectors, and working crew were well trained, but sustainability awareness was little involved
Technique	Standard Procedure	8	8	Overlay procedure followed the State standard
	Uneven Surface	1	1	Its connection to Cropper Rd was milled and paved to make a smooth connection
Material	Quality Certification	5	5	Main contractor has a quality control lab at its plant
	Material Production	4	0	N/A
	Local Material	2	2	HMA was hauled from Frankfort, approximately 20 miles away; tack coat was ordered from a company in South Carolina that is approximately 280 miles away
	Recycle Material	4	3	100% of the milled materials were recycled, and 25% of the HMA was recycled asphalt mixture
Energy& Water	Energy Consumption I, Construction	3	2	Idling of construction equipment was observed
	Energy Consumption II, Transport	2	1	Carpool was observed
	Water Consumption	1	0	N/A
Environment	Wastes	6	3	Asphalt mixture waste was removed, little was left on the turf along the route; asphalt wastes were left on adjacent parking lot
	Air Quality	2	0	Traditional construction equipment were used
	Noise Control	2	0	N/A
	Vibration Control	2	0	N/A
Safety	Traffic Control	10	4	Only roll-up flagger sign was observed; manual traffic control was observed
	Construction Safety	10	10	Working crew were trained under OSHA and other requirements, all working crew were wearing safety vests
	Drainage	4	4	Crown (1 in) was made when paving
Community	Report the Problem	1	0	N/A
	Landscape Maintenance	1	1	Some of the tree branches were too low but got pruned
	Notification	2	1	Approximate starting and finishing date were published on local newspaper and Facebook, but the residents were not aware of the dates
	Community Adaption	4	0	N/A
	Sustainability Promotion	1	0	N/A
Innovation	Sustainability Representative	4	1	Superintendent considers and is responsible for environmental and social issues

	Certified Sustainable Pavement	2	0	N/A
Indicators Amount		31		N/A: Information not available
Total Pts		107	63	
Percentage Earned		58.9%		
Certification Level		★		

The project earned a total of 63 points under 31 PSIM Indicators, so the project's PSI is 31/58.9%, which means this pavement maintenance project was sustainable and achieved one PSIM star.

Strength:

- Sustainability was considered by the project team
- 25% of HMA was recycled materials, 100% of milled materials were recycled
- Schedule from contractor matched the one from County
- Inspectors from County Road Department were on site every day

Weakness:

- Insufficient notification to the neighbors
- Insufficient traffic control
- Asphalt wastes were not completely removed

5.3.3 Case Study 6

Overlay on Flood Road in Pleasureville, KY was selected as a case study. The overlay area was approximately 1070 ft long and 12~16 ft wide. The neighborhood was mainly residential houses, a church (no activities during observation), lawn, and trees. Main distresses on the pavement are cracking (transverse, longitudinal, and alligator), patching that was failing, and grass on the shoulder as well as in the cracking.

PSIM inspector was on site on Sep 13, 2016 (project date) and Oct 1, 2016 to observe the condition of old pavement, contractor's (a paving company located at Frankfort, KY) work, and finishing status. Some field observations during and after overlay are shown in Fig. 5.6.

Fig. 5.6. Field view of overlay on Flood Road in Pleasureville, KY

The PSIM evaluation results are shown as in the Table 5.6 below.

Table 5.6 PSIM evaluation results of case study 6

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	County Road Department, KYTC, main contractor, and subcontractors were involved
	Budget Plan	3	1	Bidding documents were submitted by main contractor
	Quality Management	4	3	County inspector was in the field every day, and State inspector checked in upon completion
	Emergencies	3	1	Backup paving machine was available; no specific emergency reaction plan
	Maintenance Schedule	3	2	Main contractor decided the schedule based on the maintenance timeline provided by County, and the schedules from main contractor and County were almost the same
	Project Record	4	2	Inspection reports were submitted by inspectors; Projects list was published on Shelby County website
	Work Zone Management	3	2	Construction equipment were parking on Pleasureville Rd with a little traffic control; the hauling trucks were well organized
	Crew Training	4	4	Superintendent, inspectors, and working crew were well trained, but sustainability awareness was little involved

	Project Interaction	2	2	Pleasureville Rd was overlaid later in the same month, a step was made at the junction of Flood Rd and Pleasureville Rd
Technique	Distress Reason	4	0	Previous overlays which were conducted on Flood Rd at least three times should be inspected to decide they should be removed or not
	Standard Procedure	8	8	Overlay procedure followed the State standard
	Uneven Surface	1	0	A step was made at the junction of Flood Rd and Pleasureville Rd
Material	Quality Certification	5	5	Main contractor has a quality control lab at its plant
	Material Production	4	0	N/A
	Local Material	2	2	HMA was hauled from Frankfort, approximately 20 miles away; tack coat was ordered from a company in South Carolina that is approximately 280 miles away
	Recycle Material	2	1	25% of the HMA was recycled asphalt mixture
Energy& Water	Energy Consumption I, Construction	3	2	Idling of construction equipment was observed
	Energy Consumption II, Transport	2	1	Carpool was observed
	Water Consumption	1	0	N/A
Environment	Wastes	6	3	Little waste was produced by working crew, but old asphalt fragments were not removed
	Air Quality	4	1	No dust control while cleaning debris
	Noise Control	2	0	No noise mitigation
	Vibration Control	2	0	No vibration mitigation
Safety	Traffic Control	10	4	Only roll-up flagger sign was observed; manual traffic control was observed
	Construction Safety	10	10	Working crew were trained under OSHA and other requirements, all working crew were wearing safety vests
	Drainage	4	4	Crown (1 in) was made when paving
Community	Report the Problem	1	0	N/A
	Notification	2	1	Approximate starting and finishing date were published on local newspaper and Facebook, but the residents were not aware of the dates
	Community Adaption	4	0	N/A
	Sustainability Promotion	1	0	N/A
Innovation	Sustainability Representative	4	1	Superintendent considers and is responsible for environmental and social issues
	Certified Sustainable Pavement	2	0	N/A

Indicators Amount	32		N/A: Information not available
Total Pts	110	60	
Percentage Earned	54.5%		
Certification Level	★		

The project earned a total of 60 points under 32 PSIM Indicators, so the project's PSI is 32/54.5%, which means this pavement maintenance project was sustainable and achieved one PSIM star.

Strength:

- Sustainability was considered by the project team
- 25% of HMA was recycled materials
- Schedule from contractor matched the one from County
- Inspectors from County Road Department were on site every day

Weakness:

- Insufficient notification to the neighbors
- Insufficient traffic control
- Pavement maintenance technique was selected without finding inspecting the cause of distresses

5.4 Mill and Overlay in Louisville, KY

If existing pavement materials have major problems, existing pavement structure is adequate, and there are vertical limitations, mill and overlay can be used to maintain the pavement (Rettner, n.d.). City Department of Public Works is responsible for the projects selected in this section. The general construction process are described as follows based on the PSIM inspectors' observation:

- Clean the pavement surface to be generally free of debris and trash;

- Mill the asphalt surface at depth of 1 inch to 2.5 inches across the site;
- Clean the milled surface;
- Spray the tack coat;
- Pave using HMA (CL2 Asph Surf 0.38D PG 64-22) at 1.5 inches to 2 inches thickness:
- Compact using vibratory rollers;
- Apply pavement marking if applicable.

Different resources were used to obtain the information of the projects, including project list and weekly schedule from city Public Works, field visits, working crew (superintendent, foreman, technicians, and equipment operators) interviews, city inspectors interviews, flaggers interviews, emails with the Assistant Director of the City Department of Public Works Division of Streets and Road Operations, and using Google Map.

5.4.1 Case Study 7

Approximately 0.9 miles of Southern Avenue (from South 38th Street to Wilson Avenue) in Louisville, KY was milled and overlaid from Sep 15, 2016 to Sep 20, 2016. A local asphalt paving company was the main contractor working with several other sub-contractors.

PSIM inspector was on site on Sep 15, Sep 16, Sep 20, and Sep 26 of 2016 to observe the condition of old pavement, contractors' work, and finishing status. Southern Avenue is a minor arterial. Distresses observed on site include cracking (transverse, longitudinal, and alligator), patching that was failing, and elevations of manholes are lower than adjacent pavement surface. There are residential houses, churches, a park, and a food mart along the pavement section. Some field observations during and after maintenance are shown in Fig. 5.7.

Fig. 5.7. Field view of mill and overlay on Southern Avenue in Louisville, KY

The PSIM evaluation results are shown as in the Table 5.7 below.

Table 5.7 PSIM evaluation results of case study 7

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	The contractor has three project teams for such milling and paving jobs, and the project team communicated well with other project participants
	Budget Plan	3	1	Project estimate and funding source were available
	Quality Management	4	3	Inspector from Public Works was on site throughout the project
	Emergencies	3	2	New asphalt plant was immediately contacted after previous asphalt plant was down
	Maintenance Schedule	3	2	Tight schedule; stakeholders were aware of the schedule; schedule provided by Public Works was not accurate
	Project Record	4	3	Inspection reports from inspector were available
	Work Zone Management	3	1	Hauling trucks were well organized along the working route; Construction equipment were parked on adjacent roads without traffic control
	Crew Training	4	3	Working crew, flaggers, inspects were well trained, but no one was familiar with sustainability
Technique	Distress Reason	4	0	N/A
	Standard Procedure	8	6	Contractor has standard working process
	Disturbance and Repair	2	2	Kerosene was applied on manhole covers to avoid asphalt sticking
	Uneven Surface	2	2	Manholes that were lower than finished pavement surface were raised by metal ring and manually leveled
Material	Quality Certification	5	5	Tickets of asphalt mixture were available; quality control lab was established for the asphalt plant
	Material Production	4	0	N/A
	Local Material	2	2	Asphalt was ordered from two local contractors, one is less than 20 miles away and the other is less than 15 miles away
	Recycle Material	4	3	All milled materials will be recycled; 12%~15% of paving materials were recycled materials
Energy& Water	Energy Consumption I, Construction	3	2	Idling of construction equipment was observed
	Energy Consumption II, Transport	2	1	Carpool was observed before and after daily works
	Water Consumption	1	0	N/A
	Heat Island Alleviation	6	6	A little asphalt wastes were observed after finishing the project
Environment	Wastes	4	1	No dust control during milling, brooming, and blowing; milled materials were not covered in the hauling trucks so there was smoking; HMA was covered in the hauling trucks
	Air Quality	2	1	Low-noise equipment were adopted

	Noise Control	2	1	Low-vibration equipment was adopted for milling; skid steer loader used to mill hard-to-reach areas generated high vibrations
	Vibration Control	10	8	Different traffic control crews was assigned for milling or paving; flaggers used signs, flashing devices, and other equipment to control traffic; detour was not given when one direction was shut down; traffic control devices were removed right after the project was finished; traffic control contractors had meeting with the inspector to discuss requirements before the starting the project
Safety	Traffic Control	10	10	Uniform or safety vest were observed for all working crew
	Construction Safety	3	0	Deteriorated curb was not repaired
	Appurtenance	8	4	Pedestrians were notified when they wanted to step on the pavement but the pavement was still hot; new curb ramps were constructed several days before the milling process
	Pedestrian and Bicyclists	4	3	Kerosene was applied on sewer covers but there are still a little asphalt mixture falling into the sewer during the paving; crown was considered when paving
	Drainage	1	1	Louisville Public Works has "Report a Pothole or other city services issue"; Louisville MetroCall 311 and 311 app
Community	Report the Problem	2	1	Signboards were put along the pavement showing project would be conducted during Sep 12 and Sep 20
	Notification	4	0	N/A
	Community Adaption	1	0	N/A
	Sustainability Promotion	4	0	N/A
Innovation	Sustainability Representative	2	0	N/A
	Certified Sustainable Pavement	2	2	The contractor has three project teams for such milling and paving jobs, and the project team communicated well with other project participants
Indicators Amount		35		N/A: Information not available
Total Pts		126	76	
Percentage Earned		60.3%		
Certification Level		★★		

The project earned a total of 76 points under 35 PSIM Indicators, so the project's PSI is 35/60.3%, which means this pavement maintenance project was sustainable and achieved two PSIM stars.

Strength:

- More than 10% of HMA was recycled materials, 100% of milled materials were recycled
- Inspector from City Public Works was on site every day
- Adjust the elevations of manholes to the finished pavement surface
- Curb ramps were installed before pavement construction

Weakness:

- Schedule from contractor was very different from the one from City Public Works
- Insufficient dust control

5.4.2 Case Study 8

Approximately 0.63 miles of Portland Avenue (from North 15th Street to North 22nd Street) in Louisville, KY was milled and overlaid from Sep 20, 2016 to Sep 21, 2016. A local asphalt paving company was the main contractor working with several other sub-contractors.

PSIM inspector was on site on Sep 10, Sep 21, and Sep 26 of 2016 to observe the condition of old pavement, contractors' work, and finishing status. Portland Avenue is a one-way minor arterial Distresses observed on site include cracking (transverse and longitudinal) and potholes. There are residential houses, industrial and commercial businesses, and restaurants along the pavement section. Field observations of maintenance are shown in Fig. 5.8.

Fig. 5.8. Field view of mill and overlay on Portland Avenue in Louisville, KY

The PSIM evaluation results are shown as in the Table 5.8 below.

Table 5.8 PSIM evaluation results of case study 8

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	The contractor has three project teams for such milling and paving jobs, and the project team communicated well with other project participants
	Budget Plan	3	1	Project estimate and funding source were available
	Quality Management	4	3	Inspector from Public Works was on site throughout the project
	Emergencies	3	0	N/A
	Maintenance Schedule	3	2	Tight schedule; stakeholders were aware of the schedule; schedule provided by Public Works was not accurate
	Project Record	4	3	Inspection reports from inspector were available
	Work Zone Management	3	2	Hauling trucks were well organized along the working route; equipment and vehicles were parked on the route, on adjacent road, or on a restaurant parking lot
	Crew Training	4	3	Working crew, flaggers, inspects were well trained, but no one was familiar with sustainability
Technique	Distress Reason	4	0	N/A
	Standard Procedure	8	6	Contractor has standard working process
	Disturbance and Repair	2	2	Kerosene was applied on manhole covers to avoid asphalt sticking
	Uneven Surface	2	2	Manholes that were lower than finished pavement surface were raised by metal ring and manually leveled
Material	Quality Certification	5	5	Tickets of asphalt mixture were available; quality control lab was established for the asphalt plant
	Material Production	4	0	N/A

	Local Material	2	2	Asphalt was ordered from local contractor less than 20 miles away
	Recycle Material	4	3	All milled materials will be recycled; 12%~15% of paving materials were recycled materials
Energy& Water	Energy Consumption I, Construction	3	2	Idling of construction equipment was observed
	Energy Consumption II, Transport	2	1	Carpool was observed before and after daily works
	Water Consumption	1	0	N/A
	Heat Island Alleviation	6	6	A little asphalt wastes were observed after finishing the project
Environment	Wastes	4	2	Water was applied during milling, which significantly reduce dust production during milling, brooming, and blowing; milled materials were not covered in the hauling trucks so there was smoking; HMA was covered in the hauling trucks
	Air Quality	2	1	Low-noise equipment were adopted
	Noise Control	2	1	Low-vibration equipment was adopted for milling; skid steer loader used to mill hard-to-reach areas generated high vibrations
	Vibration Control	10	10	Different traffic control crews was assigned for milling or paving; flaggers used signs, flashing devices, and other equipment to control traffic; detour was given by signs when the route was shut down; traffic control devices were removed right after the project was finished; traffic control contractors had meeting with the inspector to discuss requirements before the starting the project
Safety	Traffic Control	10	8	3 persons in the working crew worn hard hat during working; uniform or safety vest were observed for all working crew
	Construction Safety	7	2	N/A
	Pavement Marking	3	0	Deteriorated curb was not repaired
	Appurtenance	8	4	The safety of pedestrians and bicyclists were considered during construction; new curb ramps were constructed several days before the milling process
	Pedestrian and Bicyclists	4	3	Kerosene was applied on sewer covers but there are still a little asphalt mixture falling into the sewer during the paving; crown was considered when paving
	Drainage	1	1	Louisville Public Works has “Report a Pothole or other city services issue”; Louisville MetroCall 311 and 311 app
Community	Report the Problem	2	1	Signboards were put along the pavement less than 24 hours ahead
	Notification	4	0	N/A
	Community Adaption	1	0	N/A
	Sustainability Promotion	4	0	N/A

Innovation	Sustainability Representative	2	0	N/A
	Certified Sustainable Pavement	2	2	The contractor has three project teams for such milling and paving jobs, and the project team communicated well with other project participants
Indicators Amount		36		
Total Pts		133	78	
Percentage Earned		58.6%		
Certification Level		★		

The project earned a total of 78 points under 36 PSIM Indicators, so the project's PSI is 36/58.6%, which means this pavement maintenance project was sustainable and achieved one PSIM star.

Strength:

- More than 10% of HMA was recycled materials, 100% of milled materials were recycled
- Inspector from City Public Works was on site every day
- Adjust the elevations of manholes to the finished pavement surface
- Curb ramps were installed before pavement construction
- Good traffic control through the project

Weakness:

- Schedule from contractor was very different from the one from City Public Works
- Insufficient notification to the neighbors

5.4.2 Case Study 9

Craft Drive and Quest Drive in Louisville, KY are local roads which serve the residents living in apartments. Approximately 0.26 miles was milled and overlaid on Sep

21, 2016. A local asphalt paving company and a local milling company were the main contractors working with other sub-contractors.

PSIM inspector was on site on Sep 21 and Sep 27 of 2016 to observe the condition of old pavement, contractors' work, and finishing status. Distresses observed on site include cracking (transverse, longitudinal, and alligator), patching that was failing, and potholes. Some field observations during and after maintenance are shown in Fig. 5.9.

Fig. 5.9. Field view of mill and overlay on Craft Drive and Quest Drive in Louisville, KY

The PSIM evaluation results are shown as in the Table 5.9 below.

Table 5.9 PSIM evaluation results of case study 9

Category	Indicators	Max Pts	Act Pts	Explanation
Management	Project Team	2	2	Two contractors were involved in milling and paving; the project team communicated well with other project participants
	Budget Plan	3	1	Project estimate and funding source were available
	Quality Management	4	3	Inspector from Public Works was on site throughout the project
	Emergencies	3	0	N/A
	Maintenance Schedule	3	2	Tight schedule; stakeholders were aware of the schedule; schedule provided by Public Works was not accurate

	Project Record	4	3	Inspection reports from inspector were available
	Work Zone Management	3	2	Hauling trucks were well organized along the working route; the left-turn lane on Gilmore Ln and community parking lots were used for equipment parking
	Crew Training	4	3	Working crew, flaggers, inspects were well trained, but no one was familiar with sustainability
	Project Interaction	2	0	Adjacent parking lot for community residents was milled and paved after this project was finished, the edge of the finished pavement sections was milled
Technique	Distress Reason	4	0	N/A
	Standard Procedure	8	6	Contractor standard
Material	Quality Certification	5	5	Tickets of asphalt mixture were available; quality control lab was established for the asphalt plant
	Material Production	4	0	N/A
	Local Material	2	2	Asphalt was ordered from local contractor less than 5 miles away
	Recycle Material	4	3	All milled materials will be recycled; 12%~15% of paving materials were recycled materials
Energy& Water	Energy Consumption I, Construction	3	2	Idling of construction equipment was observed
	Energy Consumption II, Transport	2	1	Carpool was observed before and after daily works
	Water Consumption	1	0	N/A
	Heat Island Alleviation	6	6	A little asphalt wastes were observed after finishing the project
Environment	Wastes	4	2	Water was applied halfway through the brooming, which significantly reduce dust production during brooming and blowing; milled materials were not covered in the hauling trucks so there was smoking; HMA was covered in the hauling trucks
	Air Quality	2	1	Low-noise equipment were adopted
	Noise Control	2	1	Low-vibration equipment was adopted for milling; skid steer loader used to mill hard-to-reach areas generated high vibrations
	Vibration Control	10	8	Different traffic control crews was assigned for milling or paving; flaggers used signs, flashing devices, and other equipment to control traffic; traffic control devices were removed right after the project was finished; traffic control contractors had meeting with the inspector to discuss requirements before the starting the project; sometimes the traffic at two locations needed to be controlled but there was only one flagger
Safety	Traffic Control	10	10	Uniform or safety vest were observed for all working crew
	Construction Safety	3	0	Deteriorated curb was not repaired; At least 2 speed bumps were milled and were not restored
	Appurtenance	2	2	The safety of pedestrians was considered during construction

	Pedestrian and Bicyclists	4	4	Crown was made when paving
	Drainage	1	1	Louisville Public Works has “Report a Pothole or other city services issue”; Louisville MetroCall 311 and 311 app
Community	Report the Problem	2	1	Residents in the community were not aware of the starting and finishing date
	Notification	4	0	N/A
	Community Adaption	1	0	N/A
	Sustainability Promotion	4	0	N/A
Innovation	Sustainability Representative	2	0	N/A
	Certified Sustainable Pavement	2	2	Two contractors were involved in milling and paving; the project team communicated well with other project participants
Indicators Amount		34		N/A: Information not available
Total Pts		118	71	
Percentage Earned		60.2%		
Certification Level		★★		

The project earned a total of 71 points under 34 PSIM Indicators, so the project’s PSI is 34/60.2%, which means this pavement maintenance project was sustainable and achieved two PSIM stars.

Strength:

- More than 10% of HMA was recycled materials, 100% of milled materials were recycled
- Inspector from City Public Works was on site every day
- Tight schedule

Weakness:

- Schedule from contractor was very different from the one from City Public Works
- Insufficient dust control

- Little cooperation with another adjacent maintenance project in the same month
- Insufficient notification to the community
- Speed bumps were removed without following remediation

5.5 Summary Table of 9 Case Studies

The evaluation results of case studies picked in this Chapter are summarized Table 5.10 below. Based on the certification level proposed in PSIM, the two projects of utility cut restoration in Louisville were not sustainable; the rejuvenation project in Corydon, the three projects of overlay in Pleasureville, and one mill and overlay project in Louisville were granted one PSIM star; two projects of mill and overlay picked in Louisville earned two PSIM stars.

Table 5.10 Evaluation results of the 9 case studies

Maintenance Activity	Rejuvenation	Utility Cut Restoration		Overlay			Mill and Overlay		
Location	Corydon, IN	Louisville, KY		Pleasureville, KY			Louisville, KY		
Case Study No.	1	2	3	4	5	6	7	8	9
Indicators Amount	26	29	32	31	31	32	35	36	34
Percentage Earned	60.6%	37.5%	31.3%	53.9%	58.9%	54.5%	60.3%	58.6%	60.2%
Certification Level	★	-	-	★	★	★	★★	★	★★

The results of 9 case studies show that PSIM is an effective tool to measure sustainability performance of selected types of pavement maintenance projects, and these projects varies in scope, budget, location, and purpose. PSIM evaluates the ongoing and finished activities mainly by the efforts from PSIM inspector, so this rating tool can be helpful to track and monitor the sustainability features during and after maintenance projects. As can be seen from the section of “Weakness” under each case study, some selected projects could reach higher certification with minimal effort, which means PSIM is able to help maintenance project team to achieve sustainability.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The pavement infrastructure is a valuable asset to the nation, and a lot of effort has been made every year to maintain the pavement system and serve the pavement users. Sustainable pavement and sustainable transportation has gained more attention in recent years because people have realized pavement construction has negative impacts on surrounding environment and communities (Southerland, 1994). As a critical stage during pavement life cycle, there have been potential consensus that pavement maintenance has intrinsic feature of sustainability because proper maintenance keeps pavements serviceable and extend their lives. However, during conventional pavement maintenance projects, sustainability has not been well considered and many non-sustainable practices have occurred.

A thorough review within the sustainable transportation industry reveals that researchers have not well responded to the sustainability features of pavement maintenance projects, but sustainability is an important aspect for pavement maintenance to provide a long and satisfactory service life, and to benefit all the stakeholders as much as possible.

This research is the first step to address the challenges of those observed non-sustainable maintenance practices, and to respond NCHRP's request for an assessment (rating) tool. Some accomplishments of this research are:

- Pavement maintenance includes all the proactive preservation activities and reactive repair activities.

- A descriptive definition of sustainable pavement maintenance was provided based on 6 principles, which were extracted from the definitions of sustainable pavement or sustainable transportation from FHWA, popular rating tools, and other well-known organizations. The definition will serve as the theoretical basis for the new rating tool.

- To make different pavement maintenance projects comparable on the basis of sustainability and better promote the concept of sustainable pavement maintenance, a sustainability rating tool for pavement maintenance was developed in an innovative way consisting 5 steps.

- The sustainability rating tool is named as PSIM (Pavement Sustainability Index for Maintenance) has 8 categories, 53 indicators, and 200 possible points. The indicators are intended to cover all possible sustainability features of a maintenance project.

- To consider the opinions from different stakeholders of maintenance project, AHP method was adopted to determine the priority of each PSIM Category;

- The points under each PSIM indicator were determined after reviewing 350 manuals and websites published by 8 State DOTs, which were believed to have the best sustainability practices.

- PSIM has a unique certification method based on both of the quantity of indicators involved and the percentage of points earned under involved indicators.

- PSIM can be used as self-assess or third-party rating tool depending on who conducts the rating process.
- 9 pavement maintenance projects located in Kentucky and Indiana were successfully evaluated by PSIM.
- Charts for comparing the sustainability of different pavement maintenance techniques are provided.
- Two new technologies that could bring sustainability features to pavement maintenance projects have been discussed under the PSIM indicator of "Creative Idea", which indicates that PSIM is ready to evolve and is able to incorporate creative ideas.

Together with the defined sustainable pavement maintenance, the developed sustainability rating tool will be able to assist project teams with more information in the integration of sustainability practices, provide guidance to project teams about how to evaluate the sustainability of a project and understand how their practices influence the sustainability, and coordinate sustainability with the developments of pavements (both paved and unpaved), roadsides, and related appurtenances/facilities.

Since PSIM is the beginning of the research field of sustainable pavement maintenance, it still can be improved and should be improved. Following recommendations can be referred for future research effort:

- More participants can be invited to be involved in AHP survey to determine the priority of each PSIM indicator, especially the different stakeholders of pavement maintenance project.
- Rating strategies under some current PSIM indicators need the subjective

judgment from PSIM inspector, such as the indicators under Category Management. Quantitative rating strategies can be developed for objective results.

- Evaluation results of PSIM can be calibrated. First, case studies in this research were all conducted by the main researcher, but more PSIM inspectors can be trained and involved to evaluate the same projects to check the consistency of evaluation results across different PSIM inspectors. Second, PSIM can be tested on other types of maintenance projects, so that its rating framework and certification level can be further calibrated based on application results and feedbacks.

REFERENCES

Ali, H. H., & Al Nsairat, S. F. (2009). Developing a green building assessment tool for developing countries – Case of Jordan. Building and Environment, 44(5), 1053-1064. doi:10.1016/j.buildenv.2008.07.015

Amekudzi, A., Meyer, M., Ross, C., & Barrella, E. (2011). Transportation Planning for Sustainability Guidebook. Washington, DC: Federal Highway Administration.

Anderson, J., Weiland, C., & Muench, S. (Eds.). (2011). Greenroads Manual (1.5th ed.). Seattle, WA: University of Washington.

Anton, S. R., & Sodano, H. A. (2007). A Review of Power Harvesting Using Piezoelectric Materials (2003~2006). Smart Materials and Structures, 16(3), R1-R21. doi:10.1088/0964-1726/16/3/r01

Ashtankar, P. V., Bendle, P. H., Kene, K., Kalbande, M. R., Makhe, P., & Dhomne, S. M. (2014). Road Power Generation (RPG) by Flip plate Mechanism. International Journal of Science, Engineering and Technology Research, 3(3), 560-562.

Ballari, M., & Brouwers, H. (2013). Full Scale Demonstration of Air-Purifying Pavement. Journal of Hazardous Materials, 254-255, 406-414. doi:10.1016/j.jhazmat.2013.02.012

Barfod, M. B. (Ed.). (2014). Graphical and technical options in Expert Choice for group decision making. Kongens Lyngby, Denmark: Technical University of Denmark, Transport.

Bennett-Smith, M. (2013, July 9). Smog-Eating Pavement In Netherlands Can Cut Pollution By Up To 45 Percent, Study Says. The Huffington Post. Retrieved from http://www.huffingtonpost.com/2013/07/09/smog-eating-pavement-cut-pollution_n_3563472.html

Bloser, S., Creamer, D., Napper, C., Scheetz, B., & Ziegler, T. (2014). Environmentally Sensitive Road Maintenance Practices for Dirt and Gravel Roads. Washington, DC: U. S. Department of Agriculture.

Boonen, E., & Beeldens, A. (2014). Recent Photocatalytic Applications for Air Purification in Belgium. Coatings, 4(3), 553-573. doi:10.3390/coatings4030553

Bureau of Transportation Statistics. (2015). National Transportation Statistics. Washington, DC: U.S. Department of Transportation.

Cackler, T., Alleman, J., Kevern, J., & Sikkema, J. (2012). Environmental Impact Benefits with “TX Active” Concrete Pavement in Missouri DOT Two-Lift Highway Construction Demonstration (DTFH61-06-H-00011 Work Plan 22). Ames, IA: National Concrete Pavement Technology Center.

Cash flow Valuation Online. (n.d.). Expert Choice Tutorial. Retrieved from http://cashflow88.com/decisiones/saaty2.pdf

Chan, S., Bennett, B., Lane, B., & Kazmierowski, T. (2012, October). GreenPave - Ontario's Pavement Sustainability Rating System. Poster session presented at 2012 Conference and Exhibition of the Transportation Association of Canada - Transportation: Innovations and Opportunities, Fredericton New Brunswick, Canada.

Choctawhatchee, Pea and Yellow Rivers Watershed Management Authority. (2000). A Guideline for Maintenance and Service of Unpaved Roads. Troy, AL: Author.

Committee for a Responsible Federal Budget. (2015). The Road to Sustainable Highway Spending. Retrieved from http://crfb.org/sites/default/files/road_to_sustainable_highway_spending.pdf

CorpCROP. (n.d.). Sustainability is the purpose of every element of our model. Retrieved from http://www.corpcrop.com/purpose/

Daily Mail Reporter. (2008, December 26). Streets ahead: The road that generates electricity from moving cars. Daily Mail. Retrieved from http://www.dailymail.co.uk/sciencetech/article-1096753/Streets-ahead-The-road-generates-electricity-moving-cars.html

Distractify Staff. (2015, January 7). 30 Surprising Facts About How We Actually Spend Our Time. Retrieved from http://distractify.com/old-school/2015/01/07/astounding-facts-about-how-we-actually-spend-our-time-1197818577

Edil, T. B. (n.d.). Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways [PowerPoint slides]. Retrieved from http://www.cte.ncsu.edu/eeconference/sessions/documents/08-3_Edil.pdf

Federal Highway Administration. (1998). Problems Associated With Gravel Roads (FHWA-SA-98-045). Washington, DC: Author.

Federal Highway Administration. (2013). Harnessing Pavement Power: Developing Renewable Energy Technology in the Public Right-of-Way (FHWA-HRT-13-094). Washington, DC: Author.

Federal Highway Administration. (2013). Highway Statistics 2013. Retrieved from http://www.fhwa.dot.gov/policyinformation/statistics/2013/

Federal Highway Administration. (n.d.). FHWA CSS Primer: What is CSS? Retrieved from https://www.fhwa.dot.gov/context/css_primer/whatis.htm

Federal Highway Administration. (n.d.). Relating INVEST to Other Sustainability Tools. Retrieved from https://www.sustainablehighways.org/1470/relating-invest-to-other-sustainability-tools.html

Federal Highway Administration. (n.d.). Why and When Would I Score an Operations and Maintenance Program? Retrieved from https://www.sustainablehighways.org/920/why-and-when-would-i-score-an-operations-and-maintenance-program.html

Federal Highway Administration, & Federal Transit Administration. (2013). 2013 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance. Retrieved from website: https://www.fhwa.dot.gov/policy/2013cpr/pdfs/cp2013.pdf

Ford, M. (2010, August 6). Could pollution-eating concrete clean up our urban jungles? Retrieved from http://edition.cnn.com/2010/TECH/innovation/08/06/concrete.pollution.solution/index.html

Geiger, D. R. (2005). Pavement Preservation Definitions Memo. Federal Highway Administration.

Genesee Transportation Council. (2010). Managing Unpaved Roads - Fact Sheets. Retrieved from http://www.gtcmpo.org/sites/default/files/pdf/2010/Fact%20Sheet_Managing%20Unpaved%20Roads.pdf

Greenroads Foundation. (n.d.). Greenroads v2 Online. Retrieved from https://www.greenroads.org/v2

Hall, K. T., Correa, C. E., Carpenter, S. H., & Elliot, R. P. (2001). Pavement Distress Types and Causes of Rehabilitation Strategies for Highway Pavements (NCHRP Web Document 35). National Cooperative Highway Research Program.

Harmon, T. (2010). Sustainable Transportation. International Sustainable Pavements Workshop: Virginia Tech/Nottingham Transportation Engineering Centre.

Hassan, M., Mohammad, L. N., Asadi, S., Dylla, H., & Cooper, S. (2013). Sustainable Photocatalytic Asphalt Pavements for Mitigation of Nitrogen Oxide and Sulfur Dioxide Vehicle Emissions. Journal of Materials in Civil Engineering, 25(3), 365-371. doi:10.1061/(asce)mt.1943-5533.0000613

Henderson, T. (2009, August 4). Energy harvesting roads in Israel. Energy Harvesting Journal. Retrieved from http://www.energyharvestingjournal.com/articles/1589/energy-harvesting-roads-in-israel

Hill, D., Agarwal, A., & Tong, N. (2014). Assessment of Piezoelectric Materials for Roadway Energy Harvesting (CEC-500-2013-007). Sacramento, CA: California Energy Commission.

Hirsch, A. (2012, January). Overview of Sustainability Rating System Trends in Transportation. Paper presented at Transportation Research Board 91st Annual Meeting, Washington, DC.

Illinois Department of Transportation, & Illinois Joint Sustainability Group. (2012). I-LAST: Illinois-Livable and Sustainable Transportation Rating System and Guide (2.02 ed.).

Islam, M. S., Rahman, S. K., & Jyoti, J. S. (2013). Generation of Electricity Using Road Transport Pressure. International Journal of Engineering Science and Innovative Technology, 2(3), 520-525.

Jawad, D. (2013). Sustainable Transport Rating Tool via Traffic Impact Studies. Journal of Traffic and Logistics Engineering, 1(1), 30-35. doi:10.12720/jtle.1.1.30-35

Jeon, C. M., & Amekudzi, A. (2005). Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics. Journal of Infrastructure Systems, 11(1), 31-50. doi:10.1061/(asce)1076-0342(2005)11:1(31)

Jingdongwf. (2013, December 31). Procedure and Methodology of Analytic Hierarchy Process. Retrieved March 12, 2017, from http://jingyan.baidu.com/article/cbf0e500eb95582eaa28932b.html

Kazmierowski, T. (2012, August). Quantifying the Sustainable Benefits of Flexible Pavement Preservation Techniques in Canada. Paper presented at National Pavement Preservation Conference, Nashville, TN.

Khadilkar, D. (2013, April 20). Energy-Harvesting Street Tiles Generate Power from Pavement Pounder. Scientific American. Retrieved from https://www.scientificamerican.com/article/pavement-pounders-at-paris-marathon-generate-power/

King, A. O. (2006). Maintenance and Preservation: A Definition. Retrieved from https://www.crab.wa.gov/LibraryData/RESEARCH_and_REFERENCE_MATERIAL/Road_Maintenance/060206MaintenanceVSPreservation.doc

Li, L., & Qian, C. (2009). A Lab Study of Photo-Catalytic Oxidation and Removal of Nitrogen Oxides in Vehicular Emissions and Its Fieldwork on Nanjing No. 3

Bridge of Yangtze River. International Journal of Pavement Research and Technology, 2(5), 218-222.

Litman, T. (2007). Developing Indicators for Comprehensive and Sustainable Transport Planning. Transportation Research Record: Journal of the Transportation Research Board, 2017, 10-15. doi:10.3141/2017-02

McCormack, S. M., Sturgill, R., Howell, B., Van Dyke, C., & Kreis, D. (2014). Green Infrastructure (KTC -14-10/SPR447-12-1F). Lexington, KY: Kentucky Transportation Center.

McDonald, K. (n.d.). Stakeholder and User Analysis. Retrieved from http://blog.projectconnections.com/kent_mcdonald/2016/08/stakeholder-and-user-analysis.html

Miller, J. S., & Bellinger, W. Y. (2003). Distress Identification Manual for the Long-Term Pavement Performance Program (FHWA-RD-03-031). McLean, VA.

Ministry of Transportation of Ontario, Materials Engineering and Research Office. (2014). GreenPave Reference Guide (2.0th ed.). Toronto, Canada: Ministry of Transportation of Ontario.

Muench, S. T., & Van Dam, T. J. (2014). Pavement Sustainability TechBrief (FHWA-HIF-14-012). Washington, DC: Federal Highway Administration.

National Concrete Pavement Technology Center. (2014). Concrete Pavement Preservation Guide (FHWA-HIF-14-014). Washington, DC: Federal Highway Administration.

Nebraska Department of Roads. (2002). Pavement Maintenance Manual. Retrieved from http://www.transportation.nebraska.gov/docs/pavement.pdf

Nelson, D., Krekeler, P., & Rossi, M. (2011, August). Incorporating Sustainability Into NYSDOT's Decisions. Paper presented at The 2011 International Conference on Ecology & Transportation, Seattle, WA.

Nelson, D., & Krekeler, P. (2012, January). A State-level Perspective on The Future of Sustainability Decision Making. Paper presented at Transportation Research Board 91st Annual Meeting, Washington, DC.

New Mexico Department of Transportation. (2007). Pavement Maintenance Manual. Retrieved from https://www.pavementpreservation.org/wp-content/uploads/presentations/New%20Mexico%20Department%20of%20Transportation's%20Pavement%20Maintenance%20Manual.pdf

New York State Department of Transportation. (n.d.). GreenLITES. Retrieved from https://www.dot.ny.gov/programs/greenlites

North American Sustainable Transportation Council, & Portland Bureau of Transportation. (2012). STARS Pilot Plan Application Manual (1.0th ed.). Portland, OR: North American Sustainable Transportation Council.

North American Sustainable Transportation Council, Santa Cruz County Regional Transportation Council, & Portland Bureau of Transportation Sustainable Transportation Council. (2011). STARS Fact Sheet. Portland, OR: North American Sustainable Transportation Council.

North American Sustainable Transportation Council, Upstream Public Health, Portland Bureau of Transportation, & Multnomah County Health Department. (2012). STARS Pilot Project Application Manual. Portland, OR: North American Sustainable Transportation Council.

Oswald, M. R., & McNeil, S. (2010). Rating Sustainability: Transportation Investments in Urban Corridors as a Case Study. Journal of Urban Planning and Development, 136(3), 177-185. doi:10.1061/(asce)up.1943-5444.0000016

Partodezfoli, M., Rezaey, A., Baniasad, Z., & Rezaey, H. (2012). A Novel Speed-Breaker for Electrical Energy Generation Suitable for Elimination of Remote Parts of Power Systems where is Near to Roads. Journal of Basic and Applied Scientific Research, 2, 6285-6292.

Petty, S., Banerjee, F., Llort, Y., Deakin, E., Markle, P., Howard, C., … Taft, A. (2001). Sustainable transportation practices in Europe (FHWA-PL-02-006). Washington, DC: Federal Highway Administration.

Ramadan, M., Khaled, M., & Hage, H. E. (2015). Using Speed Bump for Power Generation - Experimental Study. Energy Procedia, 75, 867-872. doi:10.1016/j.egypro.2015.07.192

Recycled Materials Resource Center. (2010). BE2ST-IN-HIGHWAYSTM (Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways). Madison, WI: University of Wisconsin–Madison.

Reddy, B. A., Sahaj, T. V., Kumar, Y. A., & Reddy, D. R. (2015). Modified Design of Speed Breaker for Power Generation. International Journal of Research in Engineering and Technology, 4(14), 78-81. doi:10.15623/ijret.2015.0414018

Reid, L., Bevan, T., Davis, A., Neuman, T., Penney, K., Seskin, S., … Schulz, J. (2015). INVEST: Sustainable Highways Self-Evaluation Tool (1.2nd ed.). Washington, DC: Federal Highway Administration.

Rettner, D. (n.d.). Rehabilitation Selection for Asphalt Overlay, Mill and Overlay, Cold In Place Recycling and Full Depth Reclamation [PowerPoint slides]. Retrieved from http://www.ceam.org/vertical/Sites/%7BD96B0887-4D81-47D5-AA86-9D2FB8BC0796%7D/uploads/Concurrent_Session_10_-_David_Rettner.pdf

Roberts, R. L., Kopp, J. D., Rockaway, T. D., Mohsen, J. P., & Zhang, Y. (2015). Report of Trench Backfill Procedure Updates for LWC, LG&E, and MSD Pavement Restoration. Louisville, KY.

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. European Journal of Operational Research, 48(1), 9-26. doi:10.1016/0377-2217(90)90057-i

Sarma, B. S., Jyothi, V., & Sudhir, D. (2014). Design of Power Generation Unit Using Roller Mechanism. IOSR Journal of Electrical and Electronics Engineering, 9(3), 55-60. doi:10.9790/1676-09315560

Schilleman, B., & Gough, J. (2012). Sustainability in Your Words. ITE Journal, 82(5), 20-24. Retrieved from http://www.ite.org/membersonly/itejournal/pdf/2012/JB12EA20.pdf

South Dakota Department of Transportation. (2010). Pavement Preservation Guidelines. Retrieved from http://sddot.com/resources/manuals/PavementPreservationGuidelines1112011.pdf

Southerland, M. (1994). Evaluation of ecological impacts from highway development (EPA 300-B-94-006). Washington, DC: United States Environmental Protection Agency, Office of Federal Activities.

Stephanos, P. (2009). Strategic, Safe, and Sustainable: Today's Vision for Pavements (FHWA-HRT-10-009). Washington, DC: Federal Highway Administration.

Sustainable Pavement Preservation and Maintenance Practices. (2014). In K. Gopalakrishnan, W. J. Steyn, & J. Harvey (Eds.), Climate change, energy, sustainability and pavements (pp. 393-418). New York, NY: Springer.

Takamura, K., Lok, K. P., & Wittlinger, R. (2001, March). Microsurfacing for Preventive Maintenance: Eco-Efficient Strategy. Paper presented at International Slurry Seal Association Annual Meeting, Maui, HI.

TechVideoCollection. (2011, April 14). Eco friendly Electricity generation: Electricity from speed breakers [Video file]. Retrieved from https://www.youtube.com/watch?v=dY025opRZUM

Tighe, S. L., & Gransberg, D. D. (2011). Sustainable Pavement Maintenance Practices (Research Results Digest 365). Washington, DC: National Cooperative Highway Research Program.

Triantaphyllou, E., & Mann, S. H. (1995). Using the Analytic Hierarchy Process for Decision Making in Engineering Applications: Some Challenges. International Journal of Industrial Engineering: Application and Practice, 2(1), 35-44.

Triantaphyllou, E., & Mann, S. H. (1995). Using The Analytic Hierarchy Process for Decision Making In Engineering Applications: Some Challenges. International Journal of Industrial Engineering: Applications and Practice, 2(1), 35-44.

Tsunokawa, K., & Hoban, C. (Eds.). (1997). Roads and the Environment: A Handbook. Washington, DC: World Bank.

U.S. Green Building Council. (2016). LEED v4 for Building Operations and Maintenance (4th ed.). Washington, DC.

U.S. Green Building Council. (2016). LEED v4 for Neighborhood Development (4th ed.). Washington, DC.

U.S. National Arboretum. (2008, August). Invasive Plants. Retrieved from www.usna.usda.gov/Gardens/invasives.html

Utah Department of Transportation. (2009). Pavement Preservation Manual - Part 3: Preservation Treatments. Retrieved from http://www.udot.utah.gov/main/uconowner.gf?n=11034902304422298

Van Dam, T. J., Harvey, J. T., Muench, S. T., Smith, K. D., Snyder, M. B., Al-Qadi, I. L., … Kendall, A. (2015). Towards Sustainable Pavement Systems: A Reference Document (FHWA-HIF-15-002). Washington, DC: Federal Highway Administration.

Venner Consulting, & Parsons Brinckerhoff. (2004). Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance (NCHRP 25-25(04)). Washington, D.C.: National Cooperative Highway Research Program.

Venturini, L., & Bacchi, M. (2009, October). Research, Design, and Development of A Photocatalytic Asphalt Pavement. Paper presented at 2nd Int. Conf. on Environmentally Friendly Roads, Road and Bridge Research Institute, Warsaw, Poland.

VicRoads. (2011). Integrated VicRoads Environmental Sustainability Tool (INVEST). Kew Vic, Australia.

Véron-Okamoto, A., & Sakamoto, K. (2014). Toward a Sustainability Appraisal Framework for Transport (ADB Sustainable Development Working Paper Series No. 31). Asian Development Bank.

Zhang, Y., & Mohsen, J. P. (2016, October). Project-Based Sustainability Rating Tool For Pavement Maintenance. Paper presented at International Conference on Sustainable Infrastructure, Shenzhen, China.

Zietsman, J., & Ramani, T. (2011). Sustainability Performance Measures for State DOTs and Other Transportation Agencies (NCHRP 08-74). Retrieved from National

Cooperative Highway Research Program website: http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP08-74_FR.pdf

Zimmer, L. (2013, April 10). Kinetic Energy-Harvesting Tiles Generate Power from Paris Marathon Runners. Retrieved from http://inhabitat.com/kinetic-energy-harvesting-tiles-generate-power-from-paris-marathon-runners/

Appendix A: PSIM Scorecard

Management **28 pts**				
Project Team	2pts	All project-related information should be reported to the project team and responsibilities of each team members should be established		
Budget Plan	3pts	Budget plan is needed to determine and monitor project expenses		
Quality Management	4pts	Procedure and performance quality of the project should be guaranteed for successful delivery		
Emergencies	3pts	Reaction plans for emergencies are necessary to avoid the delay of project delivery		
Maintenance Schedule	3pts	Maintenance activities should be implemented and finished in time, performance monitoring should be planned ahead	2pts	Project schedule (daytime and nighttime work)
			1pt	Follow-up maintenance activities schedule
Project Record	4pts	Information of previous and current maintenance activities should be conveniently retrieved		
Work Zone Management	3pts	Work zone should be well defined and managed considering the needs of working crew, traffic, and neighbors		
Crew Training	4pts	Working crew should be aware of construction procedure, equipment operation, performance requirements, and sustainability		
Project Interaction	2pts	Communication must be well conducted to reduce the conflicts between different construction projects in the same area		
Technique **20 pts**				
Technique Selection	2pts	Reasons should be given if specific maintenance techniques were selected from multiple options		
Distress Reason	4pts	Actual reasons leading to the distresses should be investigated and used as guide for maintenance		
Standard Procedure	8pts	Standard maintenance procedure should be followed for consistent results		

Disturbance and Repair	2pts	Any damage to adjacent infrastructure should be repaired		
Uneven Surface	2pts	Appropriate approach should be implemented to remove obvious faulting between maintained and adjacent pavements	1pt	Faulting
			1pt	Elevation
Preservation	2pts	Preservation prevents distresses and is believed to have intrinsic sustainable features		

Material

20 pts

Quality Certification	5pts	Quality of construction materials should be guaranteed by industry standards or lab tests		
Material Production	4pts	Sustainability considerations of asphalt/concrete plant		
Local Material	2pts	Construction materials are encouraged to be obtained locally		
Material Storage	2pts	Construction materials should be appropriately protected while being stored on site		
Recycle Material	4pts	Excessive or waste materials are encouraged to be recycled	2pts	Construction materials have been recycled
			2pts	Recycled materials have been used
			1pt	In-place recycling
Alternative Material	1pt	Alternative materials are recommended if they can reasonably replace energy-intensive materials		
Earthwork	2pts	Cut-fill balance and stockpile of soil should be carefully considered if subgrade work is involved		

Energy&Water

12 pts

Efficient Lighting	3pts	Renewable energy and high-efficiency bulb are recommended for construction and traffic lighting
Energy Consumption I, Construction	3pts	Considering energy used by construction equipment and working crew on site
Energy Consumption II, Transport	2pts	Considering energy used by transporting construction materials, equipment, and working crew
Energy Consumption III, Asphalt Mixture	2pts	Considering energy used by heating asphalt to mix with aggregates
Water Consumption	1pt	Considering water used during the project
Heat Island Alleviation	1pt	Considering methods that can reduce the heat either absorbed by or released from the asphalt pavement

Environment

26 pts

Wastes	6pts	Dealing with solid, liquid, or contaminated wastes		
Air Quality	4pts	Considering pollutants emitted to air	1pt	Emissions
			1pt	Smoke
			2pts	Dust
Noise Control	4pts	Appropriate methods should be considered to mitigate construction and traffic noise	1pt	Quiet pavement
			1pt	Noise barrier
			2pts	Construction noise
			1pt	Noise level at sensitive receptors
Vibration Control	2pts	Maintenance activities resulting noticeable vibration should be appropriately scheduled and minimized		
Erosion and Sediment Control	4pts	Environmental impact can be minimized by preventing erosion, treating sediment, and stabilizing slope	2pts	Temporary measures during construction
			2pts	Permanent measures
Ecology Conservation	6pts	Natural environment disturbed by maintenance activities should be restored and protected as much as possible		

Safety

62 pts

Traffic Control	10pts	Appropriate and reasonable traffic control should be planned and implemented		
Construction Safety	10pts	Considering safety issues for working crew and construction equipment		
Pavement Marking	7pts	Pavement marking should be restored after being disturbed		
Appurtenances	10pts	Considering safety structures and devices for pavement users and neighbors	3pts	Existing appurtenance is restored or maintained
			3pts	Existing appurtenance is improved
			3pts	New appurtenance is installed
			1pt	Appurtenance investigation

Pedestrian and Bicyclists	8pts	Considering the needs from pedestrian and bicyclists	2pts	Safety of pedestrians and bicyclists during project
			3pts	Improvements of facilities for pedestrians
			3pts	Improvements of facilities for bicyclists
Drainage	10pts	Drainage system should be protected, well maintained, or improved	4pts	Disturbance of existing drainage system
			6pts	Improvements of drainage system
Glare Control	2pts	Appropriate methods should be implemented to mitigate glare from construction lighting and vehicle headlight	1pt	Glare from oncoming vehicles
			1pt	Glare from construction lighting
Snow and Ice Removal	5pts	Considering activities and materials involved in snow/ice control	3pts	Deicing materials
			2pts	Route priority
Community **18 pts**				
Report the Problem	1pt	Reporting channels can be provided to increase public involvement		
Landscape Maintenance	4pts	Considering aesthetic design and related safety issues of adjacent vegetation	1pt	Pruning for safety purposes
			1pt	Fertilizer and pesticide
			1 or 2pts	Other landscape maintenance and designs
Aesthetic Design	2pts	Considering aesthetic design and related safety issues of adjacent man-made objects	1pt	Aesthetic during maintenance
			1pt	Aesthetic improvement for the pavement
Culture Conservation	3pts	Considering cultural elements within pavement system	2pts	Maintaining the pavement with cultural features
			1pt	Maintaining the pavement adjacent to cultural attractions
Notification	2pts	Basic information about the project should be delivered to the public and conveniently noticed		
Ease of Use	1pt	Considering any approach to improve the comfort for pavement users and the usability of the pavement system		
Community Adaption	4pts	Maintenance activities should be planned and implemented by considering the characteristics and needs from neighborhood		
Sustainability Promotion	1pt	Concept of sustainable pavement maintenance should be recommended to the public by promotion or education		

Innovation
14 pts

Creative Idea	8pts	Considering any creative techniques that can improve sustainability of pavement maintenance project
Sustainability Representative	4pts	Individual being familiar with sustainable infrastructure is recommended to be involved in
Certified Sustainable Pavement	2pts	Extra points can be earned if the existing pavement was certified by sustainable transportation/pavement program

The PSIM logo is designed by Yibo Zhang, the eight icons for rating categories are designed by Freepik and Yibo Zhang.

Appendix B: PSIM Manual

B.1 Category Management

Management category is established to assess sustainability of the activities conducted during the planning and execution process of a project. PSIM enables organizations to clarify sustainability strategy into action.

As mentioned earlier in the six principles of sustainable maintenance, pavement maintenance should be viewed as a part of the whole transportation system. Those projects would create short-term and long-term effects to the sustainability of the whole system. At project level, maintenance should be considered as independent (which means maintenance planning and working crew are totally responsible for the project and have the right to solve any problems by themselves) to get everything done from working crew's entering the construction site to the implementation of performance monitoring. At higher level, maintenance should be considered as an element of the whole transportation system: maintenance should be managed to serve pavement users better and to cooperate with other infrastructure construction nearby in addition to guaranteeing performance.

People who are working in the same project should be educated and work together to see the big picture of the pavement maintenance.

1 Project Team

Benefits according to TBL:

- Any problems during the project should be notified to the project team in time so that any negative impacts due to the lack of information will be significantly removed.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

A project team can be established after the maintenance project has been decided, or one project team can be assigned to be in charge of one specific type of maintenance (for example, utility cut restoration project team will conduct all the utility cut restoration missions). The project team should include individuals who work on the project, such as property owner, consultant, contractor, inspector, government agency, and resource supplier.

The roles and responsibilities of project team manager and each member should be determined once the team is established.

The project team should be informed of any activities conducted on site. The team should have periodic meetings to adjust schedules or solve problems. The top concerns will be the successful delivery of the project and minimal negative effects on neighbors.

Sometimes only one people rather than a team will be assigned to be in charge of a project. In these cases, person in charge of the maintenance project should be designated. The person in charge should be able to make contact with all the representatives of stakeholders through the project.

Related Indicators:

All other indicators

How To Measure:

See if the project team is established and if the responsibilities of each member are clear.

Possible Points:

0~2

Rating Strategy:

See if the project team is established and if the responsibilities of each member are clear.

0----Project team is not set up and person in charge is not designated;

+1----Person in charge is designated or project team is set up and the responsibilities of each member are well defined;

+1----Person in charge or project manager is able to contact all team members and representatives of stakeholders.

2 Budget Plan

Benefits according to TBL:

- Economy: Budget plan helps control the life-cycle costs and resource consumption of maintenance projects.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Budget plan predicts the costs of maintenance activities. There are three methods of cost analysis that can supplement the normal budget plan.

LCCA (Life-Cycle Cost Analysis) is a tool used to determine the most cost-effective solution among different alternatives for a project through its whole life. All the costs are usually converted into the net present value (NPV) to make the costs of different alternatives comparable. As for sustainable pavement maintenance, the life-cycle of the project is defined as shown in the table below.

"LCCA considers all agency expenditures (including planning, engineering, design, construction, maintenance, operations, and administration costs) and user costs (including time, safety, fuel, and other vehicle operating costs associated with normal operations and work zone delays) throughout the life of an alternative, not only initial investments" (Reid, et al., 2015). Life-cycle cost can be analyzed in two different ways: deterministic or probabilistic. FHWA provides a tool named RealCost to perform LCCA on pavements.

Life-cycle definitions of different pavement maintenance projects

<table>
<tr><td>Projects</td><td>Beginning of life-cycle</td><td>End of life-cycle</td></tr>
<tr><td>Preservation projects</td><td>Planning to conduct preservation</td><td rowspan="3">Implementing monitoring and collecting data</td></tr>
<tr><td>Maintenance projects</td><td>Recording the distresses</td></tr>
<tr><td>Rehabilitation projects</td><td>Investigating the distresses</td></tr>
</table>

LCA (Life-Cycle Assessment) is a technique to assess environmental impacts (according to *Defining Life Cycle Assessment* published by EPA on Oct 17, 2010) during all the phases of a project by quantifying the inputs and outputs of material flows and evaluating the impacts of these material flows to the environment. There are two main types of LCA: consequential assessment and attributional assessment. The lifecycle here generally means material acquisition, processing, manufacturing, assembly, packaging, transportation/distribution, use, and reuse/recycle/disposal (according to Wikipedia definition). ISO 14040 and 14044 standards give four phases to carry out a LCA including goal and scope definition, inventory analysis, impact assessment, and interpretation.

“Benefit - Cost Analysis (BCA) assesses the benefits of projects and programs in comparison to their costs. It normally includes all direct user and agency costs and benefits that the agency is able to estimate, including operating costs, travel time costs, and often other impacts such as crash and pollution costs, but broader economic impacts are excluded in traditional BCA. Benefit - cost analysis is typically applied in transportation studies to identify the NPV of the societal benefits that can be associated with a project or program, net of the investment costs (Reid, et al., 2015).”

If conducting the analysis to compare alternatives, one of the alternatives can be a no-built/remain-the-same option or the traditional option without any sustainability considerations.

Related Indicators:

All other indicators

How To Measure:

See if any LCCA, LCA, or BCA documents on records.

Possible Points:

0~3

Rating Strategy:

0----none of the documents mentioned in this section is provided in the project documents;

+1----only budget plan is provided;

+1----any of LCCA, LCA, and BCA is provided and well described (including the inputs, outputs, and calculations), or agency or contractor has its own policy on any of LCCA, LCA, and BCA. A maximum of 2 pts can be earned

Resources:

Life-Cycle Cost Analysis. FHWA.

http://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm

Life-Cycle Cost Analysis Software. FHWA.

http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm

Operations Benefit/Cost Analysis Desk Reference. FHWA. FHWA-HOP-12-028.

http://www.ops.fhwa.dot.gov/publications/fhwahop12028/fhwahop12028.pdf

TIGER Benefit-Cost Analysis Resource Guide (2015). FHWA.

https://www.transportation.gov/sites/dot.gov/files/docs/Tiger_Benefit-Cost_Analysis_%28BCA%29_Resource_Guide_1.pdf

3 Quality Management

Benefits according to TBL:

- The quality of construction itself should be well monitored to prevent additional work or/and potential reconstruction.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Both of QC and QA belong to quality management, QA prevents mistakes or distresses in maintenance projects and avoiding problems when people use pavements while QC detects and fixes distresses.

ISO 9000 defines QC (Quality Control) as “a part of quality management focused on fulfilling quality requirements” (ISO 9000: 2005, Clause 3.2.10). QC requires the project manager and the project team or person in charge to inspect the accomplished work to ensure its alignment with the project scope (according to Joseph Philips. *Quality Control in Project Management*. The project Management Hut. Nov 2008). QC team is optional. ASTM has published some QC standards, such as http://www.astm.org/Standards/quality-control-standards.html.

QA (Quality Assurance) is defined in ISO 9000 as “part of quality management focused on providing confidence that quality requirements will be fulfilled” (ISO 9000: 2005, Clause 3.2.11).

Sending inspectors to the construction field is a normal and effective way to conduct quality management. Some examples of those items to be monitored during inspection include maintenance procedure, material test (such as asphalt mixing temperature and concrete curing time), corrective activities if necessary, and more.

Field tests are recommended, testing items and frequency should be specified.

Punishment and remediation for quality failure (discrepancy) needs to be specified, such as partial payment.

Related Indicators:

Category Technique and Safety

How To Measure:

See if any QC or QA documents on records, and if any inspection is conducted.

Possible Points:

0~4

Rating Strategy:

0----No quality management activities or documents;

+2----Inspection is scheduled and observed in the field, and inspection report is prepared by inspectors;

+1----Project is successfully delivered, and remediation is conducted if any discrepancy is observed;

+1----Quality management (QA or QC) is well described in writing.

4 Emergencies

Benefits according to TBL:

- Society: Preparation for the worst situation reduces the response time to the emergency, which also minimizes delivery delay and reduces public complaints.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Emergency mentioned here means anything that is unpredictable and has a potential to affect or delay normal maintenance activities. Inappropriate reaction to contingencies will impair project efficiency. If severe weather (heavy rain/snow/fog/wind) or other unpredictable situation (such as accident, abnormal equipment failure, material supplying failure, temporary mega event, hazardous spills, and natural disaster) happens during maintenance, project team or person in charge should provide emergency response, such as schedule modification and equipment/material backup plan.

Emergency not happening in the construction field should also be considered, especially during materials/wastes transporting.

An emergency dealing plan should include typical components that could happen during specific maintenance activities, emergency contacts, onsite reaction, and backup plan if necessary.

Dialing 911 under certain circumstances is necessary but is not considered as an emergency dealing plan.

Related Indicators:

Category Environment and Safety

How To Measure:

See if any emergency dealing plan is provided.

Possible Points:

0~3

Rating Strategy:

0----No emergency dealing plan is provided;

+2----Onsite working crew is knowledgeable about typical situations of emergencies; or emergency happened during maintenance project but was well handled;

+1----Emergency dealing plan is available and well described.

5 Maintenance Schedule

Benefits according to TBL:

- Economy: Integrated and reasonable maintenance schedule demonstrates when and how to conduct future maintenance, facilitating the communication among people and helping avoiding associated potential loss
- Society: enhance people's satisfaction by removing inappropriate project schedules that may cause inconvenience for the nearby community.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

There are two components needing to be scored under this indicator: schedule of the maintenance project (daytime construction and night work) and, the follow-up maintenance schedule.

For daytime construction, a well-described maintenance schedule should be provided by contractor and reviewed by the project team, including (but not limited to) anticipated starting and finishing date, daily working hours, daily usage of materials and equipment, and the schedule of meetings or communications. Project team should be aware of any changes of schedule. Weekly update from contractor to the project team members is preferable. Such update can be conducted in the form of meeting, phone call, or email.

Night work of maintenance occurs if the project is urgent or it is not practical to do the job during the daytime. As to the night work, the project team or the people in charge should communicate actively with the nearby community to avoid unnecessary conflicts.

Once future maintenance needs have been predicted after the pavement has been built or maintained, the distresses do not need to be reported by surveying team or public so that they will not be long-standing issues and causes public complaints, and the influencing time brought by deteriorated pavements will also be shortened or even removed. Additional points can be awarded if such schedule plan of following maintenance is provided. Two situations are eligible for points: 1) the upcoming maintenance project is embedded into the schedule plan, or 2) follow-up maintenance activities are scheduled after the current maintenance project is complete.

Related Indicators:

C-5

How To Measure:

See if the project schedule and schedule plan of pavement maintenance are provided.

Possible Points:

0~3

Rating Strategy:

Components	Project schedule (including daytime and nighttime work)	Follow-up maintenance activities schedule
Maximum pts	2	1
Possible pts	0 pt if there is no informal or formal forms of communication aimed at keeping the whole project team informed of all the schedule changes; 1 pt if project schedule is provided and notified to the project team; 1 pt if the neighbors participated the determination of project schedule	1 pt if the schedule of follow-up maintenance activities is available

Benefits according to TBL:

- Economy: Project record helps predict future maintenance needs, reducing the cost related to distress surveying.
- Environment: Tracking environmental commitments guarantees the environmental principles are consistently met throughout project.
- Society: Keeping track of the project records can benefit the society by increasing project transparency, so people who are interested in the details could be offered a chance to take a closer look.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

A complete set of project record should be built and maintained by the project team or person in charge, including three types of records: historical record, construction record, and maintenance prediction.

The historical record may include initial construction information of the pavement and any historical maintenance activities records since the pavement was built. Historical maintenance information can be used to address potential risks, track emerging distresses and provide reference to types of issues once appeared before.

The construction record might include three stages of activities. Those activities are inspection on pavements waiting for maintenance (including funding source, project location, contractors, and critical dates), supervision on construction process, and post-construction monitoring. Those records could be in the form of text (log), audio, photo, and video. Supervision on current projects includes not only the construction activities but also the sustainable commitments. Sustainability should be tracked by project record so that construction quality and adherence to commitments will be consistently met. The post-construction monitoring should include, but not be limited to, the designation of monitoring crew, the indicators to be monitored, and the frequency and duration of monitoring.

The maintenance prediction might include recommendations and schedules of any preservation or routine maintenance.

All the documents and information mentioned above should be carefully stored to track the maintenance work. A database for maintenance is preferred. The database can be independent or associated with other infrastructure database. It should be well organized, easily accessible, and periodically updated.

Complementary online map is recommended to conveniently locate maintenance projects and show their basic information.

Related Indicators:

All other indicators

How To Measure:

See if the project record is documented, if the data are stored, and if the database is established.

Possible Points:

0~4

Rating Strategy:

0----Project record is not provided;

1----Project record is poorly stored but still accessible;

2----Project record is well documented and the data is well stored but the database is not established;

3----The records and data are well stored and the database is established;

+1----Complementary online map is generated and can be accessed by interested parties.

7 Work Zone Management

Benefits according to TBL:

- Economy: Well-managed working environment improves construction efficiency and reduces incident-related costs.
- Environment: Surrounding environment of work zone should be protected during and after construction.
- Society: Maximize safety of working crew and pavement users, and restore work zone to original condition after construction to reduce public complaints.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Work zone should be well organized for construction safety and project efficiency. For pavement maintenance project, the location of work zone normally is close to the location of distress. However, sometimes part of some working areas might be located in some places like private road, turf, or parking lot due to some restrictions. In this case, project team should notify the affected community to minimize the unnecessary conflicts and impacts due to the lack of communication.

While designing the work zone, project team or person in charge should consider the property owners and businesses affected by the construction to minimize the impacts on them.

Work zone management might include the determination of the boundary of work zone, the parking of construction equipment and other vehicles, the working route, the route of material transporting and other vehicles in the field, the regulation of predicted activities of working crew, and the cleaning of the work zone after finishing the construction. Activities related to traffic control will be discussed in the Safety Category.

Work zone has its life cycle, which starts when the first construction equipment arrives and ends until the last vehicle of working crew leaves.

Related Indicators:

Mn-9, Mt-4, S-1, S-2, S-5, C-7

How To Measure:

See if any inappropriate management activities at work zone negatively affect safety or efficiency.

Possible Points:

0~3

Rating Strategy:

0----Inappropriate management or ignorance of management at work zone that negatively affect construction process is observed;

+2----The work zone is well managed, or problems related to work zone management are well handled;

+1----The activities through the work zone life cycle are well planned as written documents.

Resources:

Work Zone Management Program. FHWA. http://ops.fhwa.dot.gov/wz/index.asp

8 Crew Training

Benefits according to TBL:

- Economy: Proper crew training improves construction efficiency.
- Environment: Proper crew training could make working crew realize the importance of environment protection with readily guidance about how to protect environment.
- Society: Provide working crew with necessary construction knowledge, which can be transferred into long run benefits for the whole society.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

All the members serving in the working crew must be trained prior to entering the construction site. The purpose of training is to enable working crew to be able to apply skills, knowledge, and attitudes under different conditions. At least one individual with over 5 years of experience in pavement construction should be involved as crew member or mentor.

Under training program or training personnel, 5 types of knowledge are recommended to be included: 1) basic knowledge on the use of equipment, devices, tools, and materials; 2) background knowledge of the information of current construction site (specifically such as soil and neighbors); 3) technique knowledge that is maintenance technique procedure; 4) safety knowledge; 5) sustainability knowledge.

To establish the sustainability outcomes during maintenance activities, basic sustainability knowledge should be provided, such as introduction of each PSIM indicator, how the crew can contribute to sustainable development at work zone, and commitments to environmental legislative requirements.

Working crew that need training include, but are not limited to, managers, inspectors, superintendents, foremen, operators, and laborers.

Examples of training types include, but are not limited to, topic-specific emails, topic-specific handouts, workshops and presentations, preconstruction meetings, classroom training, and field training.

Tracking and assessment of training efforts are recommended. Proof or certification of finished training is preferred.

Safety training is discussed under this indicator, working crew's behaviors after training are considered under Category Safety.

Related Indicators:

All other indicators

How To Measure:

See if the working crew is trained as expected and if any veteran is involved.

Possible Points:

0~4

Rating Strategy:

0----The working crew are not well trained;

+1----The working crew are trained under a training program or training personnel with five types of knowledge as described by this indicator, training of each type of knowledge can earn 1 pt but training of sustainability knowledge can earn 2pts, a maximum of 3 pts can be earned;

+1---- At least one experienced employee guides the crew or serves in the crew.

9 Project Interaction

Benefits according to TBL:

- Cooperation among different projects could help reduce the potential economic, environmental, and social conflicts.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

The work zone of one pavement maintenance project may be very close to some other projects'. “Very close” is defined here as projects are close enough to have influences on each other. Such projects can occur simultaneously or successively.

Communication and cooperation can play important roles under this situation. Periodic meetings or other means of negotiations among the project teams can help eliminate potential conflicts and remove repetitive maintenance activities.

For example, coordination should be considered between pavement authorities and utility agencies. Lack of such cooperation might require newly maintained pavement structure to be dug up shortly after completion to install or maintain utilities, which leads to disruption of pavement integrity and wastage of resources and efforts.

Emergency maintenance is unpredictable so will not be discussed under this indicator.

Related Indicators:

Category Management and Safety

How To Measure:

See whether there are enough communication among the project teams working in close or overlapped area.

Possible Points:

0~2

Rating Strategy:

0----The project teams are not aware of there are other projects ongoing very close to their own work zone;

1----The project teams communicate effectively with other projects teams nearby to minimize potential conflicts;

2----Cooperation plan and timeline are provided by the project teams.

B.2 Category Technique

Pavement maintenance techniques are used to prevent pavement deterioration, fix the functional/structural distresses, or/and restore pavement performance. Category

Technique is designed to evaluate the technique-related problems that have direct influences according to triple bottom lines during maintenance.

1 Technique Selection

Benefits according to TBL:

- Maintenance techniques themselves have economic, environmental, and social influences, and they contribute to the sustainability to various extents.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Different maintenance techniques can be used to solve the same distresses, and different techniques often have various effects on project expenses, surrounding environment, and nearby community.

This indicator won't be applied if the desired types of technique are unavailable due to reasons like lack of material supply, unavailability of maintenance crew, or some traditional maintenance habits. Otherwise the project team should carefully analyze the advantages and disadvantages of the techniques available in terms of economy, environment and society to select the right one.

PSIM provides a **comparison chart** for the common techniques to maintain asphalt, concrete, and unpaved pavement, as can be seen in Appendix. Ten sustainability impact factors are discussed and assigned priorities during technique selection process. For example, some of the maintenance techniques might not be practical under certain weather conditions. Weather adaption will be able to reduce construction delay and traffic interruptions, and to increase the maintenance productivity. The project team or person in charge should pay attention to the weather forecast and has effective measures under different weather conditions, so that the impacts of weather on construction efficiency can be minimized.

To select more sustainable maintenance techniques, project team should make good use of the PSIM **comparison chart** and relate their own situations.

The selected method used by project team should at least include two aspects of TBL.

Related Indicators:

T-3

How To Measure:

See if appropriate reasons are provided to select maintenance techniques from multiple options.

Possible Points:

0~2

Rating Strategy:

0----Only analyze and select techniques from financial perspective;

1----More than one perspective are considered based on TBL (Economy, Society, Environment);

2----PSIM comparison chart is used or the technique selection process fully reflects 3 perspectives of TBL (Economy, Society, Environment).

Resources:

Road Weather Management Program. FHWA.

http://www.ops.fhwa.dot.gov/weather/index.asp

Best Practices for Road Weather Management. FHWA. FHWA-HOP-12-046.

http://ops.fhwa.dot.gov/publications/fhwahop12046/fhwahop12046.pdf

2015 Road Weather Management Performance Measures Survey, Analysis, and Report. FHWA. FHWA-HOP-16-001.

http://www.ops.fhwa.dot.gov/publications/fhwahop16001/fhwahop16001.pdf

2 Distress Reason

Benefits according to TBL:

- Economy: Prevent unnecessary reconstruction or modification which may cause huge financial loss due to the failure to meet specific requirements.
- Environment: Enhance the involvement of surrounding communities. Increase sustainability awareness among average people.
- Society: Enhance the involvement of surrounding communities. Increase sustainability awareness in the public.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

There are always certain problems beneath each type of pavement distress. But different reasons may lead to similar distresses.

Most issues could be addressed by analyzing distress location (joint, edge, middle), pavement location (urban, rural), pavement profile (upgrade, downgrade, curve), weather condition (climate, season, daily weather, temperature, precipitation), subgrade condition (natural soil, artificial backfilling, compaction), previous maintenance process, and current maintenance operation. For example, rutting on asphalt pavement may be resulted from structure problem (such as insufficient subgrade compaction) or material problem. However sometimes it may take the project team a while with careful inspection and investigation to find out the problem.

Example:

April 20 2015

August 26, 2015

September 12, 2015

October 13, 2015

November 14, 2015

June 26, 2016

Pavement distress and treatment at South Shelby Street & Fetter Avenue, Louisville, KY

Two potholes and alligator cracking were found along the curb at the intersection of South Shelby Street & Fetter Avenue in Louisville, KY, and the elevation of potholes was lower so that stormwater gathered there after precipitation. Both potholes were patched sometime before April 2015. However, since the patching area was still lower and alligator cracking was not fixed, water could easily stay and enter the cracks. Three months later, one patch failed. In October 2015, top 1 to 2 inches of this section was milled and overlaid, and the pavement condition was very good ever since. Therefore, repetitive maintenance happens and wastes money if the actual reason is not found.

Related Indicators:

T-1

How To Measure:

See if distresses are inspected and analyzed before the maintenance technique is selected.

Possible Points:

0~4

Rating Strategy:

0---- Distress inspection and analysis are not included in the maintenance;

2---- Distress inspection and analysis are imbedded into problem solving process to find out the root of distress;

+2---- Follow-up investigations are in place.

3 Standard Procedure

Benefits according to TBL:

- Improve construction efficiency.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Projects should be conducted under standard procedure and comprehensive specifications.

It is not mandatory to follow the standard procedure of each maintenance technique at national level (such as FHWA recommendations). Transportation Department, Public Works, or other similar agencies are encouraged to have their own standard procedures to guide the pavement maintenance projects in their areas.

Related Indicators:

How To Measure:

See if the working crew follows maintenance standard procedures.

Possible Points:

0~8

Rating Strategy:

2----The maintenance is conducted according to experience not standard procedure;

6----The project team follow the standard procedure from contractor or local agency;

8----The maintenance project is conducted according to a standard procedure at regional level (such as metropolitan area, County, State);

-1----Any step during the standard procedure is omitted, a minimum of 0 pt can be assigned under this indicator.

4 Disturbance and Repair

Benefits according to TBL:

- The disturbance on pavement structure or other components within pavement system will increase the possibility and frequency of unnecessary future maintenance.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Sometimes the maintenance activities can cause damage to adjacent pavement surface (which may be still in good condition) or even structures or facilities, such activities should be carefully inspected and proper repair work should be conducted.

There are some common unsustainable phenomena like some construction equipment make scratches on adjacent pavement surface in operation. If such disturbance happens on asphalt surface pavement, smoothness will be affected so that driving comfort will be impaired; if concrete surface pavement has been disturbed, the slab might be broken and then cracking or faulting might happen. Disturbance on unpaved pavement/shoulder will be less harmful but still need attention.

Disturbance on roadside facilities such as mailboxes or poles along the pavement is another potential problem, and should be inspected at all times.

Example:

June 14, 2015

5501 Manor Lane, Louisville, KY

During a utility cut restoration, a backhoe left one scratch on adjacent pavement surface, and no remediation was conducted thereafter. Extra costs will be expected if remediation has been planned. The scratch was approximately 3/4 inches deep and possibly affect motorists' riding comfort. Cracking will potentially develop along this scratch easily since it is thinner than anywhere else.

Related Indicators:

How To Measure:

See if the existing structures within pavement system are disturbed or damaged during maintenance activities.

Possible Points:

0~2

Rating Strategy:

0----The existing pavement sections or appurtenances were disturbed and no remediation afterwards.

2----The existing pavement sections or appurtenances were disturbed and well repaired.

5 Uneven Surface

Benefits according to TBL:

- Economy: Reduce unnecessary automotive fuel assumption and other related cost due to uneven surface.
- Environment: Reduce emissions by reducing fuel consumption.
- Society: Improve ride quality by providing smoother pavement surface.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

When vehicle runs over rough or uneven pavement, driver safety and ride quality will be at risk while the vehicles will wear and tear quickly and consume more fuel.

Two components need to be measured under this indicator: one is faulting at the edge between maintained area and adjacent pavement; the other is the elevation difference between manholes, inlets, or valve boxes within the maintenance area and pavement surface.

Faulting may occur during and after construction phase. Appropriate slope along the edge should be installed so that vehicle can pass over the edge smoothly. If the maintenance area is relatively small, or faulting occurs during maintenance construction, another option to warn motorists about faulting is to control traffic away from the faulting areas by appropriate signs.

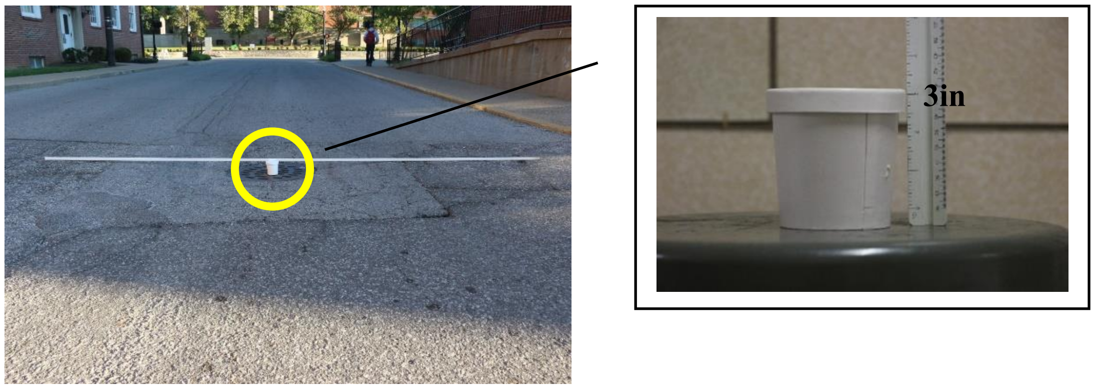
The elevations of manholes, inlets, or valve boxes should be adjusted according to the elevation of finished pavement surface.

Examples:

September 12, 2015

Eastern Parkway & South 3rd Street, Louisville, KY

Milling often causes faulting between milled section and adjacent section. There was a 1~2 inches of faulting during a mill and overlay project at the intersection of Eastern Parkway & South 3rd Street in Louisville, KY. When passing the milled area, motorists will possibly press brake pedal trying to reduce the vibration. If the faulting is serious enough, ABS (Anti-lock Braking System) can be triggered which possibly causes temporary “soft brake”. This type of “soft brake” is not the result of any malfunction of auto parts, but it can be very annoying. It is difficult for motorists to notice this type of faulting while driving at night, or so appropriate sign is strongly recommended to help warn motorists.



October 17, 2015

Alley east to W. S. Speed Hall at University of Louisville

Manholes are another possible reason for uneven surface after maintenance. A sewer cover was not raised to the elevation of finished pavement surface on the Alley east to W.S. Speed Hall at University of Louisville, and the difference of elevation was more than 3 inches. Ride quality can be improved for faculty and students if the difference of elevation is removed.

Related Indicators:

How To Measure:

See if the smoothness at the edge of maintenance area or around manholes is improved during or after maintenance construction.

Possible Points:

0~2

Rating Strategy:

Components	Faulting	Elevation
Maximum pts	1	1
Possible pts	0 if faulting is observed during or after construction	0 if obvious elevation difference is observed around manholes, inlets, or valve boxes
	1 pt if slope is installed to remove faulting effects	1 pts if the elevation of manholes, inlets, or valve boxes is adjusted to the finished surface

6 Preservation

Benefits according to TBL:

- Economy: more durable and smooth pavement can lower cost of fuel consumption, and postpone relatively expensive rehabilitation.
- Society: Well-planned preservation can postpone the time consuming rehabilitation, so there will be less inconvenience for the pavement users.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Preservation is a proactive improvement for pavement structure compared to those reactive repair activities. Pavement life can be extended with frequent small modification and preservation. It's easier to fix small problems when the pavement is still in good condition.

How To Measure:

See if preservation practices are involved in the project.

Possible Points:

0~2

Rating Strategy:

1----25% to 75% of the project area involves preservation practices;

2----Over 75% of the project area involves preservation or the project is a preservation project.

B.3 Category Material

Material is always one of the top concerns of sustainability, not only because materials themselves are precious resources, but also because it takes a lot of energy and work to produce, transport, store, and dispose materials. Category Material is designed to promote responsible use of construction materials, and improve the sustainability for the maintenance activities related to construction materials.

1 Quality Certification

Benefits according to TBL:

- Economy: Prevent extra material costs and reconstruction work due to the material quality issue.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

The materials can be purchased from supplier or manufactured by contractors or working crew. The quality of materials must meet related standards, including paving materials such as asphalt, concrete, aggregates, sand, and other materials such as materials for pavement marking and sealing.

The material supplier should be able to provide documents showing that the quality of material meets certain specifications. The testing laboratory or technicians are recommended to be certified by such certification program such as AMRL (AASHTO's Materials Reference Laboratory), USCOE (U.S. Army Corps of Engineers) validation, CCRL (Cement and Concrete Reference Laboratory), NICET (National Institute for Certification in Engineering Technologies), ACI (American Concrete Institute), ASTM (American Society of Testing Materials), ICO (International Code Council), and some other state-level programs.

Different accreditation, qualification, or certification programs might cover different types of construction materials, only the accreditation or certification programs related to the supplied materials can earn points under this indicator.

All construction materials should be inspected by the inspector at scheduled intervals. Inspection results should be overall consistent with the information on material tickets. Onsite sample tests are preferred to conduct at least once for the same group purchased, produced, or transported together.

Mn-3 discusses maintenance activities, while this indicator considers those materials used during maintenance activities.

Related Indicators:

Mn-3

How To Measure:

See if there are any material quality control practices conducted before construction work begins.

Possible Points:

0~5

Rating Strategy:

0----No quality control activity is observed, or the supplied material fails on quality test but no remediation;

+1----Material supplier has a testing laboratory;

+1----Each certification achieved by the testing laboratory will earn 1 pt, maximum 3 pts;

+1----Onsite material inspection shows general accordance with the ticket information, or onsite sample test is conducted and the test result generally meets the plan; and appropriate remediation is conducted if the supplied material fails on quality test.

2 Material Production

Benefits according to TBL:

- Promote sustainability at the plant of asphalt, cement, or concrete.

Application:

☑ Asphalt	☑ Concrete	☒ Unpaved

Explanation:

Asphalt and cement are the most commonly used paving materials, and the production of asphalt mixture, cement or concrete consumes a lot of energy.

NAPA (National Asphalt Pavement Association) Diamond Achievement Commendation or Diamond Achievement Sustainable Commendation is recommended for asphalt plant.

ENERGY STAR® certified cement production plant, NRMCA (National Ready Mixed Concrete Association) certified sustainable concrete plant, or NRMCA Green-Star certified plant are recommended for concrete production.

Related Indicators:

How To Measure:

See if asphalt, cement, or concrete plant involved is certified by sustainability program.

Possible Points:

0~4

Rating Strategy:

0----None of recommendations is adopted;

2----50% or more of the asphalt mixture is supplied by NAPA Diamond certified asphalt plant, or 50% or more of the cement is supplied by ENERGY STAR® certified cement plant, or 50% or more of the concrete is supplied by NRMCA certified concrete plant;

4----All of the asphalt mixture is supplied by NAPA Diamond certified asphalt plant, or all of the cement is supplied by ENERGY STAR® certified cement plant, or all of the concrete is supplied by NRMCA certified concrete plant.

Resources:

ENERGY STAR® Industrial Insights TM: Cement Manufacturing Plants.

https://www.energystar.gov/sites/default/files/tools/Industry_Insights_Cement_2015.pdf

NRMCA Sustainable Concrete Plant Certification.

http://www.nrmca.org/sustainability/Certification/PlantCertification.asp

3 Local Material

Benefits according to TBL:

- Economy: Using local materials can propel the local economy as well as reduce the transporting cost.
- Environment: Preserve energy and reduce emissions resulted from transporting materials.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Buying local materials can save the shipping time with distance advantage, so that the fuel and energy for transporting can be saved compared to ordering materials far away from the construction site. "Local" is defined as the producer is located within 100 miles (LEED v4) from construction site.

Related Indicators:

How To Measure:

See the ratio between local materials and the consumed materials.

Possible Points:

0~2

Rating Strategy:

0----No local materials at all;

1----Over 50% of the materials consumed are local;

2----All of the materials consumed are local.

4 Material Storage

Benefits according to TBL:

- Economy: Prevent the costs due to inappropriate material storage
- Environment: Save material resource, and reduce contamination from inappropriate material storage.
- Society: Provide neat and clean storage site.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Selection of storage location should consider the traffic disturbance the project may cause, the convenience of the hauling drivers and the disturbance the project may cause outside of the work zone.

An inventory of the materials (construction materials, backfilling materials, earthen materials, etc.) stored on site should be on record and available to project team.

Storage location is determined by the location and scale of the project, traffic, and surrounding community. The storage location might be moved during the project if necessary.

Construction materials should be protected from being affected by undesired factors like weather or traffic. Meanwhile, the surrounding environment should be protected from the negative impacts from the material storage.

Appropriate signs are recommended on site. The information shown on signs might include material type, brief project description, storage period, and emergency contact.

Reusable material, disposable material and material needs to be recycled should be stored separately if possible.

Example:

June 20, 2015

3300 ~ 4125 Preston Highway, Louisville, KY

Preston highway (north bound) was cut to replace a 12” water main. It was raining intermittently from the dusk on June 17 to the morning on June 18, and there was heavy rain from the late afternoon on June 18 to the morning on June 19. However, the working crew did not have any protection for the DGA stockpile on site.

Related Indicators:

How To Measure:

See if material storage-related document on file and the actual practices on site.

Possible Points:

0~2

Rating Strategy:

0----No instruction for materials storage and materials are stored in the field without protection;

+1----Materials are well located and stored;

+1----Tags, signs or signboards are provided to show material information.

5 Recycle Material

Benefits according to TBL:

- Economy: Recycling used materials is more economical than purchasing virgin materials.
- Environment: Recycling can help conserve valuable raw material resources, reduce construction wastes and negative environmental impacts, and reduce the energy and emissions caused by manufacturing virgin materials.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Two aspects need to be considered under this indicator: 1) whether the project are using recycled materials to replace part or all of the virgin materials; 2) and recycling construction materials extracted from the project.

Recycling is a critical way to save precious non-renewable resources (aggregates and binders), save energy to produce and transport virgin materials, reduce waste, and lower construction costs in different ways.

Certain used materials extracted from other transportation projects can be used for pavement maintenance purposes. Those reusable materials include paving materials (such as asphalt, concrete, fine and coarse aggregates) and other materials (including those extracted from non-pavement structures).

Example ways of recycling old pavement materials include reclaimed asphalt pavement (RAP), recycled concrete aggregate (RCA), cold - in - place recycling (CIR), hot - in - place recycling (HIR) and full depth reclamation (FDR). FHWA (http://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/toc.cfm) defines Reclaimed Asphalt Pavement (RAP) as the removed and/or reprocessed pavement materials containing asphalt and aggregates, and Reclaimed Concrete Pavement (RCP) as that consists of high-quality, well-graded aggregates (usually mineral aggregates), bonded by a hardened cementitious paste. RAP and RCP can be recycled or reused in maintenance constructions at 100% or with certain virgin materials, either for the purposes of subgrade, surface, or backfilling.

Hot/Cold In-place Recycling is preferred because it saves the time and costs to ship reclaimed materials from other places.

INVEST V1.2 PD-20.1 to PD20.3 gives recommendations to calculate average recycled content within a transportation project.

Other than pavement structure, recycled materials also can be considered for wood concrete forms, metal guide posts, lighting poles, road signs, and traffic markers.

Example:

2011 (adapted from ASCE: 2013 Report Card for America's Infrastructure: Roads)

Interstate 81, Staunton, VA

In 2011, a 3.66-mile section of pavement on I-81 was rehabilitated by full-depth reclamation, cold in-place recycling, and cold central-plant recycling with special traffic control plan. The project reduced construction time by two-thirds, minimized fuel consumption from hauling, reduced traffic disruptions, improved safety in work zone, and saved millions of dollars compared to conventional method.

Related Indicators:

How To Measure:

Calculate the percentage of reclaimed materials used and the percentage of materials recycled during construction.

Possible Points:

0~4

Rating Strategy:

	Construction materials have been recycled	Recycled materials have been used
Maximum points	2	2

Possible points	Earn 1 pt if over 50% of the waste construction materials are recycled	Earn 1 pt if recycled materials replace virgin materials at any percentage during construction
	Earn 2 pts if 100% of the waste construction materials are recycled	Earn 2 pts if the ratio between recycled materials and virgin materials used during construction is over 1:1
+1----In-place Recycling technique is used on site, a maximum of 4 pts can be awarded under this indicator		

Resource:

Find a C&D Recycler. Construction & Demolition Recycling Association.

http://www.cdrecycling.org/find-a-c-d-recycler

6 Alternative Material

Benefits according to TBL:

- Economy: It can largely reduce the material cost by shifting from some conventional materials to some reusable materials used in other industries.
  - Environment: Preserve traditional paving materials, reduce the carbon footprint during the production and transportation of traditional paving materials, and reduce the disposal of alternative materials by using them on pavement construction.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Waste materials or by-products from other industries can be reused for different structural layers of pavement, including subgrade fill, in maintenance projects, either as the substitutes for aggregates or binders, so that traditional construction materials can be conserved. Some examples are coal ash, fly ash, foundry sand, slag, tires, asphalt shingles, and certain demolition materials. FHWA has a list of the normal alternative materials used on pavements (http://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/toc.cfm). Certain performance standards need to be met when such alternative materials are used. Besides, similar alternative materials could be applied to other components of pavement system, such as pipes used for culverts and sewers and concrete facilities along the pavement.

Related Indicators:

How To Measure:

See the percentage of alternative materials used during construction.

Possible Points:

0~1

Rating Strategy:

0----No alternative material used;

1----Alternative materials are used to replace part of binders or aggregates at 10% or more;

1-----Non-traditional construction materials are used to improve certain performance of pavement, but not for replacement purpose.

7 Earthwork

Benefits according to TBL:

- Economy: Reduce the shipping costs to move earthen materials.
- Environment: Minimize environmental disturbance by balancing cut and fill and by reducing transporting of earthen materials.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Project cost is significantly influenced by geotechnical issues such as balance of earthworks (VicRoads, 2011). Cut and fill of earthwork during maintenance project should be balanced to reduce the shipping of earthen materials (soil and rock) and backfilling materials in and out of the construction site, so that construction time, energy consumption, emissions, dust, noise, vibration, disruption to pavement network from the operation of hauling trucks can be reduced.

The earthwork stockpiles should be protected from water and wind as recommended by M-4 "Material Storage".

INVEST V1.2 PD-21.1a provides a method to calculate the "cut and fill volumes without construction banking".

If the earthen material is not suitable for backfilling due to saturation, contamination, or other reasons, it should not be disposed in or near the construction field (unless it is a temporary stockpile); instead, it should be sent to disposal or treatment facility. Such decision should be made before earthwork construction to avoid costly scope modification. Borrow pit should be local if needed.

Related Indicators:

How To Measure:

See the difference between cut (excavation) and fill (embankment), and the ratio of that difference compared to total earthwork volume.

Possible Points:

0~2

Rating Strategy:

+1----The difference between cut and fill is no more than 20% of the total earthwork volume;

+1----Earthen material is well treated or disposed if it is not suitable for backfilling;

+1----An earthwork management plan is provided.

B.4 Category Energy&Water

Energy and water are the last group of the project inputs. Energy can be saved by reducing wastage, improving efficiency, and using renewable energy sources. The purposes of Category Energy & Water are to save energy including electricity and fuel and to minimize water wastage. The direct sustainability benefits include reducing the emission resulted from electricity production and fuel consumption, and protecting water resource.

For Indicator 1~4, an energy management plan is recommended to describe the project's planned actions to reduce energy consumption, to use alternative or renewable energy, to increase energy efficiency, and to reduce vehicle miles travelled (VMT).

1 Efficient Lighting

Benefits according to TBL:

- Economy: Save the cost of electricity and the potential electric wire installment.
- Environment: Conserve electrical energy.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

The lighting facilities or devices are mainly powered by electricity, including construction lighting (especially for night construction), traffic or road lighting (luminaries and traffic signal equipment), and lighting for traffic control. All types of lighting are recommended to adopt high efficiency lighting such as light-emitting diode (LED) and high pressure sodium lamps, or using renewable energy (such as solar and wind, so that the installation costs of electric wire can be saved). However, relevant lighting requirements must be met, such requirements can be found from FHWA's Nighttime Lighting Guidelines for Works Zones, FHWA Lighting Handbook, and MUTCD Chapter 6F.

The project team is recommended to record electricity consumption data during the entire project on lighting.

Example:

2007 (adapted from http://gizmodo.com/led-streetlights-will-change-hollywood-and-make-every-c-1514840416)

San Jose, CA

Starting in 2007, 62,000 streetlights in San Jose, CA were planned to be replaced by LED lights and equipped by remote monitoring and adaptive control. The project significantly reduced the city's $6 million annual streetlight operating and maintenance costs, as well as reduced energy consumption and emission (Schilleman & Gough, 2012).

Related Indicators:

How To Measure:

See if high efficiency lighting or renewable energy are involved in maintenance project.

Possible Points:

0~3

Rating Strategy:

For each of three components,

0----Traditional lighting devices are used;

+1----High efficiency lighting is used;

+1----Renewable energy is used (battery is not eligible for earning points unless it is charged by renewable energy).

A maximum of 3 pts can be earned under each component.

+1----The electricity consumption data for lighting purpose is recorded.

Resources:

Renewable Energy Guide for Highway Maintenance Facilities. NCHRP Report 751.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_751.pdf

Evaluation of Renewable Energy Alternatives for Highway Maintenance Facilities. The Ohio Department of Transportation. FHWA/OH-2013-13. Dec 2013.

http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/reportsandplans/Reports/2013/Environmental/134706_FR.pdf

Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy.

http://energy.gov/eere/office-energy-efficiency-renewable-energy

Green Power Partnership, U.S. Environmental Protection Agency.

https://www.epa.gov/greenpower

INVEST V1.2 PD-17 provides a method to calculate the power consumption.

Maintenance Manual Volume 1, Chapter K Electrical. Caltrans.

http://www.dot.ca.gov/hq/maint/manual/2014/27_Chpt_K_July_2014.pdf

2 Energy Consumption I, Equipment

Benefits according to TBL:

- Economy: Save the energy costs during the construction.

- Environment: Reduce the energy-related environmental harms during construction.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

The equipment used for maintenance activities varies depending on the applied techniques.

First, The construction equipment should be fuel-efficient or might select alternative fuel, INVEST V1.2 PD-26 recommends using "non - road construction equipment that have engines that meet the current U.S. EPA Tier emission standards (Tier 3/Interim, Tier 4 as of April 2011) in effect for non-road engines of the applicable engine power group".

Second, the construction route should be carefully designed if there are multiple construction sites at the same time or if the project scale is large enough, in order to reduce the energy consumption and emissions resulted from construction equipment.

Third, construction-related equipment should be well maintained to prevent such situations that the equipment/vehicle designated to the construction site fail to fulfill the mission and need to be replaced or repaired. Such situations consume additional time and labor to fix.

Finally, in order to prevent fuel wastage, crew should be encouraged to operate equipment efficiently and idling should be minimized.

The project team is recommended to record energy consumption data related to construction.

Related Indicators:

EW3

How To Measure:

See if the energy consumption by construction equipment is optimized.

Possible Points:

0~3

Rating Strategy:

2----Fuel-efficient or alternative fuel technology are applied on over half of the construction equipment;

+1----Route design is conducted if there are multiple construction sites involved at the same time or if the project scale is large enough;

+1----All of the construction equipment are able to fulfill the construction missions when required, and energy consumption data of construction equipment is recorded;

-1----Idling of construction equipment is observed;

0----None of the situations discussed here are observed.

Resources:

Idle Reduction. U.S. Department of Energy.

http://www.afdc.energy.gov/conserve/idle_reduction_basics.html

Emission Standards Reference Guide for On-road and Nonroad Vehicles and Engines.

EPA. https://www.epa.gov/emission-standards-reference-guide

3 Energy Consumption II, Transport

Benefits according to TBL:

- Economy: Reduce energy consumption by reducing vehicle travelling distance and promoting transport efficiency.
- Environment: Reduce emissions by reducing vehicle travelling distance and promoting transport efficiency.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

There are two types of the “transport” used during pavement maintenance project, one is crew transportation (crew for operation, investigation, supervision, inspection, and monitoring), and the other is material transportation.

Carpooling or vanpooling is preferred for crew when available.

To prevent fuel waste, optimal route design for materials transportation is recommended; to prevent the delay, the hauling trucks can be tracked by installing GPS modules on the vehicle.

The vehicles with high fuel efficiency, alternative fuel, or low emission are preferred for both crew and materials. Transport-related equipment and vehicles should also be well maintained to prevent such situations that the equipment/vehicle designated for the maintenance project fail to fulfill the mission and need to be replaced or repaired. In addition, idling should be minimized all the time.

The project team is recommended to record energy consumption data related to transport.

Related Indicators:

EW2

How To Measure:

See if the energy consumption by transporting vehicles is optimized.

Possible Points:

0~2

Rating Strategy:

+1----Fuel-efficiency or alternative fuel technology are applied on over half of the transporting vehicles;

+1----Carpool is considered for crew transportation;

+1----Optimal route design is conducted for material transportation, or hauling trucks are tracked during the project;

-1----Idling of transporting vehicles is observed;

+1----The energy consumption data related to transport is recorded;

0----None of the situations discussed here is observed.

4 Energy Consumption III, Asphalt Mixture

Benefits according to TBL:

- Environment: Reduce the emissions and carbon footprint by reducing energy consumption during asphalt mixture production.
- Society: Improve the working environment during paving process.

Application:

☑ Asphalt	☒ Concrete	☒ Unpaved

Explanation:

Warm mix asphalt is recommended and the mixing temperature should be reduced by at least 30 ºF.

Related Indicators:

How To Measure:

See if warm mix asphalt is applied to pavement maintenance.

Possible Points:

0~2

Rating Strategy:

1----Over half of the asphalt mixture used for the project is warm mix asphalt and the mixing temperature is reduced by 30 ºF or more;

2----All of the asphalt mixture used for the project is warm mix asphalt and the mixing temperature is reduced by 30 ºF or more;

5 Water Consumption

Benefits according to TBL:

- Economy: Reduce water consumption and related cost.
- Environment: Conserve water resource.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

There are two components under this indicator.

First, water is used for construction purposes, such as on-site concrete production, dust control, and cooling construction equipment. The related equipment should be free of leaking. The excessive and uncontaminated water is encouraged to be disposed into natural water system or to be used for irritation purpose, instead of wasting such as disposing on site or into sewer.

Second, water consumption caused by landscape irrigation should be considered under this indicator. The irritation might be reduced or even removed by selecting proper vegetation or/and improving irrigation efficiency irrigation efficiency can be calculated by the WaterSense Water Budget Tool from EPA (LEED v4 ND).

The use of non-potable water, recycled water, or other alternative water resources is recommended.

The water consumption data for the entire project is recommended to be recorded to track water consumption and support water management.

Related Indicators:

C2

How To Measure:

See if water is wasted during the project.

Possible Points:

0~1

Rating Strategy:

0----More than half of excessive and uncontaminated water is wasted during and after the project; or less than half of the water consumed is non-potable; or any equipment using water is leaking while in service;

1----Less than half of excessive and uncontaminated water is wasted during and after the project; or over half of the water consumed is non-potable; or proper vegetation is selected for landscape to reduce irritation;

1----The water consumption data for the entire project is recorded.

6 Heat Island Alleviation

Benefits according to TBL:

- Environment: Improve the microclimate near the maintained pavement section.

Application:

☑ Asphalt	☒ Concrete	☒ Unpaved

Explanation:

There are three ways to reduce the heat island effect. First, increase additional vegetation; second, apply reflective materials to the pavement surface; third, apply open-grid, permeable pavement or other types of pavement structure with similar functions.

Related Indicators:

T-3

How To Measure:

See if any activity is conducted to alleviate the heat island effect during maintenance project.

Possible Points:

0~1

Rating Strategy:

0----Heat island effect is ignored during maintenance project in urban areas;

1----Heat island effect is considered and the alleviation technique is well implemented in maintenance project.

Resources:

U.S.EPA, Heat Island Compendium.

https://www.epa.gov/heat-islands/heat-island-compendium

B.5 Category Environment

Category Environment is to deal with any kind of pollution resulted from maintenance project to environment and people. This category is aimed to remove as much negative impacts of maintenance activities on surrounding nature and community as possible.

1 Wastes

Benefits according to TBL:

- Economy: encourage appropriate disposal of solid and liquid waste resulted from maintenance activities.
- Environment: minimize the pollution of the wastes generated by maintenance activities on the environment.
- Society: prevent the negative impacts of the wastes generated by maintenance activities on the nearby community.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Wastes in PSIM mean the materials that will not be used on the same project or any other similar pavement construction project; the materials are not wasted if they are recycled or reused on the same or any other pavement construction project. Both solid and liquid waste is discussed under this indicator.

Examples of solid waste resulted from maintenance activities include but are not limited to waste from repairing existing pavement (asphalt or concrete mixture), utility and appurtenance waste (such as pipes, cables, guardrails, signs), metals, plastic, excess earthen material, removed vegetation, and packaging of materials or devices. Routine maintenance might involve solid waste including litter, debris, sediment, animal carcasses, abandoned vehicles, etc.

Solid waste should be either collected by project team or person in charge and then sent to certain facilities, or managed by waste management company. In the former case, how to treat, store, or dispose the wastes should be kept on record; in the latter case, all waste handling invoices should be kept.

The storage locations for wastes and recyclable materials shouldn't be the same.

Liquid waste and saturated waste resulted from maintenance activities should be appropriately treated and disposed before getting into drainage system or natural water bod. How to treat and dispose those wastes should be kept on record. All invoices should be filed if waste management company is involved.

Safe storage areas and disposal should be provided for hazardous waste, such as painting or marking that contains lead, treated wood waste, and contaminated earthen material.

Example:

June 19, 2015

Fern Valley Road & Shepherdsville Road, Louisville, KY

After a utility cut restoration project at the intersection of Fern Valley Road & Shepherdsville Road in Louisville, KY, asphalt wastes and some other garbage were left along the curb and on the turf outside the curb.

Related Indicators:

How To Measure:

See if the waste is well disposed or treated.

Possible Points:

0~6

Rating Strategy:

0----Wastes are still observed without appropriate treatment after finishing the project;

2----Any type of wastes is well disposed, a maximum of 6 pts can be earned;

2----Hazardous wastes are well treated and disposed if there is any, a maximum of 6 pts can be earned under this indicator.

Resources:

Caltrans. Special Provisions for Hazardous Waste and Materials Requiring Special Management or Safety Precautions.

http://www.dot.ca.gov/hq/env/haz/hw_sp.htm

2 Air Quality

Benefits according to TBL:

- Environment: Reduce air pollution.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Various regulations or standards have been established for air quality control such as NEPA (National Environmental Policy Act) and CAA (Clean Air Act). Pollutants in the air caused by pavement maintenance activities include emissions, smoke, and dust.

The emissions might come from construction equipment and vehicles used by working crew.

The smoke might result from in-place recycling of asphalt pavement.

The removing, hauling, and stockpiling of certain materials (such as soil), or certain maintenance techniques (such as milling, and grading) might generate dust. Dust can always be observed during the maintenance of gravel and dirt pavement. Dust discussed here refers to Particulate Matter (PM) and it might have negative impacts on human health, crops, certain scientific experiments, and certain industrial operations.

The practices to improve air quality include economical energy-efficient construction equipment, preventing materials that may cause air pollution to be exposed to the air, and adopting dust control practices.

Dust control practices include reducing the speed of construction equipment and traffic on dusty surfaces, wetting dusty surfaces by water or other wetting agents, covering dusty materials during hauling and stockpiling, and planting vegetation at exposed areas (if applicable).

Directional dust monitoring is recommended to differentiate between dust resulting from maintenance activities and from local resources. Directional dust gauge can be used for this purpose, and the results should meet the requirements from NAAQS (National Ambient Air Quality Standards).

Related Indicators:

How To Measure:

See if air quality is considered during the project.

Possible Points:

0~4

Rating Strategy:

<table>
<tr><td>Components</td><td>Emissions</td><td>Smoke</td><td>Dust</td></tr>
<tr><td>Maximum points</td><td>1</td><td>1</td><td>2</td></tr>
<tr><td rowspan="2">Possible points</td><td colspan="3">0 pt if any type of air pollution is observed without according remediation.</td></tr>
<tr><td>1 pt if half of construction equipment and vehicles are energy-efficient or using alternative technologies.</td><td>1 pt if materials with potential of air pollution are well protected.</td><td>1 pt if Dust control activity is observed;
1 pt if directional dust monitoring is conducted</td></tr>
</table>

3 Noise Control

Benefits according to TBL:

- Environment: Alleviate the noise level from traffic or construction.
- Society: Reduce the disturbance and annoyance to pavement users, working crew, and neighbors.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Long term and high exposure to noise might lead to annoyance and health problems. Two types of noise might happen during maintenance construction work, traffic noise and construction noise.

Traffic noise is mainly caused by the interaction between tires and pavement surface, it annoys pavement users (motorists, pedestrians, and bicyclists) and nearby community. Both the noise source (type and smoothness of pavement surface) and the noise transmission path can influence the noise level.

For the community close to highway, noise barrier can be considered, especially for those noise-sensitive areas. Points can be awarded under Category Material if recycled materials are used to build noise barrier. Traffic noise can be mitigated from the source by adopting quiet pavement, such as stone-matrix asphalt, open-graded friction course (OGFC), rubberized asphalt, and other types of design with similar function.

Maintenance activities may cause construction noise, which may disturb pavement users, workers, and nearby communities. Construction noise can be mitigated by adopting the equipment with lower noise and by limiting the usage of noisy equipment within certain time periods of the day (project team might negotiate with the nearby community to determine this), or by adopting temporary noise barrier or curtain.

Any type of monitoring (by sensors) and control of noise level throughout the project is recommended.

Those particularly noisy maintenance activities are recommended to be conducted during daytime.

Related Indicators:

How To Measure:

Measure the noise level on site, and check whether the project team keeps of record of traffic and construction noise.

Possible Points:

0~4

Rating Strategy:

Components	Traffic noise		Construction noise
	Quiet pavement	Noise barrier	
0 pt	If no action is conducted to mitigate noise.		
Maximum pts	1	1	2
Possible pts	1 pt if quiet pavement is built for the maintained section.	1 pt if noise barrier is built for the maintained section.	1 pt if construction equipment generating lower noise is adopted; 1 pt if a schedule of using noisy equipment is established; 1 pt if temporary noise attenuation is adopted during construction; 1 pt if the construction noise is monitored during the project
+1----Noise at the most affected noise sensitive receptors meets the requirements.			

Resources:

Caltrans. Environmental Handbook, Volume I: Guidance for Compliance, Chapter 12 Noise. http://www.dot.ca.gov/ser/vol1/sec3/physical/ch12noise/chap12noise.htm

FHWA. Highway Traffic Noise: Analysis and Abatement Guidance. http://www.fhwa.dot.gov/environment/noise/regulations_and_guidance/analysis_and_abatement_guidance/revguidance.pdf

FHWA. Highway Construction Noise Handbook. http://ntl.bts.gov/lib/34000/34300/34369/DOT-VNTSC-FHWA-06-02.pdf

Noise, Center for Environmental Excellence by AASHTO. http://environment.transportation.org/environmental_topics/noise/

4 Vibration Control

Benefits according to TBL:

- Environment: Alleviate the vibration level.
- Society: Reduce vibration-related discomfort for pavement users, working crew, and surrounding neighborhoods.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Vibration can always be noticed but ignored during pavement construction projects. It's worth attention since vibration may cause discomfort to pavement users and damages to structures. Unfortunately, not all of the construction vibration can be avoided.

A vibration notice to the neighbors is recommended to be shown to the public as early as the project team decides to use any construction equipment that generates vibration in the project.

Construction vibration can be mitigated by adopting the equipment with lower vibration and by limiting the usage of equipment generating vibration within certain time periods of the day (project team might negotiate with the nearby community to determine this). Any type of monitoring (by sensors) and control of vibration throughout the project is recommended.

Related Indicators:

How To Measure:

Measure the vibration on site, and check whether the project team keeps of record of vibration.

Possible Points:

0~2

Rating Strategy:

+1----Construction equipment generating lower vibration is adopted;

+1----A schedule of using equipment that generates vibration is established, and construction vibration is monitored during the project

5 Erosion and Sediment Control

Benefits according to TBL:

- Economy: Reduce the repair costs caused by erosion and sediment.

- Environment: Reduce the erosion and sediment during and after the construction.
- Society: Reduce the danger from unstable slope.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Erosion control tries to prevent the dislodging of earthen materials, while sediment control deals with earthen materials after they are dislodged and in suspension. Since the reasons of erosion or slope instability are similar, and slope stability can be also enhanced if appropriate erosion control and sediment control are conducted, so pavement slope treatment is also discussed under this indicator.

When the project is located at steep rolling topography (especially high embankment or deep cut), the drainage system directly enters into adjacent waterbodies, the earthen materials are then erosive. Temporary erosion and sediment control are recommended during the construction. Permanent measures are recommended after the pavement maintenance.

Most of the State's Department of Transportation published manuals or guidelines for erosion and sediment control for pavement construction. Common techniques of erosion control include grass seeding, mulch and compost, geotextiles, check dams, wattles or fiber rolls, straw bale barriers, silt fences, chemical soil stabilizers, soil bioengineering, mechanical stabilization (such as retaining wall), and earthwork techniques (such as bench slope). Normal practices of sediment control include using biofilter or sand bags, construction entrance, dewatering, filter berm, inlet protection, oak mats, pre-fabricated or gravel barrier, sediment basin, sediment fence, sediment trap, tire wash facility, and wattles. The methods of slope stabilization include geosynthetics (such as geogrids and fabrics), cementitious stabilization, chemical stabilization, and fractured slab techniques (such as crack-seat and rubblization) (Reid, et al., 2015).

Related Indicators:

How To Measure:

See if there is any slope control document on file.

Possible Points:

0~4

Rating Strategy:

Components	Temporary measures during construction	Permanent measures
Maximum points	2	2
Possible points	1 pt for adopting each type of temporary measures for erosion or sediment control during maintenance, a maximum of 2 pts can be earned	1 pt for finishing each type of permanent measures for erosion control, sediment control, or slope stabilization, a maximum of 2 pts can be earned

Resource:

U.S. Department of Agriculture. Erosion Control Treatment Selection Guide.

https://idot.illinois.gov/Assets/uploads/files/Transportation-System/Manuals-Guides-&-Handbooks/T2/L034%20Erosion%20Control%20Treatment%20Selection%20Guide.pdf

Illinois Department of Transportation. Erosion and Sediment Control Field Guide for Construction Inspection.

http://www.idot.illinois.gov/Assets/uploads/files/Transportation-System/Manuals-Guides-&-

Handbooks/Highways/Environment/Erosion%20and%20Sediment%20Control%20Field%20Guide%20for%20Construction%20Inspection.pdf

Minnesota Pollution Control Agency. Temporary Construction Erosion and Sediment Control.
http://stormwater.pca.state.mn.us/index.php/Temporary_construction_erosion_and_sediment_control

6 Ecology Conservation

Benefits according to TBL:

- Environment: Conserve ecology system by minimizing the negative impact resulted from project.
- Society: Benefit the long-term wellbeing for the whole society with better ecology environment.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

The primary purpose of this indicator is to lower the negative impacts of maintenance activities on ecology (flora and fauna) and structures protecting ecology. Field investigation at construction site for existing site-specific ecological assessment is recommended before implementing the construction process. Ecological investigation can provide project team a general understanding of surrounding ecological situation. Ecological disturbance due to inappropriate maintenance activities can be largely eliminated by modifying maintenance plan based on the investigation results.

There are three levels of requirements under this indicator:

- Avoid impacts of maintenance activities on ecology;
- Minimize impacts of maintenance activities on ecology if such impacts cannot be avoided, such as reusing the vegetation and top soil that was removed earlier.
- Implement new ecological features for pavement system to achieve "environmental net gain", such as the practices of increasing biodiversity and wildlife habitats; upgrade existing wildlife fencing or other structures; improve deficient or inadequate planting.

Ecological protection should be considered ahead of and during the project by protecting or restoring existing animal habitats and vegetation. Cultivating new vegetation is also recommended when necessary. If existing animal habitats or vegetation must be removed, project teams should consult environment-related agencies for relocation.

The project team or person in charge should work with property owner, qualified ecologist (or environmental consultant), or appropriate organization or agency to see what species will be affected and how to minimize the impacts. Buffer area might be considered around work zone, temporary parking place of construction equipment, or material storage area if necessary.

Native vegetation is preferred if available to avoid the costs, energy consumption, and emissions caused by shipping. Native plant species are also beneficial to local ecosystem, because they are able to well adapt to local climate and soil, and are familiar to local animal species. INVEST V1.2 PD-18 recommends that "plants native to the EPA Level III ecoregion per the EPA's Level III and IV Ecoregions of the Continental United States website that contains the roadway project site or known to naturally occur within 200 miles of the roadway construction site".

The project team should refer to local vegetation policy to prevent invasive species, including noxious weeds, during site vegetation, since they can be harmful to local ecosystem (USNA, 2008).

The extreme case would happen in maintenance projects in the sensitive areas, the impacts of maintenance activities on natural environment must be minimized. If the project is located in or next to wetlands, nature parks, environment-sensitive areas, or other valuable landscapes, the project team or person in charge should refer to the original documents of pavement design and construction to see relevant information. If new vegetation is required under such circumstances, only should those free of dirt, mud, and organics be considered.

Example:

June 14, 2015

320 E Kenwood Drive, Louisville, KY

Sometimes the turf adjacent to the pavement is disturbed or even destroyed by maintenance activities. As for the maintenance project on Kenwood Drive in Louisville, KY, there was evidence that some kind of construction equipment was running over the turf, and the inspector did not see any effort to restore the turf on the following three days.

Related Indicators:

How To Measure:

See if there is any guideline for ecological protection.

Possible Points:

0~6

Rating Strategy:

-1----The damage to natural ecological system could have been avoided;

0----Maintenance activities cause damages to natural ecological system with no following remediation;

+2----Effort has been made to minimize ecological disturbance;

+2----Project team conducts the ecological investigation;

+2----Ecological situation is improved after finishing maintenance.

B.6 Category Safety

The importance of safety during any construction cannot be exaggerated. A maintenance project affects the pavement users, working crew, and the people staying in nearby community, Category Safety is designed to maximize the safety for all those three groups of people throughout the construction, so that fatal and serious injuries as well as public and private property damage can be minimized. Also, economic and social impacts from accidents will be reduced by the safety improvements.

1 Traffic Control

Benefits according to TBL:

- Economy: Increase construction efficiency and save energy costs of traffic vehicles by appropriate traffic control.
- Environment: Effective traffic control results in reduction of fuel consumption and related emissions.
- Society: Improve the safety at work zone, alleviate possible congestion, prevent road rage, and improve customer satisfaction.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

During pavement maintenance, pavement users and working crew focus on different things, but well conducted traffic control is able to balance the time of traffic interruption and construction efficiency and effectively keeps pavement users and working crew apart, so that the impact of one group on another will be minimized.

The interruption of maintenance activities on pavement users will cause safety problems. Pavement users will have little time reacting to emergencies if the traffic control is inappropriate. Motorists will be in bad temper (which is called road rage) if long delay happens due to ineffective traffic control. Motorist with road rage is more likely to drive aggressively which will put himself/herself, other pavement users, and even working crew in danger.

Ineffective traffic control will also cause environmental problems. Once being delayed and slowed down, the vehicles in traffic flow will consume more energy and produce more emissions.

Sometimes street parking should be paid attention, which should not affect the operation of construction equipment and traffic flow. Special traffic control should be considered if pavement is in bad situation (such as collapse and snow/ice), or if large vehicles (such as freight vehicles, buses, agricultural or industrial equipment) are passing the work zone.

A report of traffic control is recommended to be prepared by the flagger or the involved traffic control company. The details of lane change/closure, detour, congestion reduction methods, and implementation/maintenance/removal of traffic control devices should be described in the traffic control report.

The notification of changes of traffic pattern is discussed under Category Community.

Example:

June 20, 2015

Preston Highway & Belmar Drive, Louisville, KY

Although it was Saturday when the photo was taken, the traffic cones should not be left as shown in the photo, some traffic cones even blocked the traffic flow. Traffic control devices are useless or even harmful to traffic flow if they are not appropriately used.

Related Indicators:

How To Measure:

See if there is any traffic control document on file.

Possible Points:

0~10

Rating Strategy:

0----No traffic control on site, or accident happens due to traffic control problem;

4----Sufficient traffic control devices are installed

4----Traffic control is well conducted by certified and well trained flaggers;

2----Traffic control report is provided.

2 Construction Safety

Benefits according to TBL:

- Society: Improve the safety construction activities.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Everyone involved in the project/program must be trained with safety guideline prior to entering construction site. However, safety training is discussed under Category Management, this indicator evaluates the behaviors of working crew.

Working crew should follow the regulations of construction and equipment operation at work zone. People entering work zone should behave appropriately to keep other co-workers and themselves safe and healthy.

Fire extinguisher and other necessary safety equipment must be available at all time during construction.

If any injury, death, equipment error, property damage, or environmental disturbance happens due to unsafe behaviors, the information of the accident must be kept on record.

Related Indicators:

Mn-8

How To Measure:

Inspect whether there is a safety guideline for construction procedure.

Possible Points:

0~10

Rating Strategy:

0----There is any behavior during the project that might cause any kind of injury, death, equipment error, property damage, or environmental disturbance;

10----Safety rules are well implemented by working crew, and no accidents happens due to unsafe behaviors.

-2----Working crew partially obey safety rules, and no accidents happens due to unsafe behaviors, 2 pts deducted if any type of behavior against safety rules is observed.

Highway Safety Manual. AASHTO.

http://www.highwaysafetymanual.org/Pages/default.aspx

Maintenance Manual Volume 1, Chapter 8 Protection of Workers. Caltrans.

http://www.dot.ca.gov/hq/maint/manual/2014/10_Chpt-8_and_Appendix_T9-T17_July_2014.pdf

3 Pavement Marking

Benefits according to TBL:

- Environment: Control the VOC (volatile organic compounds) content within traffic markings to reduce the harm to workers and environment.
- Society: Restore pavement markings to provide proper functions.

Application:

☑ Asphalt	☑ Concrete	☒ Unpaved

Explanation:

Removal and restoration of traffic markings, such as lane marking and zone marking, are considered under this indicator. There are different types of pavement marking materials: solvent-based paints, water-based paints, thermoplastics, and preformed tapes.

Low-VOC marking materials emit fewer smog-producing compounds, which will be less hazardous to working crew and pavement users. Although the federal government set a 150 g/l limit on VOCs on traffic paint, the adopted marking materials are recommended to meet a 100 g/l suggested by EPA and SCAQMD (South Coast Air Quality Management District). The pavement marking materials are also recommended to be certified by State Department of Transportation.

Since pavement marking materials belong to construction materials, they should also be evaluated under the indicators of M1, M3, and M4.

Related Indicators:

How To Measure:

See if all the traffic markings involved are carefully removed and restored.

Possible Points:

0~7

Rating Strategy:

0----Pavement markings are removed during maintenance but new pavement markings are not installed;

+2---- Pavement markings are restored by certified or trained technicians;

+2----Pavement markings with high retroreflectivity are installed by certified or trained technician;

+1----The marking materials are certified by State Department of Transportation;

+2----VOC content in the marking materials is less than 100 g/l.

Resources:

Maintenance Manual Volume 1, Section M-1 Pavement Delineation. Caltrans.

http://www.dot.ca.gov/hq/maint/manual/2014/28_Chpt_M_July_2014.pdf

4 Appurtenances

Benefits according to TBL:

- Society: Improve the roadway and roadside safety.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Pavement appurtenances are accessories to roadways and important components of pavement system. They can be classified into two categories: roadway appurtenances and roadside appurtenances. Roadway appurtenances include curbs, barriers, guardrails, glare screens, pavement markings and markers, rumble strips, attenuators, and speed bumps, while roadside appurtenances include signs, traffic signals, lighting poles, delineators, noise barriers, and fences.

Glare screen, pavement marking, and noise barrier are discussed under other indicators.

Appurtenance investigation is recommended to be conducted prior to the project getting started to evaluate the service condition of existing appurtenances. Road Safety Audits (RSA) is an example of such investigation to address potential safety problems and to recommend improvements.

Improving existing ones, restoring disturbed ones, and introducing new ones are the options. The measures that can be adopted include installing safety facilities or add-ons especially at intersections, removing obstacles (such as vegetation and illegal advertising) that block the motorists' sight to signals/signs especially at curves and intersections.

Evaluation of safety improvements or actions can be done by either the predictive methods from AASHTO HSM or the AASHTO tool Safety Analyst.

Related Indicators:

How To Measure:

See if the roadway appurtenances are properly maintained or improved.

Possible Points:

0~10

Rating Strategy:

Components	Existing appurtenance is restored or maintained	Existing appurtenance is improved	New Appurtenance is installed
Maximum pts	3	3	3
Possible pts	1 pt if one type of appurtenance is restored or maintained, a maximum of 3 pts can be earned	1 pt if one type of appurtenance is improved, a maximum of 2 pts can be earned; 1 additional pt if evaluation of safety improvements is conducted	1 pt if one type of appurtenance is installed, a maximum of 3 pts can be earned
+1	Appurtenance investigation is conducted before starting the project		

Resources:

Road Safety Audits. FHWA. http://safety.fhwa.dot.gov/rsa/

FHWA Road Safety Audit Guidelines. FHWA-SA-06-06.

http://safety.fhwa.dot.gov/rsa/guidelines/documents/FHWA_SA_06_06.pdf

Chapter 8. Project Development and Design Manual. FHWA.

http://flh.fhwa.dot.gov/resources/design/pddm/

Highway Safety Manual. AASHTO.

http://www.highwaysafetymanual.org/Pages/default.aspx

Safety Analyst. AASHTO. http://safetyanalyst.org/index.htm

5 Pedestrians and Bicyclists

Benefits according to TBL:

- Society: provide safe and comfortable environment for pedestrians and bicyclists at all ages.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

30% ~ 40% of people in most states don't own a car. These people use the pavements as pedestrians or bicyclists. As another groups of pavement users, pedestrians and bicyclists should be given the same priority as motorists, especially when the maintenance involves not only pavement repair but also other ancillary facilities such as sidewalks and bicycle lanes.

The group of pedestrians also includes people with age or functional disabilities that reduce a person's mobility, sight, or hearing.

There are two components under this indicator: safety and comfort of pedestrians and bicyclists during and after the maintenance project.

During the maintenance project, the most important influence factors for the safety of pedestrians and bicyclists are the traffic flow of vehicles and the maintenance activities. The disturbances for normal pedestrian and bicycle activities might be minimized by advance warning, channelizing and barricading, temporary curb ramps, temporary walkways and bikeways, diversions and detours, and measures preventing old people or people with disabilities from entering work zones.

The maintenance project might involve new features to facilitate the transportation of pedestrian and bicycle. Practices to improve pedestrian safety include narrower lanes, curb extensions, pedestrian medians, and crossing islands (Reid, et al., 2015). Practices to improve bicyclist safety include bicycle-friendly drains, traffic calming features, buffered or separated bicycle lanes, intersection treatments (bike boxes, median refuge islands, or through bike lanes), and colored bike lanes (Reid, et al., 2015). Appurtenant signs, signals, or markings should be provided if necessary.

Related Indicators:

How To Measure:

See if any safety improvement guideline is written for pedestrians and bicyclists.

Possible Points:

0~8

Rating Strategy:

Components	Safety of pedestrians and bicyclists during project	Improvements of facilities for pedestrians	Improvements of facilities for bicyclists
Maximum pts	2	3	3
Possible pts	The implementation of each type of measures mentioned in this indicator will earn 1 pt, a maximum of 2 pts can be earned	The implementation of each type of measures mentioned in this indicator will earn 1 pt, a maximum of 3 pts can be earned	The implementation of each type of measures mentioned in this indicator will earn 1 pt, a maximum of 3 pts can be earned

Resources:

Bicycle and Pedestrian Program. FHWA.

http://www.fhwa.dot.gov/environment/bicycle_pedestrian/

Manual and Uniform Traffic Control Devices. FHWA.

http://mutcd.fhwa.dot.gov/pdfs/2009r1r2/pdf_index.htm

Americans with Disabilities Act (ADA) Standards for Accessible Design. U.S. Department of Justice. http://www.ada.gov/2010ADAstandards_index.htm

6 Drainage

Benefits according to TBL:

- Environment: Improve flow control and runoff quality.
- Society: Remove the safety problems caused by the water left on the pavement.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Water should be removed from pavement surface effectively during and after raining. Water left on pavement surface will cause hydroplaning with is dangerous for vehicles at high speed. Also, water splash caused by vehicles will affect the comfort of other pavement users.

Drainage system includes surface, subsurface, and roadside drainage facilities such as open channels, ditches, underdrains, culverts, gutters, catch basins, drop inlets, manholes, sewer pipes, and other storm water management facilities. If the maintenance project involves or is close to the drainage system, disturbance to the drainage facilities should be minimized, such as leaving wastes into sewer, removing pavement crown, and damaging or blocking drainage facility.

New drainage facilities can be installed to help alleviate the gathering of storm water quickly.

Permeable pavement can be used for storm water management. Examples of permeable pavement are porous asphalt pavement, pervious concrete pavement, and permeable pavers. Permeable pavement is highly recommended for parking lot, alley, sidewalk, and bike lane. Permeable pavement must be maintained appropriately to prevent clogging.

Related Indicators:

How To Measure:

See if any drainage improvement guideline is written.

Possible Points:

0~10

Rating Strategy:

Components	Disturbance of existing drainage system	Improvements of drainage system
Maximum pts	4	6
Possible pts	0 pt if any activity impairing the drainage capability is observed without remediation; 4 pt if the drainage capability is impaired during maintenance but remediation is conducted	1 pt if rubbish and debris in the drainage system are cleaned; 2 pt if one type of new drainage facilities is installed, a maximum of 4 pts can be earned; 1 pt if permeable pavement is installed

7 Glare Control

Benefits according to TBL:

- Environment: Reduce light pollution
- Society: Reduce the glare to improve safety of pavement users and comfort of neighbors.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Glare is a visual sensation caused by excessive and uncontrolled brightness, which is one type of light pollution and might be disabling (for pavement users) or uncomfortable (for neighbors). Although there are many things to do to reduce glare from the motorists' perspectives, maintenance activities can also contribute to glare control. Two components are discussed under this indicator, glare from oncoming vehicles and glare from construction lighting.

Headlamp and auxiliary lighting from oncoming vehicles bother many motorists especially at night. This type of glare reduces the visibility of pavement users so that it increases the risk of accident. Planting or artificial glare screens are recommended to be implemented on median or at intersections. Planting glare screens must not disturb the view of pavement users during daytime. Artificial glare screens must be fastened to the structure according to manufacturer's instructions.

The lighting luminaires for construction activities are often very bright to ensure the visibility of working crew. 23 State Department of Transportation realized construction lighting was a problem. The construction lighting is recommended to be aimed to work zone. Shields, louvers, or visors can be used to reduce the impact of excessive light on the pavement users.

Examples:

August 26, 2015

Crittenden Drive & Eastern Parkway, Louisville, KY

The photo shown above was taken by the inspector while waiting for the traffic lights. It took several seconds for the inspector to realize the traffic had already turned to green, because the construction light was so bright and dazzling that the inspector could barely see anything.

Related Indicators:

How To Measure:

See if any glare control action is conducted on site.

Possible Points:

0~2

Rating Strategy:

Components	Glare from oncoming vehicles	Glare from construction lighting
Maximum pts	1	1
Possible pts	1 pt if planting or artificial glare screen is implemented and there is no negative impacts on pavement users during daytime	0 pt if the construction lighting disturbs normal activities of pavement users and neighbors

Resources:

National Highway Traffic Safety Administration. Nighttime Glare and Driving Performance.

http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2007/Glare_Congressional_Report.pdf

Ibrahim Sameer Mohammad Odeh. Evaluation of Glare And Lighting Performance In Nighttime Highway Construction Projects.

https://www.ideals.illinois.edu/bitstream/handle/2142/15534/1_Odeh_Ibrahim.pdf?sequence=3

8 Snow and Ice Removal

Benefits according to TBL:

- Environment: Reduce the environmental harms brought by inappropriate deicers.
- Society: Restore pavement roughness and improve vehicle traction.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Deicers and abrasives are used for winter maintenance, which is typically for snow and ice removal. Two components are discussed under this indicator, deicing materials and route priorities.

Abrasives (sand, crushed gravel, grit, and cinders) only improve vehicle traction but do not offer deicing function, the application of abrasives also causes environmental and traffic problems, such as plugging drainage system, generating silica dust, uneven driving surface, repetitive application, and others. Therefore, abrasives are not recommended to use for winter maintenance.

Chlorides are typically used by transportation agencies as deicers. However, the chloride component of chloride-based deicers (sodium chloride, magnesium chloride, and calcium chloride) "does not easily precipitate. Plus it is not biodegradable, is not readily involved in biological process, and does not adsorb significantly to mineral/soil surface". The cation components of chloride-based deicers (sodium, magnesium, and calcium) are corrosive and can also impact the environment. Therefore, chlorides could negatively affect soils, vegetation, animals, air, and water bodies.

As a type of acetates, calcium-magnesium acetate (CMA) is recommended by LEED due to its low environmental impact. If CMA is not available, LEED recommends those deicers that "contain less than 5% sodium chloride, calcium chloride, magnesium chloride, potassium chloride, potassium acetate, ammonia-based products, and ferrocyanide products".

In order to maximize the effectiveness of equipment and labor, project team is recommended to assign priorities to winter maintenance routes. Optimal routes might be designed for snow and ice removal to save energy, reduce emission, and reduce relevant costs.

Avalanche control should be discussed under the indicator of Emergency Dealing.

Damage to property should be discussed under the indicator of Disturbance and Repair.

Related Indicators:

How To Measure:

See if deicing materials are properly selected and route priorities are established.

Possible Points:

0~5

Rating Strategy:

Components	Deicing materials	Route priority
Maximum pts	3	2
Possible pts	2 pt if the deicing materials are approved by transportation agency and applied by trained technician; 1 pt if deicers meet the LEED recommendations	2 pts if the route priority for snow and ice removal is established and implemented

Resources:

Snow and Ice pooled Fund Cooperative Program. AASHTO.

http://sicop.transportation.org/Pages/default.aspx

Snow and Ice Control: Guidelines and Methods. NCHRP Report 526.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_526.pdf

Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water. MDT. FHWA/MT-04-008/8117-19.

https://www.mdt.mt.gov/other/webdata/external/research/docs/research_proj/traction/final_report.pdf

Maintenance Manual Volume 1, Chapter R Snow/Ice Control. Caltrans.

http://www.dot.ca.gov/hq/maint/manual/2016/29_Chap-R_Jan_2016.pdf

Deicing Materials on Michigan Roads. Michigan Department of Transportation.

http://www.michigan.gov/mdot/0,1607,7-151-9622_11045-57246--,00.html

B.7 Category Community

Category Community focuses on the pavement users and people who are living or working near the maintenance project. It is designed to improve convenience and comfort when those people are passing or staying near the work zone. Indicators under Category Community are also designed to promote customer satisfaction, community development (economy and culture) and sustainability awareness.

1 Report the Problem

Benefits according to TBL:

- The deteriorated pavement can be detected and maintained without delay.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Although transportation agencies or other pavement owners may have their own crew to detect and report the pavement deterioration, there is always lag between formation and discovering of the deterioration. Public are always the first ones to find problems on pavements. If the information can be collected and reported to responsible agencies quickly and conveniently (such as website, mobile app, phone, and social media), the agencies will plan and conduct the pavement maintenance in time, so that public complaints can be reduced, and economic and environmental impacts associated with traveling on deteriorated pavement can be reduced.

Related Indicators:

How To Measure:

See if there is a way for public to report the pavement deterioration.

Possible Points:

0~1

Rating Strategy:

0----No such existing channel for public to report the pavement deterioration;

1----Public are able to report pavement deterioration to responsible agencies; public reports of pavement deterioration are kept in files.

2 Landscape Maintenance

Benefits according to TBL:

- Environment: Improve surrounding ecosystem.
- Society: Encourage walking and bicycling.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

E6 focuses on the existing, surrounding natural environment, while C2 considers the impacts of site vegetation and corresponding maintenance on human.

This indicator can be referred to three types of activities: 1) pruning or removal of vegetation for safety purposes; 2) pesticide and fertilizer application; 3) other landscape maintenance and design activities.

First, landscape maintenance must consider the safety for pavement users. All of the existing vegetation and landscape design associated with the project must not obscure or limit a pavement user's view of the pavement condition, traffic control devices, approaching vehicles/pedestrians/bicycles, and animals (if applicable), especially at curves and intersections.

Second, fertilizer and pesticide have harmful effects on the environment if not properly selected and applied. Synthetic fertilizer or pesticide is not recommended. All fertilizers and pesticides (including herbicides, insecticides, fungicides, and rodenticides) are recommended to be certified by Department of Transportation or other agencies and to be applied by trained technician.

Third, good design of landscape could make pavement users feel more comfortable by providing scenery along the road. Air quality will also be improved by introducing vegetation.

Landscape design of pavement maintenance project might include, but is not limited to, roadside vegetation, median vegetation, decorative planting (such as decoration on retaining walls and noise barriers), and vegetation within storm water facilities (such as bioswales and rain gardens).

Landscaped buffer can be added to make pavement system safer and more comfortable for pedestrians and bicyclists. Adjacent topography should be considered during the landscape design.

Example:

May 4, 2016

South Preston Street & Harrison Avenue, Louisville, KY

Sometimes certain landscape design that improves service environment could bring safety issues. The tree circled in the photo was trimmed very well, but it blocked the view of those motorists who want to merge from Harrison Avenue to South Preston Street.

Related Indicators:

EW5, E6

How To Measure:

See if the landscape design is provided and implemented.

Possible Points:

0~4

Rating Strategy:

Components	Pruning for safety purposes	Fertilizer and pesticide	Other landscape maintenance and designs
Maximum pts	1	1	1 or 2
Possible pts	0 pt if any vegetation blocks or obscures a pavement user's view	1 pt if fertilizers and pesticides are approved by related agencies and applied by trained technician	1 pt if landscape is maintained or designed properly; 1 additional pt if landscape is maintained or designed properly in the sensitive area

Resources:

Vegetation Control for Safety. FHWA. FHWA-SA-07-018.

http://safety.fhwa.dot.gov/local_rural/training/fhwasa07018/

Roadside Use of Native Plants. FHWA.

https://www.environment.fhwa.dot.gov/ecosystems/vegmgmt_rdsduse.asp

Level III and IV Ecoregions of the Continental United States. EPA.

https://archive.epa.gov/wed/ecoregions/web/html/level_iii_iv-2.html

FHWA Guidance on Invasive Species. FHWA.

https://www.environment.fhwa.dot.gov/ecosystems/wildlife/inv_guid.asp

Introduced, Invasive, and Noxious Plants. USDA.

http://plants.usda.gov/java/noxiousDriver

National Invasive Species Information Center. USDA.

http://www.invasivespeciesinfo.gov/index.shtml

Hawaii Department of Transportation, Landscape Architecture Program.

http://hidot.hawaii.gov/highways/landscape-architecture-program/

Florida Department of Transportation, A Guide for Tree, Palm Maintenance for Urban Roadsides and Landscape Areas.

http://www.dot.state.fl.us/statemaintenanceoffice/RDW/Guide_LandscapeandTreeMaintenance.pdf

LEED v4 OM EQ Integrated Pest Management into a comprehensive introduction and related recommendations for pest control.

3 Aesthetic Design

Benefits according to TBL:

- Society: Provide comfortable environment for pavement users.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

This indicator is designed to involve aesthetic features into consideration and better serve pavement users during and after maintenance project.

During the project, construction site fences or panels can be used to enclose or secure the work zone for aesthetic and safety purposes. Customized fences or panels can be adopted if needed.

Roadway itself and roadside conditions can be improved in aesthetic perspective. As for the roadway itself, color and texture can be controlled by choice of binders and aggregates to match adjacent infrastructure or landscape styles, to improve visibility or warning function. For other components within the pavement system or adjacent structures (such as utility poles), stains and pigments can be used for aesthetic design or artwork. Patterned concrete, masonry, and rocks can be used for aesthetic purpose along with their original functions. Natural and artificial materials used for aesthetic design should refer to the discussions under Category Materials.

Inappropriate graffiti should be removed if necessary. Coating of anti-graffiti paint can be considered.

Aesthetic design should not be too dramatic because it might distract pavement users' attention from traffic conditions, signs, and signals.

Related Indicators:

How To Measure:

See if the aesthetic features are considered and improved during and after maintenance.

Possible Points:

0~2

Rating Strategy:

Components	Aesthetic during maintenance	Aesthetic improvement for the pavement
Maximum pts	1	1
Possible pts	1 pt if construction site fences or panels are installed during maintenance and removed after finishing the activities that need to be isolated	1 pt if the aesthetic features of either roadway itself or other components of pavement system are improved

Resources:

Maintenance Manual Volume 1, Chapter E Landscape. Caltrans.

http://www.dot.ca.gov/hq/maint/manual/2014/21_Chpt_E_July_2014.pdf

Guidelines For Aesthetic Design in Highway Corridors: Tools and Treatments For Texas Highways. Texas Transportation Institute.

http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/2113-3.pdf

4 Culture Conservation

Benefits according to TBL:

- Economy: Benefit local economy by attracting travelers to the cultural attractions.
- Society: Preserve, protect and promote cultural assets.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Cultural attractions and corresponding interpretation facilities are important to community's sense of identity, spiritual connection and historical significance (VicRoads, 2011), including local scenic spots, historic sites, archaeological resources, recreation places, and education institutions. Maintenance projects might involve activities that can preserve such attractions and enhance the satisfactions of community.

Sometimes pavement itself has cultural features, such as special texture or pattern, and designated materials. Project team should protect any cultural heritage from disturbance during maintenance activities or restore it after maintenance.

If the maintenance project is close enough to or passes by a cultural attraction, an effort should be made to minimize the impacts on the attraction (such as fencing or setting signboard) or restore the disturbed cultural features. There are three situations a project may touch upon historical or cultural attractions (Reid, et al., 2015):

- Listed in US National Register of Historic Places

Any part of the project or resource within the project boundaries is listed in the United States National Register of Historic Places (NRHP) or has been determined eligible for the National Register by a State, Local, or Tribal Historic Preservation Officer.

- Along America’s Byways ® or Equivalent

Any portion of the project belongs to one of America’s Byways® (National Scenic Byway or All - American Road), a State Scenic Byway, an Indian Tribe Scenic Byway, or other route that was designated or officially recognized as such because of its significant historic, cultural, and/or archaeological features.

- Historic and/or Cultural Significance to Community

Any part of the project or resource involved the project boundaries is recognized by the community as areas having historic, cultural, and/or archaeological significant meanings to the community.

If it is very difficult or impossible to remove negative impacts on adjacent cultural heritage and the heritage can be moved, such heritage is recommended to be relocated to appropriate and agreed (by relevant heritage stakeholders) place.

Example:

October 17, 2015

East Brandeis Avenue & South Floyd Street, Louisville, KY

East Brandeis Avenue and South Floyd Street run through the Belknap Campus of University of Louisville. There was a painted Cardinal logo at the intersection. However after a maintenance project in October 2015, part of the logo was cut. The Cardinal logo was not restored until early 2016.

Related Indicators:

How To Measure:

See if local cultural environment promotion is provided and implemented.

Possible Points:

0~3

Rating Strategy:

Components	Maintaining the pavement with cultural features	Maintaining the pavement adjacent to cultural attractions
Maximum pts	2	1
Possible pts	2 pt if cultural features of the pavement are protected or restored	1 pt if cultural heritage is appropriately protected or relocated, or cultural attraction is disturbed but is restored

Resources:

America's Byways. FHWA. http://www.fhwa.dot.gov/byways/

National Register of Historic Places. National Park Service. https://www.nps.gov/nr/

Environmental Handbook, Volume 2: Cultural Resources. Caltrans.

http://www.dot.ca.gov/ser/vol2/vol2.htm

5 Notification

Benefits according to TBL:

- Society: Make surrounding communities and pavement users to be informed of basic maintenance information.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Some essential information should be available to the public as early as the project schedule has been established, especially to pavement users and neighbors, including contractor and corresponding emergency contact information, start and finish date, working hours, pattern of traffic control, and scope of influence.

There are two types of notification that can be considered, onsite and non-onsite notifications. Signs, signboards, or tags can be left in project area, so that neighbors especially business owners have enough time to prepare for the change of traffic pattern. Traditional (such as radio and newspaper) and social media (such as Facebook and Twitter) as well as the website of involved agency (such as transportation department and Public Works) are recommended to provide those information mentioned above before and during the project construction.

Related Indicators:

How To Measure:

See if any notification is given.

Possible Points:

0~2

Rating Strategy:

0----No notification is provided;

+1----Onsite notification is provided as early as the project schedule has been established;

+1----Offsite notification is provided as early as the project schedule has been decided;

6 Ease of Use

Benefits according to TBL:

- Society: Make pavements easy to use by improving mobility and reducing congestion.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Ease of use means the users could save physical, cognitive, and affective effort when using pavement. This indicator considers any activities regarding on the convenience and comfort to use the pavement and other components within the pavement system.

Different groups of pavement users should be considered.

For example, new facilities or infrastructure that connect pavement to existing facilities or neighborhood can be constructed; appropriate lane management (left or right turning lane, carpool lane, and transit lane) can be adopted; public transportation connection can be installed.

Intelligent Transportation System (ITS) is another way to offer better service and make pavement easy to use. Proper implementation of ITS is able to reduce driving time by

minimizing congestion, to help plan route by collecting and processing traffic information, and to alleviate tension and impatience by dealing with uncertainties.
ITS means “electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system”.
There are different application categories for ITS, including (Reid, et al., 2015) electronic payment & pricing, emergency management/response & recovery, enforcement, information dissemination, information management, lane management, ramp control, road weather management, surveillance, traffic control, traffic incident management, traveler information, crash prevention and safety, and work zone management. If any ITS technologies are involved, the applied ITS technologies, benefits, and technology suppliers should be specified. Only the intelligent transportation system or devices that can be installed on the infrastructure within pavement system are eligible for points.
Example:

2010 (adapted from ASCE: 2013 Report Card for America’s Infrastructure: Roads)

Atlanta, GA

In June 2010, smart signal control had been successfully implemented in 29 intersection along an 8.2-mile-pavement in Atlanta, GA. The project was expected to save $5.9

million each year on the reduction of travel times, and achieve 34% reduction in fuel consumption as of 2013.

Related Indicators:

How To Measure:

See if any improvement on pavement usability is implemented.

Possible Points:

0~1

Rating Strategy:

1----Any type of facility that can improve pavement usability is implemented into the pavement system.

Resource:

ITS Applications Overview. USDOT. http://www.itsoverview.its.dot.gov/

7 Community Adaptation

Benefits according to TBL:

- Economy. Support local businesses and community development. Conserve the financial resources required for infrastructure.
- Society. Reduce the negative impacts of maintenance activities on communities. Provide convenient and safe connections between pavements and other infrastructures.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Based on the surrounding communities, pavement might be built as normal roadways (such as streets and highways), sidewalks, parking lots, playground, trails, scenic/recreational pavements, runways, bridge deck pavements, and tunnel pavements. Communities' needs vary as the type of pavement changes.

There are two types of community needs that should be considered to guide maintenance activity, one is from infrastructure (such as adjacent railways or utilities) and the other comes from neighbors.

The pavement section that needs to be maintained might influence other infrastructure, such as other pavements (intersections of paved and paved, unpaved and unpaved, paved and unpaved), railways, tunnels, bridges, ferries, and utilities. Special considerations should be conducted at these access points, because construction materials or/and traffic directions are different at edges, which might lead to unpredictable distresses or failures. Also, the pavement maintenance construction should not affect the normal operation of other infrastructure. If such affection is unavoidable, advance notice and appropriate remediation are recommended.

The neighbors might be residences, schools, stores, shopping malls, office buildings, warehouses, hotels, hospitals, recreation areas, and natural landscape. The neighbors often have their own particular concerns on pavements, which should be considered as early as field investigation starts before the maintenance activity. For example, a busy parking lot for a company building will be overlaid, the working crew can divide the parking lot into two areas, and work on the second half after the first one is open to the traffic. A survey is recommended to be conducted before the project in nearby communities to find out their concerns.

Community investigation is recommended to promote community engagement. The investigation should provide guidance (VicRoads, 2011) on who should be contacted, how to invite them to become involved, what project information to give them, and the process of involve community opinions (collection, assessment, and feedback). Complaints from adjacent community and feedback from project team should be considered for timely two-way exchange.

Related Indicators:

How To Measure:

See if the needs from adjacent communities are considered.

Possible Points:

0~4

Rating Strategy:

0----No consideration on adjacent community;

+1----People from other adjacent infrastructure or neighbors are able to travel with minor delay compared to normal traffic;

+1----Complaints are well received and handled;

+2----Community investigation is conducted before the project to involved community engagement and give project team a general idea of the neighbors.

Benefits according to TBL:

- Society: Promote and educate the concept of sustainable pavement maintenance to the public.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Increasing public awareness of the implementing sustainability principles into pavement maintenance projects is as important as making those projects sustainable. There are different ways to promote sustainable projects and the idea of sustainability to the public, such as:

- Signboard. Install and maintain off-road signboard displaying the PSIM certification level (if applicable) and the information about the sustainability features of the project;
- Website. The project information can be included on a publicly available website which is able to receive feedback and comments;
- Public presentation. Project team or person in charge might give presentation to the public, to the interested teachers and students, or to the maintenance-related professionals

No matter which approach is taken, the promotion documents (electronic or printed reports, flyers, or newsletters) stating the sustainable practices during the project should be well developed and stored.

Related Indicators:

How To Measure:

See if sustainability practices during the project is promoted.

Possible Points:

0~1

Rating Strategy:

0----No consideration on sustainability promotion;

1----The documents to promote public awareness of sustainability are well developed and stored, and any of the three types of promotion activities are conducted.

B.8 Category Innovation

Category Innovation discusses any creative and practical idea that can be applied to maintenance to improve sustainability. If the project team or person in charge decides to involve a new idea, the proof of sustainability improvements must be provided to PSIM developer.

1 Creative Idea

Benefits according to TBL:

- Encourage any idea that can potentially improve the sustainability of pavement maintenance while still can guarantee good pavement performance.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

All stakeholders are encouraged to work collaboratively on solutions that integrate sustainability practices into pavement maintenance activities. Any creative idea with the potential to improve sustainability of maintenance not included in this rating tool can be considered to earn points under this indicator, such as innovative technique, computer application, and modification to equipment or technique procedure.

If such creative idea is involved in the project, the project team should provide a summary report of that idea. The summary report should be submitted to PSIM inspector to review and subject to approval to be eligible for awarding points whether the project will be self-evaluated or certified under PSIM. One example of summary report are provided in the Appendix.

The idea can serve as example of sustainable pavement maintenance for future projects if it is approved. If the idea has been successfully implemented on other pavement construction project previously, bonus point can also be awarded.

Related Indicators:

How To Measure:

See if the summary report of the creative idea can be approved.

Possible Points:

0~8

Rating Strategy:

2----The summary report is approved, and the idea improves sustainability in one sector of TBL;

4----The summary report is approved, and the idea improves sustainability in two sectors of TBL;

6----The summary report is approved, and the idea improves sustainability in three sectors of TBL;

+2----The summary report is approved, and the idea has been successfully implemented on other pavement construction project previously,

2 Sustainability Representative

Benefits according to TBL:

- Introduce valuable experience about sustainable pavement or sustainable transportation to the project.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

The project team is recommended to have one team member as the "sustainability representative". The sustainability representative must have the experience of participating the project of sustainable pavement or sustainable transportation. With the presence of sustainability representative, the unsustainable issues during the project can be solved without delaying.

The responsibilities of sustainability representative include:

- Representing project team on sustainability issues,
- Review the environmental and social issues associated with the site,
- Designing and implementing the sustainability plan for the project,

- Training working crew with basic sustainability knowledge,
- Tracking sustainability performance, and
- Submitting sustainability documents such as the evaluation under PSIM indicators.

Sometimes the most sustainable practices under different indicators might conflict with each other, so that the sustainability representative should work with other members of the project team to find a balance of trade-offs based on the project situation and their own judgment.

Related Indicators:

All other indicators

How To Measure:

See if anyone with the experience of sustainable pavement project is involved.

Possible Points:

0~4

Rating Strategy:

2----Sustainability representative is not designated, but a member in the project team completes at least two of the responsibilities mentioned in this indicator;

4----At least one sustainability representative is designated, and the sustainability representative completes at least four of the responsibilities mentioned in this indicator.

3 Certified Sustainable Pavement

Benefits according to TBL:

- Economy: Promote the economic, environmental, and social benefits from sustainable pavement.

Application:

☑ Asphalt	☑ Concrete	☑ Unpaved

Explanation:

Maintenance is the extension and critical stage of pavement construction. If the pavement is designed, built, or operated with sustainability features, the concept of sustainable pavement maintenance will be easier to be accepted when maintaining such pavement. It also can be anticipated that some sustainability experience of initial construction may be adopted or referred during maintenance.

If the maintained pavement has been certified by any one of the nine evaluation programs for sustainable pavement or sustainable transportation listed below, the maintenance project will be awarded points. Other sustainability evaluation programs for pavement or transportation that are not presented in the table below can be also considered, but a document containing the details of rating and certification of the program should be submitted to the PSIM inspector for approval. If the maintenance project involves multiple pavement sections, all of the pavement sections should be certified to be eligible for points.

Name	**Origin**	**Release Date**
INVEST	Washington D.C.	Oct 2012
Greenroads	Washington State	2009
GreenLITES	New York State	Sep 2008
I-LAST	Illinois State	Jan 2010
BE^2ST	Wisconsin State	July 2010
STARS	Oregon State	Nov 2010
INVEST	Australia	Mar 2011
STAR	Asia	Jan 2014
GreenPave	Canada	Mar 2012

Related Indicators:

How To Measure:

See if the pavement section that will be maintained is part of a certified sustainable pavement project.

Possible Points:

0~2

Rating Strategy:

2----Pavements being maintained are certified by the nine sustainability evaluation programs mentioned above or any other approved programs.

Appendix C: PSIM Survey Sheet for Category Priority

Pavement Sustainability Index for Maintenance
Analytic Hierarchy Process Survey Sheet

Name	
Company/Institution	
Position/Role	
Survey Date	

Circle appropriate numbers	
1	equal importance
2	equal to moderate importance
3	moderate importance
4	moderate to strong importance
5	strong importance
6	strong to very strong importance
7	very strong importance
8	very strong to extreme importance
9	extreme importance

Sheet made by:
Yibo Zhang
[redacted]
Contact Info

	Column A is more important																Column B is more important	
Column A																		Column B
Management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Technique**
Management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Material**
Management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Energy&Water**
Management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Environment**
Management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Safety**
Management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Community**
Management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Innovation**
Technique	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Material**
Technique	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Energy&Water**
Technique	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Environment**
Technique	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Safety**
Technique	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Community**
Technique	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Innovation**
Material	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Energy&Water**
Material	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Environment**
Material	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Safety**
Material	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Community**
Material	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Innovation**
Energy&Water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Environment**
Energy&Water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Safety**
Energy&Water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Community**
Energy&Water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Innovation**
Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Safety**
Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Community**
Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Innovation**
Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Community**
Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Innovation**
Community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Innovation**

Appendix D: Survey Results of AHP Survey

Table D.1 AHP survey Results for PSIM, before improvement

Respondents	Mn Management	T Technique	Mt Material	EW Energy&Water	E Environment	S Safety	C Community	I Innovation	Inconsistency
1	0.158	0.048	0.106	0.234	0.239	0.146	0.047	0.022	**0.06**
2	0.174	0.032	0.099	0.062	0.212	0.348	0.051	0.023	**0.09**
3	0.035	0.098	0.064	0.157	0.093	0.245	0.285	0.022	**0.05**
4	0.057	0.099	0.067	0.033	0.179	0.352	0.192	0.022	**0.07**
5	0.064	0.093	0.117	0.031	0.302	0.316	0.055	0.022	**0.08**
6	0.069	0.047	0.089	0.034	0.165	0.323	0.248	0.026	**0.04**
7	0.046	0.122	0.115	0.082	0.051	0.538	0.023	0.023	**0.07**
8	0.119	0.136	0.150	0.025	0.080	0.404	0.048	0.037	**0.24**
9	0.144	0.149	0.146	0.045	0.061	0.278	0.128	0.049	**0.1**
10	0.266	0.164	0.093	0.088	0.088	0.164	0.048	0.088	**0.00454**
11	0.443	0.199	0.055	0.034	0.091	0.055	0.034	0.091	**0.02**
12	0.130	0.107	0.103	0.113	0.100	0.148	0.151	0.149	**0.15**
13	0.063	0.183	0.186	0.079	0.139	0.288	0.032	0.030	**0.15**
14	0.308	0.043	0.101	0.097	0.151	0.233	0.040	0.027	**0.03**
15	0.058	0.047	0.126	0.027	0.181	0.488	0.047	0.026	**0.16**
16	0.040	0.071	0.056	0.033	0.125	0.546	0.065	0.063	**0.05**
17	0.068	0.081	0.061	0.044	0.088	0.530	0.057	0.072	**0.05**
18	0.074	0.094	0.152	0.134	0.206	0.159	0.094	0.088	**0.23**
19	0.062	0.096	0.067	0.097	0.221	0.315	0.029	0.113	**0.89**
20	0.133	0.058	0.037	0.031	0.077	0.521	0.121	0.022	**0.13**
21	0.167	0.086	0.043	0.045	0.046	0.377	0.219	0.017	**0.12**
22	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	**0**
23	0.136	0.081	0.174	0.015	0.188	0.142	0.130	0.134	**0.76**

24	0.126	0.105	0.054	0.083	0.109	0.325	0.143	0.054	**0.5**
25	0.154	0.080	0.080	0.052	0.060	0.396	0.064	0.112	**0.06**
26	0.074	0.093	0.073	0.047	0.123	0.463	0.056	0.073	**0.35**
27	0.180	0.105	0.113	0.130	0.090	0.142	0.074	0.166	**1.15**
28	0.250	0.217	0.101	0.026	0.062	0.259	0.061	0.025	**0.1**
29	0.189	0.147	0.043	0.030	0.038	0.306	0.066	0.182	**0.12**
30	0.139	0.206	0.123	0.027	0.096	0.282	0.089	0.038	**0.14**
31	0.049	0.043	0.102	0.075	0.173	0.495	0.023	0.040	**0.16**
Mean	0.13226	0.10500	0.09745	0.06887	0.12771	0.31319	0.09177	0.06390	**0.197565806**
Ranking	**2**	**4**	**5**	**7**	**3**	**1**	**6**	**8**	
Normalization	**0.132**	**0.105**	**0.097**	**0.069**	**0.128**	**0.313**	**0.092**	**0.064**	
Total Pts					**200**				
Calculated Pts	**26.45**	**21.00**	**19.49**	**13.77**	**25.54**	**62.63**	**18.35**	**12.78**	
Category Pts	**26**	**21**	**19**	**14**	**26**	**63**	**18**	**13**	
	Management	**Technique**	**Material**	**Energy&Water**	**Environment**	**Safety**	**Community**	**Innovation**	
	Mn	T	Mt	EW	E	S	C	I	

Table D.2 AHP survey Final Results for PSIM, after improvement

Respondents	Mn	T	Mt	EW	E	S	C	I	Original Inconsistency	Improved Inconsistency	Improving Rounds
	Management	Technique	Material	Energy&Water	Environment	Safety	Community	Innovation			
1	0.158	0.048	0.106	0.234	0.239	0.146	0.047	0.022	**0.06**	0.06	
2	0.174	0.032	0.099	0.062	0.212	0.348	0.051	0.023	**0.09**	0.09	
3	0.035	0.098	0.064	0.157	0.093	0.245	0.285	0.022	**0.05**	0.05	
4	0.057	0.099	0.067	0.033	0.179	0.352	0.192	0.022	**0.07**	0.07	
5	0.064	0.093	0.117	0.031	0.302	0.316	0.055	0.022	**0.08**	0.08	
6	0.069	0.047	0.089	0.034	0.165	0.323	0.248	0.026	**0.04**	0.04	
7	0.046	0.122	0.115	0.082	0.051	0.538	0.023	0.023	**0.07**	0.07	
8	0.067	0.119	0.152	0.036	0.104	0.456	0.044	0.022	**0.24**	0.09	5
9	0.144	0.149	0.146	0.045	0.061	0.278	0.128	0.049	**0.1**	0.1	
10	0.266	0.164	0.093	0.088	0.088	0.164	0.048	0.088	**0.00454**	0.00454	
11	0.443	0.199	0.055	0.034	0.091	0.055	0.034	0.091	**0.02**	0.02	
12	0.132	0.079	0.083	0.111	0.101	0.149	0.152	0.192	**0.15**	0.1	2
13	0.065	0.172	0.244	0.082	0.151	0.228	0.034	0.024	**0.15**	0.08	3
14	0.308	0.043	0.101	0.097	0.151	0.233	0.040	0.027	**0.03**	0.03	
15	0.047	0.059	0.140	0.026	0.226	0.421	0.052	0.030	**0.16**	0.09	3
16	0.040	0.071	0.056	0.033	0.125	0.546	0.065	0.063	**0.05**	0.05	
17	0.068	0.081	0.061	0.044	0.088	0.530	0.057	0.072	**0.05**	0.05	
18	0.051	0.092	0.184	0.095	0.233	0.219	0.066	0.060	**0.23**	0.09	4
19	0.022	0.093	0.084	0.023	0.342	0.340	0.018	0.078	**0.89**	0.1	12
20	0.153	0.061	0.038	0.031	0.077	0.530	0.089	0.022	**0.13**	0.1	1
21	0.137	0.099	0.046	0.048	0.040	0.386	0.225	0.019	**0.12**	0.09	2
22	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	**0**	0	
23	0.071	0.027	0.256	0.031	0.124	0.122	0.132	0.237	**0.76**	0.09	10
24	0.277	0.134	0.072	0.052	0.084	0.210	0.126	0.045	**0.5**	0.09	7
25	0.154	0.080	0.080	0.052	0.060	0.396	0.064	0.112	**0.06**	0.06	
26	0.138	0.063	0.066	0.025	0.077	0.531	0.034	0.066	**0.35**	0.1	4

27	0.296	0.046	0.028	0.044	0.054	0.146	0.105	0.280	**1.15**	0.1	10
28	0.250	0.217	0.101	0.026	0.062	0.259	0.061	0.025	**0.1**	0.1	
29	0.201	0.155	0.047	0.034	0.042	0.225	0.074	0.223	**0.12**	0.1	1
30	0.181	0.206	0.117	0.028	0.071	0.285	0.088	0.026	**0.14**	0.08	2
31	0.053	0.044	0.102	0.051	0.177	0.515	0.024	0.035	**0.16**	0.1	2
Mean	0.13845	0.10055	0.10110	0.06110	0.12887	0.31023	0.08987	0.07003	**0.197565806**	**0.073372258**	
Ranking	**2**	**5**	**4**	**8**	**3**	**1**	**6**	**7**			
Normalization	**0.138**	**0.101**	**0.101**	**0.061**	**0.129**	**0.310**	**0.090**	**0.070**			
Total Pts				**200**							
Calculated Pts	**27.68**	**20.11**	**20.22**	**12.22**	**25.77**	**62.03**	**17.97**	**14.00**			
Category Pts	**28**	**20**	**20**	**12**	**26**	**62**	**18**	**14**			
	Management	**Technique**	**Material**	**Energy&Water**	**Environment**	**Safety**	**Community**	**Innovation**			
	Mn	T	Mt	EW	E	S	C	I			

Appendix E: State DOTs' Practices under PSIM Indicators

The practices of 8 state DOTs (Caltrans, CDOT, FDOT, KYTC, MnDOT, NYSDOT, ODOT-Oregon, and WSDOT) will be reviewed in this appendix. The procedure of determining points under each indicator by reviewing State DOTs' practices are shown below:

- Collect the manuals related to pavement maintenance construction from State DOT website;
- Review the manuals and find out which manuals/chapters/sections are discussing PSIM Indicators;
- List the manuals/chapters/sections as "practices" of the State DOT under the corresponding indicator, there will be three levels to demonstrate the quantity of manuals/chapters/sections involved (level 1 – three chapters/sections or fewer; level 2 – one manual or three to five chapters/sections; level 3 – no less than two manuals or six chapters/sections);
- Determine if the "practices" are ready to be applied on pavement maintenance practices, which will be demonstrated by three coefficient:
    - 3 pts – "yes/ready": Details are well described and can be adopted on pavement maintenance projects directly with little modification
    - 2 pts – "partially/somewhat ready": Ideas are adopted on other projects but details need to be modified to be adopted on pavement maintenance projects, or only part of indicator descriptions are considered
    - 1 pt – "no/not ready": Sustainability was not involved yet but highly recommended to be included
    - 0 – "-/not discussed": Researcher was not able to find related information online;
- Multiply the "level" and "coefficient" as the Practice Score of the State DOT (the score ranges from 0 to 9);
- The Average Practice Score under each indicator that was calculated from 8 State DOTs practices is then slightly modified by how many sectors of TBL that indicator involves;

- The Modified Practice Score will be the PSIM points under each indicator.

The quantity of manuals or websites that have been reviewed is 350. This appendix does not mean to provide and review all the manuals or websites published by the 8 State DOTs. There should be some other manuals or websites that were not collected or reviewed by PSIM developer, or some manuals or websites cannot be accessed by public at all. Therefore, the review results (as can be seen from the following tables) in the appendix are trying to provide a general idea of the sustainability practices of the 8 State DOTs.

E.1 Caltrans

Table E.1 Sustainability Practices of Caltrans under PSIM Indicators

As of 10/20/2016			
Management	Project Team	no	Caltrans Project Management Handbook Chapter 4
	Budget Plan	no	Highway Design Manual Section 619; PDPM Chapter 20; RTL Guide Section 7
	Quality Management	partially	Construction Manual Chapter 6, Section 4-11; Quality Control Manual for Hot Mix Asphalt for the Quality Control Quality Assurance Process; Quality Control Quality Assurance Manual For Asphalt Concrete Production and Placement
	Emergencies	partially	Maintenance Manual Volume 1 Section 4.15, Section 4.23, Section D1.07, Chapter D5, Chapter S; Emergency Projects Environmental Process and Requirements; Construction Manual Section 2-103, Section 2-107, Section 3
	Maintenance Schedule	partially	Maintenance Manual Volume 1 Chapter 11; Guidelines for Preparing PEAR Section 7.2; Construction Manual Section 2-208
	Project Record	no	Highway Design Manual Section 605
	Work Zone Management	partially	Maintenance Manual Volume 1 4.21; Construction Manual Section 2-215
	Crew Training	partially	Maintenance Manual Volume 1 4.01 4.19
	Project Interaction	no	Project Communication Handbook
Technique	Technique Selection		
	Distress Reason		
	Standard Procedure	yes	Maintenance Manual Volume 1 3.01, A, B; Standard Specifications Division V~VI

	Disturbance and Repair	yes	Maintenance Manual Volume 1 2.09
	Uneven Surface		
	Preservation	no	Highway Design Manual Section 603, Section 612
Material	Quality Certification	yes	Maintenance Manual Volume 1 Section 2.10, Chapter 6; Construction Manual Section 3-608~3-610; Highway Design Manual Section 114; Construction Manual Supplement Chapter 6; Standard Specifications Section 6, Division XI
	Material Production	yes	Material Plant Quality Program
	Local Material	yes	Construction Manual Section 3-603; Standard Specifications Section 6
	Material Storage	no	Disposal Site Quality Team
	Recycle Material	partially	Highway Design Manual Section 617.2; Standard Specifications Section 30
	Alternative Material		
	Earthwork	no	Guidelines for Preparing PEAR Section 6.9; Construction Manual Section 4-19; Standard Specifications Section 19
Energy& Water	Efficient Lighting	yes	Maintenance Manual Volume 1 Chapter K; Construction Manual Section 4-86
	Energy Consumption I, Construction	partially	Maintenance Manual Volume 1 4.04, 4.12, 4.13, Exhibit 12.02; Environmental Handbook, Volume I: Guidance for Compliance Chapter 13
	Energy Consumption II, Transport	partially	Environmental Handbook, Volume I: Guidance for Compliance Chapter 13
	Energy Consumption III, Asphalt Mixture	partially	Standard Specifications Section 39
	Water Consumption	no	Construction Manual Section 4-17
	Heat Island Alleviation		
Environment	Wastes	partially	Maintenance Manual Volume 1 Section C5.34, Chapter D1, Chapter F, Section G.03; Environmental Handbook, Volume I: Guidance for Compliance Chapter 9, Chapter 10; Environmental Handbook, Volume 5: Stormwater; Environmental Handbook, Volume 6: Hazardous Waste Management; Guidelines for Preparing PEAR Section 6.7-6.8, Section 6.11; Construction Manual Section 2-212, Section 7-106~7-108; Highway Design Manual Section 110.2, Chapter 810, Chapter 890; Standard Specifications Section 13; PPDG Chapter 3~5
	Air Quality	yes	Environmental Handbook, Volume I: Guidance for Compliance Chapter 11; Guidelines for Preparing PEAR Section 6.12; Ambient Air Quality Standards; Construction Manual Section 4-10 (7-104), Section 4-18; Highway Design Manual Section 110.3; Standard Specifications Section 18
	Noise Control	yes	Environmental Handbook, Volume I: Guidance for Compliance Chapter 12; Guidelines for Preparing PEAR Section 6.13; Highway Design Manual Chapter 1100; PDPM Chapter 30

	Vibration Control	no	Guidelines for Preparing PEAR Section 6.13
	Erosion and Sediment Control	partially	Maintenance Manual Volume 1 Section C5.25; Construction Manual Section 4-21, Section4-72; Highway Design Manual Section 707; Standard Specifications Section 21, 72
	Ecology Conservation	yes	Environmental Handbook, Volume I: Guidance for Compliance Chapter 14-15, Chapter 17-20, Chapter 23; Environmental Handbook, Volume 3: Biological Resources; Guidelines for Preparing PEAR Section 6.1, Section 6.3, Section 6.15; Construction Manual Section 7-103; Highway Design Manual Section 110.4; Standard Specifications Section 14; PDPM Chapter 18
Safety	Traffic Control	yes	Maintenance Manual Volume 1 Chapter 7; Construction Manual Section 2-205; CA-MUTCD Part 6~9; Highway Design Manual Section 110.7; Standard Specifications Section 12, Division IX
	Construction Safety	partially	Maintenance Manual Volume 1 Section 4.06-4.07, Section 4.15; Construction Manual Section 2-106
	Pavement Marking	yes	Maintenance Manual Volume 1 Section M-1; Construction Manual Section 4-84; CA-MUTCD Part 3
	Appurtenances	yes	Maintenance Manual Volume 1 Chapter 8, Chapter 9, Section C2-1, Section C2-2, Section C5-2, Section C5-4, Section M-3; Construction Manual Section 3-703, Section 4-82; CA-MUTCD Part 2, Part 4, Part 5; Standard Specifications Section 73
	Pedestrian and Bicyclists	no	Construction Manual Section 2-216; Highway Design Manual Section 105, Section 110.1, Section 1003; Maintenance Manual Volume 1 4.14
	Drainage	yes	Maintenance Manual Volume 1 Section C5-3; Construction Manual Section 4-68~4-70; Highway Design Manual Chapter 650, Chapter 800, Chapter 820~840; Standard Specifications Division VII
	Glare Control		
	Snow and Ice Removal	partially	Maintenance Manual Volume 1 Chapter 5, Chapter R
Community	Report the Problem	yes	Submit Maintenance Service Request or ADA Access Service Request
	Landscape Maintenance	yes	Maintenance Manual Volume 1 Section C2-3, Chapter E; Construction Manual Section 4-20; Highway Design Manual Section 110.5, Section 902; Standard Specifications Section 20
	Aesthetic Design	partially	Maintenance Manual Volume 1 Section C5.33, Section D 1.05, Section D1.06; Environmental Handbook, Volume I: Guidance for Compliance Chapter 27; Guidelines for Preparing PEAR Section 6.5; Construction Manual Section 7-103H; Highway Design Manual Section 109; Standard Specifications Section 80
	Culture Conservation	partially	Environmental Handbook, Volume I: Guidance for Compliance Chapter 20, Chapter 28; Environmental Handbook, Volume 2: Cultural Resources; Guidelines for Preparing PEAR Section 6.6; General Guidelines for Identifying and Evaluating Historic Landscapes; Construction Manual Section 7-103E, Section 7-103G
	Notification	partially	Maintenance Manual Volume 1 Section M-2; Construction Manual Section 2-211
	Ease of Use	partially	Maintenance Manual Volume 1 Chapter U; Construction Manual Section 3-702

	Community Adaption	yes	Environmental Handbook, Volume I: Guidance for Compliance Chapter 22, Chapter 24; Environmental Handbook, Volume 4: Community Impact Assessment; Guidelines for Preparing PEAR Section 6.4; Construction Manual Section 2-213, Section 3-510, Section 4-83, Section 7-103F; Maintenance Manual Volume 1 Section 1.10, Chapter H, Chapter J1; Highway Design Manual Section 108; PDPM Chapter 11, 22, 29; Right of Way Manual Chapter 13
	Sustainability Promotion		
Innovation	Creative Idea		
	Sustainability Representative	no	Guidelines for Preparing PEAR Chapter 3
	Certified Sustainable Pavement		

References

Maintenance Manual Volume 1, July 2014, last updated on 3-11-2016

Environmental Handbook, Volume I: Guidance for Compliance, last updated on 12-4-2015

Environmental Handbook, Volume 2: Cultural Resources, last updated on 2-1-2016

Environmental Handbook, Volume 3: Biological Resources, last updated on 4-2-2013

Environmental Handbook, Volume 4: Community Impact Assessment, last updated on 2-3-2012

Guidelines for Preparing a Preliminary Environmental Analysis Report (PEAR), last updated Jan 2009

Disposal Site Quality Team, Sep 2001

General Guidelines for Identifying and Evaluating Historic Landscapes, Feb 1999

Emergency Projects Environmental Process and Requirements, Nov 2014

Ambient Air Quality Standards, 5-4-2016

Construction Manual, Sep 2014

2014 California Manual on Uniform Traffic Control Devices (CA-MUTCD)

Highway Design Manual, 7-15-2016

Quality Control Manual for Hot Mix Asphalt for the Quality Control Quality Assurance Process, June 2009

Project Communication Handbook, Sep 2007

Caltrans Project Management Handbook, Oct 2007

Construction Manual Supplement For Local Agency Resident Engineers, Aug 2008

Standard Specifications, 2015

Submit Maintenance Service Request or ADA Access Service Request, http://www.dot.ca.gov/hq/maint/msrsubmit/

Material Plant Quality Program, July 2008

Quality Control Quality Assurance Manual For Asphalt Concrete Production and Placement, June 2002

Project Development Procedures Manual (PDPM), last updated Sep 26 2016

Ready to List and Construction Contract Award Guide (RTL Guide), last updated Nov 5 2016

Project Planning and Design Guide (PPDG), Feb 2016

Right of Way Manual, last updated Sep 2016

E.2 CDOT

Table E.2 Sustainability Practices of CDOT under PSIM Indicators

As of 06/07/2016			
Management	Project Team		
	Budget Plan	no	Project Development Manual Section 6.05
	Quality Management	partially	Construction Manual Section 105.3.4, Section 400.1.1, Section 401.1.5; Field Materials Manual; Design Build Manual Book 2; Quality Control Manual
	Emergencies		
	Maintenance Schedule	no	Construction Manual Section 108.3; Highway Maintenance Levels of Service Manual Section 1; Project Development Manual Section 1.02, Section 1.07; Local Agency Manual Section 8.5; Utility Manual Section 4.4.9; Standard Specifications for Road and Bridge Construction Section 108.03; Design Build Manual Book 1
	Project Record	partially	Construction Manual Section 120~121; Local Agency Manual Section 5.14, Section 8.16, Section 9.2, Section 9.9, Chapter 11; Design Build Manual Book 1
	Work Zone Management	partially	Construction Manual Section 108.6~108.7, Section 630; Roadway Design Guide Section 20.1.7; Standard Specifications for Road and Bridge Construction Section 107.16, Section 108.07, Section 630

	Crew Training	partially	Construction Manual Section 107.1.4; Highway Maintenance Levels of Service Manual Section 1; Flagger Training Manual
	Project Interaction	partially	Local Agency Manual Section 8.5; Utility Manual Section 4.5; Design Build Manual Book 1
Technique	Technique Selection		
	Distress Reason	yes	Project Development Manual Section 6.01
	Standard Procedure	yes	Roadway Design Guide Chapter 16, Section 20.7; Standard Specifications for Road and Bridge Construction Section 105, Section 300~600; Design Build Manual Book 3; Pavement Design Manual Chapter 8~10
	Disturbance and Repair	no	Construction Manual Section 107.15; Design Build Manual Book 1
	Uneven Pavement	no	Construction Manual Section 401.6, Section 604; Standard Specifications for Road and Bridge Construction Section 604
	Preservation		
Material	Quality Certification	partially	Construction Manual Section 106; Project Development Manual Section 8.12; Local Agency Manual Section 9.3~9.7; Standard Specifications for Road and Bridge Construction Section 102.10; Standard Specifications for Road and Bridge Construction Section 106, Section 700; Laboratory Manual of Test Procedures; Field Materials Manual
	Material Production	partially	Construction Manual Section 401.2.1, Section 601.3
	Local Material		
	Material Storage	partially	Construction Manual Section 401.2.2; Standard Specifications for Road and Bridge Construction Section 106.08
	Recycle Material	partially	Construction Manual Section 406
	Alternative Material	partially	Project Development Manual Section 2.12; Pipe Material Selection Guide
	Earthwork	yes	Construction Manual Section 200; Standard Specifications for Road and Bridge Construction Section 200; Design Build Manual Book 2
Energy& Water	Efficient Lighting	no	Construction Manual Section 613; Roadway Design Guide Section 3.7, Section 7.2.1.19; Utility Manual Section 5.1.4; Lighting Design Guide; Standard Specifications for Road and Bridge Construction Section 613, Section 715; Design Build Manual Book 2
	Energy Consumption I, Construction	partially	Construction Manual Section 401.4~401.5, Section 403.2
	Energy Consumption II, Transport	no	Construction Manual Section 401.3; Project Development Manual Section 4.10
	Energy Consumption III, Asphalt Mixture	partially	Approved List of WMA Technologies and Contractors
	Water Consumption		

	Heat Island Alleviation		
Environment	Wastes	partially	Construction Manual Section 107.25, Section 200.2.10, Section 208.1.2; Project Development Manual Section 2.11, Section 3.07, Section 3.15, Section 3.17, Section 8.11; Standard Specifications for Road and Bridge Construction Section 104.06, Section 107.25
	Air Quality	partially	Construction Manual Section 209; Project Development Manual Section 3.04; Standard Specifications for Road and Bridge Construction Section 107.24, Section 209
	Noise Control	partially	Project Development Manual Section 3.10, Section 5.09; Roadway Design Guide Section 3.10, Section 4.13, Chapter 18
	Vibration Control		
	Erosion and Sediment Control	partially	Construction Manual Section 506; Highway Maintenance Levels of Service Manual Section 3; Project Development Manual Section 2.11; Roadway Design Guide Section 3.6.1, Section 4.7, Section 8.2.3; Standard Specifications for Road and Bridge Construction Section 208, Section 507
	Ecology Conservation	partially	Construction Manual Section 107.13, Section 200.2.5; Project Development Manual Section 3.05~3.06, Section 3.09, Section 3.16, Section 3.18; Roadway Design Guide Section 2.7; Standard Specifications for Road and Bridge Construction Section 107.09, Section 107.13~107.14
Safety	Traffic Control	partially	Construction Manual Section 614; Project Development Manual Section 8.02; Roadway Design Guide Section 3.5, Section 3.9, Section 20.5~20.6; Local Agency Manual Section 8.7; Utility Manual Section 4.3.9; Standard Specifications for Road and Bridge Construction Section 713
	Construction Safety	partially	Construction Manual Section 107.6, Section 250; Project Development Manual Section 2.07~2.08; Local Agency Manual Section 8.2
	Pavement Marking	no	Construction Manual Section 627; Project Development Manual Section 4.09; Roadway Design Guide Section 20.9; Standard Specifications for Road and Bridge Construction Section 627; Design Build Manual Book 2; Recommended Pavement Marking Practices
	Appurtenances	partially	Construction Manual Section 107.10, Section 606, Section 609~610, Section 612; Highway Maintenance Levels of Service Manual Section 3, Section 5; Project Development Manual Section 2.09; Roadway Design Guide Section 2.6, Section 4.9~4.10, Section 4.14, Section 5.2.10, Section 7.1.3.3, Section 7.2.1.7, Section 7.2.1.11, Section 8.1.5, Section 8.2.2, Section 8.3.1, Section 20.2~20.3, Section 20.8; Cable Barrier Guide; Standard Specifications for Road and Bridge Construction Section 107.10, Section 600; Safety Selection Guide; Design Build Manual Book 2; Sign Design Manual; Guide Signing Policies and Procedures; Outdoor Advertising Manual; Outdoor Advertising Reference Guide
	Pedestrian and Bicyclists	partially	Construction Manual Section 514, Section 608; Project Development Manual Section 2.10, Section 5.04, Section 8.01, Section 8.09; Roadway Design Guide Section 2.5, Section 4.16~4.17, Section 5.2.13~5.2.14, Section 6.2.4~6.2.5, Section 7.1.4, Chapter 11~12, Chapter 14, Section 20.1.1; Standard Specifications for Road and Bridge Construction Section 514, Section 608

	Drainage	no	Construction Manual Section 603, Section 605; Roadway Design Guide Section 3.6.1, Section 4.7.2, Section 5.2.11, Section 6.2.3, Section 7.2.1.12; Drainage Design Guide; Standard Specifications for Road and Bridge Construction Section 605; Design Build Manual Book 2
	Glare Control		
	Snow and Ice Removal	yes	Highway Maintenance Levels of Service Manual Section 7
Community	Report the Problem	yes	Official State Web Portal; CDOT Contact Us page
	Landscape Maintenance	partially	Construction Manual Section 107.12, Section 200.2.13, Section 212, Section 214~215, Section 217, Section 420.2.5, Section 623; Highway Maintenance Levels of Service Manual Section 4; Project Development Manual Section 3.11, Section 8.07; Standard Specifications for Road and Bridge Construction Section 107.12; Standard Specifications for Road and Bridge Construction Section 212~217, Section 623; Design Build Manual Book 2; Landscape Architecture Manual
	Aesthetic Design	partially	Project Development Manual Section 5.05; Utility Manual Section 4.4.12
	Culture Conservation	no	Construction Manual Section 107.23, Section 200.2.4; Project Development Manual Section 3.08; Standard Specifications for Road and Bridge Construction Section 107.23
	Notification	partially	Local Agency Manual Section 8.4; Official State Web Portal
	Ease of Use	no	Standard Specifications for Road and Bridge Construction Section 107.07; Design Build Manual Book 2
	Community Adaption	partially	Project Development Manual Section 7.03~7.04; Roadway Design Guide Section 3.8, Section 4.15, Section 4.18, Section 7.2.1.18, Chapter 9, Chapter 15, Section 20.1.4; Local Agency Manual Section 5.9, Section 505; Standard Specifications for Road and Bridge Construction Section 107; Construction Manual Section 105.9~105.12
	Sustainability Promotion	no	Project Development Manual Section 2.33~2.35; Local Agency Manual Section 7.3
Innovation	Creative Idea	partially	Project Development Manual Section 1.08; Utility Manual Section 4.3.11
	Sustainability Representative		
	Certified Sustainable Pavement		

References

2014 CDOT Construction Manual, last updated 5-13-2016

2016 Field Materials Manual, 7-1-2015

2016 Laboratory Manual of Test Procedures

Highway Maintenance Levels of Service Manual, 12-22-1999

Project Development Manual, 01-31-2013, last updated 05-13-2016

Roadway Design Guide 2005, last updated 11-5-2015

Local Agency Manual 2006, last updated 03-31-2016

Pipe Material Selection Guide, last updated 4-30-2015

Drainage Design Guide 2004

Cable Barrier Guide, June 2009

Utility Manual, 1-31-2011

Lighting Design Guide, Feb 2006

Standard Specifications for Road and Bridge Construction 2011

Safety Selection Guide

Design Build Manual, 4-15-2006, last updated 6-11-2014

2014 Draft M-E Pavement Design Manual, last updated 6-26-2013

Landscape Architecture Manual, 8-18-2014

Transportation Enhancement Manual, 10-10-2000

Survey Manual, last updated 2-10-2016

Sign Design Manual 2015, last updated Mar 2015

Guide Signing Policies and Procedures 2012, last updated Feb 2016

Recommended Pavement Marking Practices, last updated Sep 1998

Flagger Training Manual, last updated Dec 2012

Outdoor Advertising Manual, Feb 2015

Outdoor Advertising Reference Guide, June 2015

2015 Quality Control Manual

Official State Web Portal, http://www.cotrip.org/home.htm

CDOT Contact Us page, https://www.codot.gov/topcontent/contact-cdot

Approved List of WMA Technologies and Contractors, Sep 18 2015

E.3 FDOT

Table E.3 Sustainability Practices of FDOT under PSIM Indicators

As of 06/19/2016			
Management	Project Team	partially	Construction Project Administration Manual Section 3.1; Florida Greenbook Section 12C
	Budget Plan	partially	State Park-and-Ride Guide Chapter 6; Construction Project Administration Manual Section 2.2; Florida Greenbook Section 1B
	Quality Management	yes	Standard Specifications for Road and Bridge Construction Section 105, 108; Construction Project Administration Manual Section 3.2~3.5; Construction Project Administration Manual Section 11.7, Chapter 12, Section 13.1; Flexible Pavement Design Manual Appendix B; Rigid Pavement Design Manual Appendix B; Plans Preparation Manual Volume I Chapter 18, 34
	Emergencies	partially	Utility Accommodation Manual Section 4.1.1; Florida Greenbook Section 1B, 1D; Radiation Safety Manual Chapter 3
	Maintenance Schedule	partially	Utility Accommodation Manual Section 4.5.1; Construction Project Administration Manual Section 2.1
	Project Record	partially	State Park-and-Ride Guide Chapter 11; Historical Cost and Other Information; Construction Contract History; Construction Project Administration Manual Chapter 5; Statewide Airfield Pavement Management Program Update Summary Report, Volume I Chapter 2; RCI User Manual
	Work Zone Management	yes	Standard Specifications for Road and Bridge Construction Section 103; Construction Project Administration Manual Section 9.2~9.3; Florida Greenbook Section 1D, Chapter 11
	Crew Training	partially	Radiation Safety Manual Chapter 8; Rigid Pavement Design Manual Section 1.8
	Project Interaction	partially	Utility Accommodation Manual Section 4.9; Construction Project Administration Manual Section 8.12
Technique	Technique Selection		
	Distress Reason	partially	Statewide Airfield Pavement Management Program Update Summary Report, Volume I Chapter 3; Airfield Pavement Distress Repair Manual; Airfield Pavement Inspection Reference Manual
	Standard Procedure	yes	Standard Specifications for Road and Bridge Construction Section 120~370; MRP Handbook; Flexible Pavement Design Manual Chapter 7; Airfield Pavement Distress Repair Manual; Inspection Methodology for Whitetopping; Florida Greenbook Section 1D, Chapter 10; Flexible Pavement Condition Survey Handbook; Rigid Pavement Condition Survey Handbook; Rigid Pavement Design Manual Chapter 10~12; Plans Preparation Manual Volume I Chapter 25
	Disturbance and Repair		

	Uneven Pavement	partially	Construction Project Administration Manual Section 11.5
	Preservation		
Material	Quality Certification	yes	Standard Specifications for Road and Bridge Construction Section 901~994; Construction Aggregates Manual; Florida Greenbook Section 12D;Florida Sampling and Testing Methods; Materials Manual
	Material Production	no	Construction Project Administration Manual Section 11.1
	Local Material		
	Material Storage		
	Recycle Material	partially	Standard Specifications for Road and Bridge Construction Section 283; Guidelines for Reworked/Repaved Asphalt Concrete
	Alternative Material	partially	Standard Specifications for Road and Bridge Construction Section 121
	Earthwork	partially	Standard Specifications for Road and Bridge Construction Section 120; Design Standards For Construction and Maintenance Operations on the State Highway System Section 500~506; Soils and Foundations Handbook; Plans Preparation Manual Volume I Chapter 3
Energy& Water	Efficient Lighting	partially	State Park-and-Ride Guide Section 7.2.13; Standard Specifications for Road and Bridge Construction Section 715; Florida Greenbook Chapter 6; Design Standards For Construction and Maintenance Operations on the State Highway System Chapter 175
	Energy Consumption I, Construction	partially	Standard Specifications for Road and Bridge Construction Section 100; Construction Project Administration Manual Section 11.2
	Energy Consumption II, Transport	no	State Park-and-Ride Guide Section 7.2.5
	Energy Consumption III, Asphalt Mixture	partially	Approved Additives/Processes and Statistics for Warm Mix Asphalt; Evaluation of Warm-Mix Asphalt Performance in Florida
	Water Consumption		
	Heat Island Alleviation		
Environment	Wastes	partially	Construction Project Administration Manual Section 11.9; Standard Specifications for Road and Bridge Construction Section 104; Best Maintenance Practices for Stormwater Runoff; Plans Preparation Manual Volume I Chapter 11; PD&E Manual Volume 2 Chapter 11, 18~23
	Air Quality	partially	PD&E Manual Volume 2 Chapter 16
	Noise Control	partially	Construction Project Administration Manual Section 8.10; Design Standards For Construction and Maintenance Operations on the State Highway System Chapter 52; Plans Preparation Manual Volume I Chapter 32; PD&E Manual Volume 2 Chapter 17
	Vibration Control	partially	Construction Project Administration Manual Section 8.10

	Erosion and Sediment Control	partially	Utility Accommodation Manual Section 4.1.5; Standard Specifications for Road and Bridge Construction Section 104, 571; Design Standards For Construction and Maintenance Operations on the State Highway System Section 104; Plans Preparation Manual Volume I Chapter 30
	Ecology Conservation	partially	Utility Accommodation Manual Section 4.5.3; Construction Project Administration Manual Section 8.2; Florida Greenbook Section 1B; PD&E Manual Volume 2 Chapter 7, 24~28
Safety	Traffic Control	yes	State Park-and-Ride Guide Section 7.1.3; Utility Accommodation Manual Section 4.4; Standard Specifications for Road and Bridge Construction Section 102, 603~695; Construction Project Administration Manual Section 9.1; Florida Greenbook Section 1D; Design Standards For Construction and Maintenance Operations on the State Highway System Chapter 6
	Construction Safety	partially	Driveway Information Guide Section 8.7; Florida Greenbook Chapter 11; Radiation Safety Manual; Survey Safety Handbook
	Pavement Marking	yes	Standard Specifications for Road and Bridge Construction Section 701, 709~713; Florida Greenbook Section 18D; Design Standards For Construction and Maintenance Operations on the State Highway System Section 17344~17347
	Appurtenances	partially	State Park-and-Ride Guide Section 7.1.4, Section 7.2.7; Standard Specifications for Road and Bridge Construction Section 515~550, 700, 705, 706; State Sign Shop Commodity Catalog; Driveway Information Guide Chapter 5, Section 9.6; Florida Greenbook Section 3C, 18C, Chapter 4; Design Standards For Construction and Maintenance Operations on the State Highway System Chapter 3~5, 7~8, 177, Section 11200~17359; Instructions for Structures Related Design Standards; Median Handbook; Plans Preparation Manual Volume I Chapter 4; Plans Preparation Manual Volume I Chapter 29
	Pedestrian and Bicyclists	partially	Utility Accommodation Manual Section 4.1.4; Driveway Information Guide Section 2.5, Section 9.8~9.9, Chapter 10; Florida Greenbook Section 1B, 1C, 2C, 3C, Chapter 8~9, Chapter 13; Design Standards For Construction and Maintenance Operations on the State Highway System Chapter 8; Plans Preparation Manual Volume I Chapter 8; PD&E Manual Volume 2 Chapter 14; Design Handbook for Florida Bus Passenger Facilities; State Park-and-Ride Guide Section 7.1.2
	Drainage	yes	State Park-and-Ride Guide Section 7.2.6; Standard Specifications for Road and Bridge Construction Section 407~449; Drainage Handbook Culvert Design; Drainage Handbook Drainage Connection Permits; Drainage Manual; Drainage Handbook Exfiltration Systems; Florida Greenbook Section 5B, Chapter 20; Design Standards For Construction and Maintenance Operations on the State Highway System Chapter 2; Drainage Handbook Open Channel; Drainage Handbook Optional Pipe Materials; Rigid Pavement Design Manual Chapter 4; Drainage Handbook Storm Drains; Drainage Handbook Stormwater Management Facility; Drainage Handbook Temporary Drainage Design
	Glare Control		
	Snow and Ice Removal		
Community	Report the Problem		

	Landscape Maintenance	yes	State Park-and-Ride Guide Section 7.2.8; Utility Accommodation Manual Section 4.5.2, Section 4.6; Standard Specifications for Road and Bridge Construction Section 570; A Guide for Roadside Vegetation Management; Guidelines for Disposal of Terrestrial Invasive Plants; A Guide for Tree, Palm Maintenance for Urban Roadsides and Landscape Areas; Driveway Information Guide Section 8.4~8.5; Design Standards For Construction and Maintenance Operations on the State Highway System Section 544; Plans Preparation Manual Volume I Chapter 9
	Aesthetic Design	partially	State Park-and-Ride Guide Section 7.2.12; Standard Specifications for Road and Bridge Construction Section 560~563; PD&E Manual Volume 2 Chapter 15, 29
	Culture Conservation	partially	Utility Accommodation Manual Section 4.1.2~4.1.3; Cultural Resource Management Handbook; Practical Application Guide for SCE Evaluations; PD&E Manual Volume 2 Chapter 9, 12
	Notification	partially	PD&E Manual Volume 1 Chapter 3; Websites for Major Projects on Florida's Highways; Active Construction Projects
	Ease of Use	no	State Park-and-Ride Guide Section 7.2.11; Design Standards For Construction and Maintenance Operations on the State Highway System Chapter 181; Plans Preparation Manual Volume I Chapter 7
	Community Adaption	partially	State Park-and-Ride Guide Section 7.2.12; Utility Accommodation Manual Section 4.1.11; Florida Greenbook Section 1B, Section 2D, Chapter 7, Chapter 16, Chapter 19; Plans Preparation Manual Volume I Chapter 6, 9, 21; Statewide Airfield Pavement Management Program Update Summary Report, Volume I Chapter 5~6; Airfield Pavement Distress Repair Manual; Construction Project Administration Manual Chapter 4, Section 8.3, Section 13.3; Public Involvement Handbook; PD&E Manual Volume 1 Chapter 11; PD&E Manual Volume 2 Chapter 10, Chapter 31; Driveway Information Guide Section 8.3, 9.2, 9.10; Design Standards For Construction and Maintenance Operations on the State Highway System Section 560; Florida Intersection Design Guide
	Sustainability Promotion	partially	State Park-and-Ride Guide Section 7.2.16, Chapter 10; Florida Greenbook Section 2E
Innovation	Creative Idea	yes	Rigid Pavement Design Manual Chapter 13
	Sustainability Representative	no	PD&E Manual Volume 1
	Certified Sustainable Pavement		

References

Design Handbook for Florida Bus Passenger Facilities, last updated June 2013

State Park-and-Ride Guide, Dec 1989, last updated June 2012

2010 Utility Accommodation Manual, August 2010

Historical Cost and Other Information, updated periodically

Standard Specifications for Road and Bridge Construction, July 2016

A Guide for Roadside Vegetation Management, 2012

Guidelines for Disposal of Terrestrial Invasive Plants

Maintenance Rating Program (MRP) 2016 Handbook,

State Sign Shop Commodity Catalog, Jan 2015

A Guide for Tree, Palm Maintenance for Urban Roadsides and Landscape Areas, 2015

Best Maintenance Practices for Stormwater Runoff, April 2015

Construction Aggregates Manual, Dec 2004

Construction Contract History

Drainage Handbook Culvert Design, Jan 2004

Construction Project Administration Manual, July 2002, last updated Jan 2013

Cultural Resource Management Handbook, Nov 2004

Design Standards For Construction and Maintenance Operations on the State Highway System, 2016

Drainage Handbook Drainage Connection Permits, July 2010

Drainage Manual, Jan 2016

Driveway Information Guide, Sep 2008

Drainage Handbook Exfiltration Systems, Feb 2012

Flexible Pavement Design Manual, Mar 2015

Statewide Airfield Pavement Management Program Update Summary Report, Volume I, June 2015

Airfield Pavement Distress Repair Manual, 2015

Airfield Pavement Inspection Reference Manual, 2015

Inspection Methodology for Whitetopping, 2011

Manual of Uniform Minimum Standards for Design, Construction and Maintenance for Streets and Highways (Florida Greenbook), May 2013

Florida Sampling and Testing Methods

Guidelines for Reworked/Repaved Asphalt Concrete, Aug 2012

Instructions for Structures Related Design Standards, Mar 2010

Florida Intersection Design Guide, 2015

Materials Manual, Mar 2000, last updated Aug 2014

Median Handbook, 2014

Drainage Handbook Open Channel, Nov 2009

Drainage Handbook Optional Pipe Materials, Aug 2014

Flexible Pavement Condition Survey Handbook, Aug 2015

Rigid Pavement Condition Survey Handbook, Aug 2015

Public Involvement Handbook, Dec 2014

Radiation Safety Manual, June 2000, last updated Feb 2008

Roadway Characteristics Inventory (RCI) User Manual, Mar 2014

Rigid Pavement Design Manual, Jan 2009

Practical Application Guide for SCE Evaluations, Dec 2015

Soils and Foundations Handbook, 2016

Drainage Handbook Storm Drains, Oct 2014

Drainage Handbook Stormwater Management Facility, Jan 2004

Survey Safety Handbook, June 1999

Drainage Handbook Temporary Drainage Design, Nov 2013

Plans Preparation Manual Volume I: Design Criteria and Process, Jan 2016

Project Development and Environmental Manual (PD&E Manual) Part 1: Process and Guidelines, July 2008

Project Development and Environmental Manual (PD&E Manual) Part 2: Analysis and Documentation, July 2008

Active Construction Projects, http://www.fdot.gov/agencyresources/maps/projects/

Websites for Major Projects on Florida's Highways, http://www.fdot.gov/info/moreDOT/majorprojects.shtm

Approved Additives/Processes and Statistics for Warm Mix Asphalt, http://www.fdot.gov/materials/quality/programs/warmmixasphalt/

Evaluation of Warm-Mix Asphalt Performance in Florida, July 2013

E.4 KYTC

Table E.4 Sustainability Practices of KYTC under PSIM Indicators

As of 06/07/2016			
Management	Project Team	yes	Construction Guidance Manual, 105 Section Engineer, 209 Preconstruction Conference, 310 Extra Work
	Budget Plan	no	Pavement Design Guide, Appendix E 3.1.4 Cost Comparison
	Quality Management	yes	Construction Guidance Manual, 106 Inspector, 401 Final Inspection; Utilities & Rails Guidance Manual, 1306 Inspection Duties
	Emergencies	yes	Construction Guidance Manual, 113 Highway Closure & Accident Reports; Maintenance Guidance Manual, 1100 Extraordinary (Disaster) Maintenance; Field Operations Guidance Manual, 1100 Extraordinary
	Maintenance Schedule	yes	Construction Guidance Manual, 309 Time; Maintenance Guidance Manual, 206 Planned Night/Weekend Work
	Project Record	partially	Construction Guidance Manual, 207 Site Manager Diary; Utilities & Rails Guidance Manual, 1900 Records & Retention; Highway Design Manual, 403 Environmental Documents
	Work Zone Management	partially	Policy and Procedures for the Safety and Mobility of Traffic Through Work Zones
	Crew Training	partially	Field Operations Guidance Manual, 500 Training $ Licensing; Kentucky Best Management Practices (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites, 4.9.8 Employee Training
	Project Interaction	partially	Utilities & Rails Guidance Manual, 800 Joint Utility Information Meeting
Technique	Technique Selection		
	Distress Reason	no	Construction Guidance Manual, 203 Field Check of Structures
	Standard Procedure	yes	2012 Standard Drawings, Section Roadway; Utilities & Rails Guidance Manual, 9000 Exhibits; Field Operations Guidance Manual; Pavement management Field Handbook
	Disturbance and Repair		
	Uneven Surface		
	Preservation		
Material	Quality Certification	yes	Kentucky Methods Guidance Manual; List of Approved Materials; Standard Specifications for Road and Bridge Construction, 800 Materials; Materials Field Sampling and Testing Manual; Materials Guidance Manual

	Material Production	partially	Standard Specifications for Road and Bridge Construction Section 401 Asphalt Mixing Plant Requirements
	Local Material	partially	Aggregate Source Book
	Material Storage	no	Environmental Handbook for Management of Highways and Transportation Facilities, 3.16 Dry Bulk materials Storage
	Recycle Material	partially	Environmental Handbook for Management of Highways and Transportation Facilities, 4.1 Reduce, Reuse, Recycle and Exchange; Standard Specifications for Road and Bridge Construction, 409 Asphalt Mixture Using Reclaimed Materials
	Alternative Material	partially	Materials Field Sampling and Testing Manual, 400 Cement; Standard Specifications for Road and Bridge Construction, 844 Mineral Admixtures for Concrete
	Earthwork	no	Standard Specifications for Road and Bridge Construction, 200 Earthwork
Energy& Water	Efficient Lighting		
	Energy Consumption I, Construction	partially	Equipment Guidance Manual; Maintenance Guidance Manual, 1700 Equipment; Environmental Handbook for Management of Highways and Transportation Facilities, 3.11 Vehicle and Equipment Cleaning and Maintenance
	Energy Consumption II, Transport	partially	Equipment Guidance Manual; Environmental Handbook for Management of Highways and Transportation Facilities, 3.11 Vehicle and Equipment Cleaning and Maintenance
	Energy Consumption III, Asphalt Mixture	no	Standard Specifications for Road and Bridge Construction Section 401 Asphalt Mixing Plant Requirements
	Water Consumption		
	Heat Island Alleviation		
Environment	Wastes	partially	Construction Guidance Manual, 114 Hazardous Wastes & Substances, 707 Construction Activities Affecting Streams, 708 Sinkholes; Environmental Analysis Guidance Manual, 1100 Water-Related Permits; Maintenance Guidance Manual, 211 Disposal of Waste Material; Highway Design Manual, 402 Environmental Issues; Environmental Handbook for Management of Highways and Transportation Facilities, 4 Waste Management; Kentucky Best Management Practices (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites, 3 Developing a BMP Plan, 4.9 Good Housekeeping and Other Runoff Controls; Drainage Manual, 202 Stormwater Management
	Air Quality	yes	Environmental Analysis Guidance Manual, 600 Air Quality Analysis; Highway Design Manual, 402 Environmental Issues; Environmental Handbook for Management of Highways and Transportation Facilities, 2.1.4 Operations That Generate Dust; Kentucky Best Management Practices (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites, 4.4.6 Dust Control
	Noise Control	yes	Construction Guidance Manual, 313 Construction Noise; Environmental Analysis Guidance Manual, 500 Noise Impact Analysis; Highway Design Manual, 402 Environmental Issues

	Vibration Control		
	Erosion and Sediment Control	partially	Construction Guidance Manual, 705 Temporary Erosion Controls, 706 Permanent Erosion Controls; Drainage Manual, 1000 Erosion Control; Field Operations Guidance Manual, 905 Slope Protection; Kentucky Best Management Practices (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites, 4.5 Slope Protection
	Ecology Conservation	yes	Environmental Analysis Guidance Manual, 1000 UST & Hazardous Materials Impact Assessment; Environmental Analysis Guidance Manual, 800 Ecological Impact Assessment; Maintenance Guidance Manual, 216 Preservation of Wetlands, 217 Preservation of Flood Plains, 1306 Maintenance of State Park Roads; Highway Design Manual, 402 Environmental Issues; Kentucky Best Management Practices (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites, 4.8 Stream and Wetland Protection
Safety	Traffic Control	yes	Construction Guidance Manual, 112 Traffic Control Through Highway & Street Work Zones; 2012 Standard Drawings, Section Traffic; Maintenance Guidance Manual, 303 Signs for Maintenance Crews; Field Operations Guidance Manual, 1512 Traffic-Control Devices Inspection; Traffic Operations Guidance Manual
	Construction Safety	yes	Construction Guidance Manual, 111 Safety; Employee Safety & Health Manual; Maintenance Guidance Manual, 302 Special Areas of Concern for Safety
	Pavement Marking	partially	Maintenance Guidance Manual, 404 Temporary Pavement Stripes; Field Operations Guidance Manual, 1400 Signings & Markings; Highway Design Manual, 1200 Signing; Traffic Operations Guidance Manual, 500 Pavement Markings & Delineation
	Appurtenances	partially	Maintenance Guidance Manual, 600 Roadside Maintenance; Field Operations Guidance Manual, 500 Roadside General, 1500 Traffic; Maintenance Guidance Manual, 408 Guardrail
	Pedestrian and Bicyclists	partially	Highway Design Manual, 1502 Guidelines for Pedestrian & Bicycle Accommodations; Maintenance Guidance Manual, 502 Maintenance of Public School Entrances & Other Pull-Offs
	Drainage	partially	Construction Guidance Manual, 900 Grade & Drain Construction; Maintenance Guidance Manual, 409 Ditches; Field Operations Guidance Manual, 900 Roadway Drainage; Kentucky Best Management Practices (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites, 4.6 Drainage
	Glare Control		
	Snow and Ice Removal	yes	Maintenance Guidance Manual, 1000 Snow & Ice; Field Operations Guidance Manual, 1000 Snow & Ice; Environmental Handbook for Management of Highways and Transportation Facilities, 2.4 Snow and Ice Management Activities
Community	Report the Problem	yes	Report a Pothole or Road Concern
	Landscape Maintenance	yes	Construction Guidance Manual, 712 Landscaping; Maintenance Guidance Manual, 700 Vegetation Management; Field Operations Guidance Manual, 600 Roadside Agronomy, 700 Mowing; Pesticide

			Guidance Manual; Environmental Handbook for Management of Highways and Transportation Facilities, 2.2 Vegetation Management Activities
	Aesthetic Design	partially	Highway Design Manual, 402 Environmental Issues
	Culture Conservation	partially	Construction Guidance Manual, 109 Archaeological Coordination, 314 Historic Preservation Laws; Environmental Analysis Guidance Manual, 900 Cultural Resource Assessment; Highway Design Manual, 402 Environmental Issues
	Notification	partially	Maintenance Guidance Manual, 402 Railroad Crossings
	Ease of Use		
	Community Adaption	yes	Environmental Analysis Guidance Manual, 700 Socioeconomic Impact Analysis; Highway Design Manual, 402 Environmental Issues, 600 Public Involvement, 1100 Access Management; Utilities & Rails Guidance Manual, 1303 Meetings, 2008 Highway-Rail Crossing Rehabilitation, 2009 Crossing Protective Device Maintenance; Construction Guidance Manual, 206-2 Work on the Railroad Right-of-Way; Maintenance Guidance Manual, 501 Maintenance of Public Road Intersections, 504 Maintenance of Private & Commercial Entrances
	Sustainability Promotion		
Innovation	Creative Idea	partially	Construction Guidance Manual, 312 Value Engineering
	Sustainability Representative		
	Certified Sustainable Pavement		

References

Construction Guidance Manual, May 2009, last updated on July 14 2015

Employee Safety & Health Manual, Jan 2010

Kentucky Methods Guidance Manual, Nov 2008, last update on Aug 15 2014

List of Approved Materials, updated daily

Aggregate Source Book, Sep 21 2015

2012 Standard Drawings

Standard Specifications for Road and Bridge Construction, June 15 2012

Drainage Manual, Jan 18 2011

Equipment Guidance Manual, Sep 2014

Environmental Analysis Guidance Manual, Sep 2014

Utilities & Rails Guidance Manual, Dec 2013

Maintenance Guidance Manual, Jan 2009, last updated on June 25 2015

Field Operations Guidance Manual, Oct 2011, last updated on Aug 8 2012

Highway Design Manual, Jan 2006

Materials Field Sampling and Testing Manual, Aug 2015

Materials Guidance Manual, Mar 2014

Pesticide Guidance Manual, Nov 2009, last updated on July 26 2011

Traffic Operations Guidance Manual, June 2005, last updated on Feb 25 2015

Pavement Design Guide, 2007

Policy and Procedures for the Safety and Mobility of Traffic Through Work Zones

Environmental Handbook for Management of Highways and Transportation Facilities, 2005

Kentucky Best Management Practices (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites

Pavement management Field Handbook, 2009

Report a Pothole or Road Concern, http://transportation.ky.gov/Pages/Report-a-Pothole.aspx

E.5 MnDOT

Table E.5 Sustainability Practices of MnDOT under PSIM Indicators

As of 06/19/2016			
Management	Project Team	yes	Contract Administration Manual Section 300; Standard Specifications for Construction Section 15
	Budget Plan	no	Road Design Manual Section 2-4.03; HPDP Cost-Effective Policy; Pavement Design Manual Chapter 7
	Quality Management		
	Emergencies	yes	Maintenance Manual Section 1-6.02; Maintenance Manual Chapter 7
	Maintenance Schedule		

	Project Record	partially	Concrete Manual Chapter 7; Contract Administration Manual Section 410~420; Pavement Design Manual Section 260; Pavement Design Manual Chapter 8
	Work Zone Management	partially	Road Design Manual Section 10-9; Contract Administration Manual Section 220
	Crew Training		
	Project Interaction		
Technique	Technique Selection		
	Distress Reason	partially	HPDP Purpose and Need Statement; Pavement Design Manual Chapter 2
	Standard Procedure	yes	Concrete Manual Chapter 0, 4, 6, 9; HPDP Design Standards and Exceptions; Maintenance Manual Chapter 3, Section 5-4.01; Pavement Design Manual Chapter 4~5; Standard Specifications for Construction Section 23; Materials Lab Supplemental Specifications for Construction Section 2301~2399
	Disturbance and Repair	partially	Standard Specifications for Construction Section 1712, 1714
	Uneven Pavement	no	Standard Specifications for Construction Section 2399
	Preservation	yes	Road Design Manual Section 2-5.02
Material	Quality Certification	partially	Concrete Manual Chapter 1~3, 5; Contract Administration Manual Section 430; Grade & Base Manual; Pavement Design Manual Section 450; Standard Specifications for Construction Section 16; Standard Specifications for Construction Division III; Materials Lab Supplemental Specifications for Construction Division I, III
	Material Production	no	Concrete Manual Chapter 4; Materials Lab Supplemental Specifications for Construction Section 1604
	Local Material		
	Material Storage		
	Recycle Material	yes	HPDP Excess Materials; Pavement Design Manual Section 410, 930; Standard Specifications for Construction Section 2215
	Alternative Material		
	Earthwork	partially	Geotechnical Engineering Manual; HPDP Groundwater, Geotechnical and Earthborn Vibrations; Standard Specifications for Construction Section 2105~2106
Energy& Water	Efficient Lighting	partially	Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments Section 3.6; Road Design Manual Section 10-6; Maintenance Manual Section 8-5.0; Roadway Lighting Design Manual; Traffic Control Signal Design Manual Chapter 7; Lighting & Signals Field Guide; Traffic Engineering Manual Chapter 10
	Energy Consumption I, Construction	partially	HPDP Energy analysis Procedure; Maintenance Manual Chapter 4; Guidance for Flashing Arrow Boards

	Energy Consumption II, Transport	no	HPDP Energy analysis Procedure
	Energy Consumption III, Asphalt Mixture	partially	Warm Mix Asphalt - WMA Guidance; Materials Lab Supplemental Specifications for Construction Section 2360
	Water Consumption		
	Heat Island Alleviation		
Environment	Wastes	partially	HPDP Contaminated Materials; HPDP Excess Materials; HPDP Regulated Materials/Waste; HPDP Water Quality; Maintenance Manual Section 5-4.15; Standard Specifications for Construction Section 1717
	Air Quality	partially	HPDP Air Quality; Standard Specifications for Construction Section 1717, 2130
	Noise Control	no	HPDP Noise
	Vibration Control	partially	HPDP Groundwater, Geotechnical and Earthborn Vibrations
	Erosion and Sediment Control	yes	Road Design Manual Section 3-4.08; Road Design Manual Section 8-5; HPDP Erosion Control; Maintenance Manual Section 5-4.07
	Ecology Conservation	yes	HPDP Fish and Wildlife; HPDP Stream or Water Body Modification; HPDP Threatened and Endangered Species; HPDP Vegetation; HPDP Wetlands; HPDP Wild & Scenic Rivers; Maintenance Manual Section 5-3.0, 5-4.08~5-4.12; Standard Specifications for Construction Section 1713
Safety	Traffic Control	yes	Road Design Manual Chapter 10, Section 12-6; MN MUTCD; Minnesota Flagging Handbook; Maintenance Manual Chapter 11; Traffic Control Signal Design Manual Chapter 3; Standard Specifications for Construction Section 1710, 1715; Temporary Traffic Control Zone Layouts Field Manual; Traffic Engineering Manual Chapter 8
	Construction Safety	yes	Maintenance Manual Section 3-3.0, 4-12.0; Standard Specifications for Construction Section 1706
	Pavement Marking	partially	Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments Section 3.1.3; Road Design Manual Section 10-3; MN MUTCD Part 3; Maintenance Manual Section 8-10.0; Traffic Control Signal Design Manual Section 8.3; Standard Specifications for Construction Section 2102; Lighting & Signals Field Guide Chapter 26; Traffic Engineering Manual Chapter 7
	Appurtenances	yes	Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments Section 3.1, 3.2, 3.7; Road Design Manual Section 4-4~4-6, 10-7~10-8, 11-9, 11-11; Maintenance Manual Section 5-4.16; Maintenance Manual Chapter 8; Traffic Control Signal Design Manual Chapter 5, Section 8.2; Standard Specifications for Construction Section 25; Lighting & Signals Field Guide; Standard Signs Manual; Traffic Engineering Manual Chapter 6, 9

	Pedestrian and Bicyclists	yes	Bikeway Facility Design Manual; Minnesota's Best Practices for Pedestrian/Bicycle Safety; Road Design Manual Section 2-3.03~2-3.04, 2-3.06, 11-3~11-4, 12-3.05~12-3.06; MN MUTCD Part 9; HPDP Bikeways and Pedestrians; Traffic Engineering Manual Chapter 13; ADA Compliance Checklist Guidance (APS); ADA Compliance Checklist Guidance (Curb Ramps); ADA Project Design Guide; HPDP Transit; Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments Section 2.1, 3.4
	Drainage	yes	Road Design Manual Chapter 8; Drainage Manual; Maintenance Manual Chapter 9; State Aid Manual Chapter 5.5
	Glare Control	no	Roadway Lighting Design Manual Section 1.3
	Snow and Ice Removal	yes	Road Design Manual Section 12-5.01; HPDP Snow Blowing and Drifting Snow Control; Maintenance Manual Chapter 2, Section 5-4.03; Field Guide for Testing Deicing Chemicals; Winter Chemical Catalog; Winter Chemicals - Approved Product List; Anti-Icing Guide
Community	Report the Problem	partially	Report a pothole or graffiti; ADA complaint form
	Landscape Maintenance	yes	Road Design Manual Section 11-10, 12-7; Maintenance Manual Section 5-4.05; Seeding Manual; Native Seed Mix Design for Roadsides
	Aesthetic Design	partially	HPDP Visual Quality
	Culture Conservation	yes	HPDP Historical and Archaeological Review; Maintenance Manual Section 5-4.13~5-4.14
	Notification	partially	Current Construction; Plans, Studies and Future Construction
	Ease of Use	partially	HPDP ITS; Traffic Control Signal Design Manual Chapter 4; Standard Specifications for Construction Section 1707; Traffic Engineering Manual Chapter 5
	Community Adaption	yes	Road Design Manual Chapter 5~6, Chapter 9, Section 11-5~11-6, Chapter 12; MN MUTCD Part 7~8; HPDP Business Impact Mitigation; HPDP Farmland Impacts; HPDP Floodplains; HPDP Land Use Impacts; HPDP Complete Streets; HPDP Municipal Consent; HPDP Railroads; Maintenance Manual Section 3-9.0, Chapter 10; Pavement Design Manual Section 600, 650, 660; State Aid Manual Chapter 5.1; Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments
	Sustainability Promotion		
Innovation	Creative Idea	yes	Concrete Manual Chapter 8
	Sustainability Representative	partially	Road Design Manual Section 11-8, 12-3.07; HPDP Construction Impacts; HPDP Critical Areas; HPDP Environmental Justice; HPDP Social and Economic Impacts; Pavement Design Manual Section 960
	Certified Sustainable Pavement		

References

Bikeway Facility Design Manual, Mar 2007

Minnesota's Best Practices for Pedestrian/Bicycle Safety, Sep 2013

Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments, Sep 2013

Road Design Manual, May 2012

Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD), Feb 2015

Concrete Manual, Sep 2003

Contract Administration Manual, May 2011

Drainage Manual, Aug 2000

Minnesota Flagging Handbook, Jan 2014

Geotechnical Engineering Manual, Dec 2013

Grade & Base Manual, Mar 2016

ADA Compliance Checklist Guidance (Accessible Pedestrian Signals), July 2014

ADA Compliance Checklist Guidance (Curb Ramps), June 2015

ADA Project Design Guide, June 2012

Highway Project Development Process (HPDP) Subject Guidance: Air Quality, Sep 2009

Highway Project Development Process (HPDP) Subject Guidance: Bikeways and Pedestrians, Dec 2006

Highway Project Development Process (HPDP) Subject Guidance: Business Impact Mitigation

Highway Project Development Process (HPDP) Subject Guidance: Complete Streets, Oct 2014

Highway Project Development Process (HPDP) Subject Guidance: Construction Impacts

Highway Project Development Process (HPDP) Subject Guidance: Contaminated Materials, May 2016

Highway Project Development Process (HPDP) Subject Guidance: Cost-Effective Policy, Apr 2012

Highway Project Development Process (HPDP) Subject Guidance: Critical Areas

Highway Project Development Process (HPDP) Subject Guidance: Design Standards and Exceptions, Feb 2014

Highway Project Development Process (HPDP) Subject Guidance: Energy analysis Procedure

Highway Project Development Process (HPDP) Subject Guidance: Environmental Justice

Highway Project Development Process (HPDP) Subject Guidance: Erosion Control
Highway Project Development Process (HPDP) Subject Guidance: Excess Materials
Highway Project Development Process (HPDP) Subject Guidance: Farmland Impacts
Highway Project Development Process (HPDP) Subject Guidance: Fish and Wildlife
Highway Project Development Process (HPDP) Subject Guidance: Floodplains
Highway Project Development Process (HPDP) Subject Guidance: Groundwater, Geotechnical and Earthborn Vibrations
Highway Project Development Process (HPDP) Subject Guidance: Historical and Archaeological Review
Highway Project Development Process (HPDP) Subject Guidance: Intelligent Transportation Systems, Nov 2015
Highway Project Development Process (HPDP) Subject Guidance: Land Use Impacts
Highway Project Development Process (HPDP) Subject Guidance: Municipal Consent, Dec 2014
Highway Project Development Process (HPDP) Subject Guidance: Noise
Highway Project Development Process (HPDP) Subject Guidance: Purpose and Need Statement
Highway Project Development Process (HPDP) Subject Guidance: Railroads
Highway Project Development Process (HPDP) Subject Guidance: Regulated Materials/Waste, May 2016
Highway Project Development Process (HPDP) Subject Guidance: Snow Blowing and Drifting Snow Control
Highway Project Development Process (HPDP) Subject Guidance: Social and Economic Impacts
Highway Project Development Process (HPDP) Subject Guidance: Stream or Water Body Modification
Highway Project Development Process (HPDP) Subject Guidance: Threatened and Endangered Species
Highway Project Development Process (HPDP) Subject Guidance: Transit
Highway Project Development Process (HPDP) Subject Guidance: Vegetation, Jan 2013
Highway Project Development Process (HPDP) Subject Guidance: Visual Quality, Aug 2010
Highway Project Development Process (HPDP) Subject Guidance: Water Quality
Highway Project Development Process (HPDP) Subject Guidance: Wetlands
Highway Project Development Process (HPDP) Subject Guidance: Wild & Scenic Rivers
Maintenance Manual, Jan 2016

Pavement Design Manual, Feb 2016

Roadway Lighting Design Manual, May 2010

Seeding Manual, 2014

Native Seed Mix Design for Roadsides, May 2010

Traffic Control Signal Design Manual, June 2016

Standard Specifications for Construction, 2016

Lighting & Signals Field Guide, 2016

Standard Signs Manual, 2016

State Aid Manual, May 2015

Temporary Traffic Control Zone Layouts Field Manual, Jan 2014

Traffic Engineering Manual, Oct 2015

Guidance for Flashing Arrow Boards, Dec 2010

Anti-Icing Guide, Sep 2010

Winter Chemicals - Approved Product List, Oct 2015

Winter Chemical Catalog, Oct 2015

Field Guide for Testing Deicing Chemicals

Report a pothole or graffiti, https://www.dot.state.mn.us/metro/maintenance/potholes.html

ADA complaint form, https://www.dot.state.mn.us/ada/complaintform.html

Current Construction, https://www.dot.state.mn.us/roadwork/current.html

Plans, Studies and Future Construction, https://www.dot.state.mn.us/roadwork/future.html

Warm Mix Asphalt - WMA Guidance, last updated April 2016

Materials Lab Supplemental Specifications for Construction, 2014

E.6 NYSDOT

Table E.6 Sustainability Practices of NYSDOT under PSIM Indicators

As of 07/13/2016

Management	Project Team	partially	Standard Highway Specifications, Volume I, Section 1.06.26; MURK 1A CAM Section 95; Design Consultant Agreements Soils-Related Task Assignments
	Budget Plan	no	Highway Design Manual Section 5.6, 21.6; Design-Build Procedures Manual Volume I Section 4.3.8; Design-Build Procedures Manual Volume II Section 1.15
	Quality Management	yes	Standard Specifications - Construction and Materials Section 105-19; Standard Highway Specifications, Volume I, Section 1.06.39, 1.06.42; MURK 1A CAM Section 92, 105-19; MURK 1D CCM Section 5.1; Comprehensive Pavement Design Manual Section 3.3; Project Development Manual Appendix 12; Design-Build Procedures Manual Volume II Section 1.9
	Emergencies	partially	MURK 1A CAM Section 97; Construction Accident Reporting Program Users Manual
	Maintenance Schedule	yes	Standard Specifications - Construction and Materials Section 108; Standard Highway Specifications, Volume I, Section 1.06.25; MURK 1A CAM Section 108; Design-Build Procedures Manual Volume II Section 1.5; Highway Design Manual Section 16.5.7
	Project Record	partially	Standard Specifications - Construction and Materials Section 104, 105-17; MURK 1D CCM Section 5.2; Office Engineer's Guidance Chapter 2; Design-Build Procedures Manual Volume I Section 7.0
	Work Zone Management	yes	Standard Specifications - Construction and Materials Section 105-13, 619; Standard Highway Specifications, Volume I, Section 1.06.47; Highway Design Manual Section 10.4, 16.4~16.5
	Crew Training	no	MURK 1D CCM Section 4.14
	Project Interaction	partially	Standard Specifications - Construction and Materials Section 105-06; MURK 1A CAM Section 105-06; Design-Build Procedures Manual Volume I Section 4.3.4
Technique	Technique Selection	partially	Comprehensive Pavement Design Manual Section 3.2, Chapter 8
	Distress Reason	partially	Comprehensive Pavement Design Manual Chapter 2
	Standard Procedure	yes	Standard Specifications - Construction and Materials Section 400~500, 621; Standard Highway Specifications, Volume I, Division IV; Highway Design Manual Section 3.3~3.4, Chapter 7, Section 23.11; MURK 1A CAM Section 105-03~105-04; MURK 1B CIM Section 300~500; Design and Construction Guidelines for Full Depth Reclamation of Asphalt Pavement; Cold In-Place Recycling Construction Inspection Guidelines; Paver-Placed Surface Treatment Construction Inspection Guidelines; Micro-Surfacing and Slurry Guidelines; Warranty Requirements for HMA Top Course; Comprehensive Pavement Design Manual Chapter 5
	Disturbance and Repair	partially	Standard Specifications - Construction and Materials Section 107-07~107-09; MURK 1A CAM Section 107-08~107-09
	Uneven Surface		
	Preservation	partially	Comprehensive Pavement Design Manual Chapter 10
Material	Quality Certification	yes	Standard Specifications - Construction and Materials Section 106, 700; Standard Highway Specifications, Volume I, Division V, Section 1.06.31; MURK 1A CAM Section 106-02; MURK 2A

			MIM; Office Engineer's Guidance Chapter 3; Independent Assurance Sampling and Testing Manual; Materials Inspection Manual; Quality Assurance Procedure for Standard Specifications, Construction and Materials
	Material Production	partially	Standard Specifications - Construction and Materials Section 401; Quality Control and Quality Assurance Procedures for HMA Production
	Local Material	partially	Standard Specifications - Construction and Materials Section 106-11; MURK 1A CAM Section 106-11
	Material Storage	yes	Standard Specifications - Construction and Materials Section 106-06; Standard Highway Specifications, Volume I, Section 1.06.34
	Recycle Material	yes	Standard Specifications - Construction and Materials Section 106-05
	Alternative Material		
	Earthwork	partially	Standard Specifications - Construction and Materials Section 200, 733; MURK 1B CIM Section 200; An Engineering Description of Soils Visual-Manual Procedure; Guidelines for Embankment Construction; Rock Slope Rating Procedure; Mechanically Stabilized Earth System Inspection Manual; Ground Anchor Inspector's Manual; Geotechnical Design Manual
Energy& Water	Efficient Lighting	no	Standard Specifications - Construction and Materials Section 670; Standard Highway Specifications, Volume I, Section 1.06.49; Highway Design Manual Chapter 12
	Energy Consumption I, Construction	partially	Standard Specifications - Construction and Materials Section 105-18; Calibration of Metering System for Recycling Equipment; The Environmental Manual Section 4.4.17
	Energy Consumption II, Transport	partially	The Environmental Manual Section 4.4.17
	Energy Consumption III, Asphalt Mixture	partially	Approved List of Warm Mix Asphalt Technologies
	Water Consumption	no	Standard Specifications - Construction and Materials Section 712-01
	Heat Island Alleviation		
Environment	Wastes	yes	Standard Specifications - Construction and Materials Section 107-10, Section 107-12; MURK 1A CAM Section 107-10, Section 107-12; Office Engineer's Guidance Chapter 8; The Environmental Manual Section 4.4.1~4.4.8, Section 4.4.20
	Air Quality	yes	Standard Specifications - Construction and Materials Section 107-11; The Environmental Manual Section 4.4.16, 4.4.19
	Noise Control	partially	Standard Specifications - Construction and Materials Section 643; The Environmental Manual Section 4.4.18
	Vibration Control	no	Highway Design Manual Section 9.6
	Erosion and Sediment Control	partially	Highway Design Manual Section 9.3; Bank and Channel Protective Lining Design Procedures; Geotechnical Design Procedure For Flexible Wall Systems; Geotechnical Design Procedure For

			Preparing Rock Slope Recommendations; Design Procedure For Launched Soil Nail Shallow Slough Treatment; Geotechnical Design Manual Chapter 10, Chapter 15~17
	Ecology Conservation	partially	Standard Specifications - Construction and Materials Section 610~611, 613, 620; MURK 1D CCM Section 2.3; The Environmental Manual Section 4.4.9, 4.4.11
Safety	Traffic Control	yes	Standard Specifications - Construction and Materials Section 729; Standard Highway Specifications, Volume I, Section 1.06.44; Highway Design Manual Chapter 16; MURK 1A CAM Section 104-08; Requirements for the Design and Construction of Underground Utility Installations Within the State Highway Right-Of-Way Chapter 5; New York State Supplement to the Manual on Uniform Traffic Control Devices; Work Zone Traffic Control
	Construction Safety	yes	Standard Highway Specifications, Volume I, Section 1.06.28; MURK 1A CAM Section 107-05~107-06; MURK 1C S&H; MURK 1D CCM Section 4.15; Employee Safety Manual; Safety Procedure Manual For Use With Nuclear Moisture-Density Gauges
	Pavement Marking	partially	Standard Specifications - Construction and Materials Section 635, 640, 685, 687~688; Highway Design Manual Section 11.4
	Appurtenances	partially	Standard Specifications - Construction and Materials Section 606~607, 609, 642, 644~647; Highway Design Manual Section 3.2, Chapter 10~11
	Pedestrian and Bicyclists	partially	Standard Specifications - Construction and Materials Section 608; Standard Highway Specifications, Volume I, Section 1.06.48; Highway Design Manual Section 5.7.15, Section 5.7.20~5.7.21, Chapter 17~18, Section 24.2~24.4
	Drainage	partially	Standard Specifications - Construction and Materials Section 602~605, 609; Highway Design Manual Chapter 8, Chapter 19; Design, Construction, and Maintenance of Recharge Basins; Comprehensive Pavement Design Manual Chapter 9
	Glare Control		
	Snow and Ice Removal	partially	Standard Specifications - Construction and Materials Section 646; Highway Design Manual Section 5.7.13
Community	Report the Problem		
	Landscape Maintenance	partially	Standard Specifications - Construction and Materials Section 614~615, 616~617, 713; Highway Design Manual Section 28.5~28.7, 28.11; The Environmental Manual Section 4.4.10
	Aesthetic Design	no	Highway Design Manual Section 5.8.8, 9.4.6, 28.4
	Culture Conservation	partially	Highway Design Manual Section 28.7; The Environmental Manual Section 4.4.12
	Notification	partially	Standard Specifications - Construction and Materials Section 107-04; Standard Highway Specifications, Volume I, Section 1.06.46, 1.06.46A; MURK 1A CAM Section 104-06; Projects in Your Neighborhood
	Ease of Use	no	Standard Specifications - Construction and Materials Section 683; Highway Design Manual Section 24.6; Project Development Manual Appendix 6

	Community Adaption	partially	Highway Design Manual Section 5.9, Chapter 6, Section 25.7, Chapter 27, Section 28.3, 28.8~28.10; The Environmental Manual Section 4.4.13~4.4.15, 4.4.22; Standard Specifications - Construction and Materials Section 105-09, 675; Standard Highway Specifications, Volume I, Section 1.06.24, Section 1.06.50; MURK 1A CAM Section 105-09; Project Development Manual Appendix 2
	Sustainability Promotion		
Innovation	Creative Idea		
	Sustainability Representative		
	Certified Sustainable Pavement		

References

Standard Specifications - Construction and Materials (US Customary Units), Sep 1, 2016

Standard Highway Specifications, Volume I, Feb 1, 2009

Highway Design Manual, May 1 2016

Manual for Uniform Record Keeping (MURK) 1A Contract Administration Manual (CAM), last updated June 2014

Manual for Uniform Record Keeping (MURK) 1B Construction Inspection Manual (CIM), last updated Nov 2015

Manual for Uniform Record Keeping (MURK) 1C Safety & Health Program Manual (S&H), July 1998

Manual for Uniform Record Keeping (MURK) 1D Construction Consultant Manual (CCM), continuously updated

Manual for Uniform Record Keeping (MURK) 2A Materials Inspection Manual (MIM), Oct 2005

Office Engineer's Guidance, 2012

Construction Program Employee Safety Manual, Mar 2016

Construction Accident Reporting Program Users Manual V3.0, Apr 2011

An Engineering Description of Soils Visual-Manual Procedure, Aug 2015

Design, Construction, and Maintenance of Recharge Basins, Aug 2015

Geotechnical Design Procedure For Flexible Wall Systems, Aug 2015

Design Consultant Agreements Soils-Related Task Assignments, Aug 2015

Geotechnical Design Procedure For Preparing Rock Slope Recommendations, Aug 2015

Design Procedure For Launched Soil Nail Shallow Slough Treatment, Aug 2015

Safety Procedure Manual For Use With Nuclear Moisture-Density Gauges, Aug 2015

Guidelines for Embankment Construction, Aug 2015

Rock Slope Rating Procedure, Aug 2015

Mechanically Stabilized Earth System Inspection Manual, Aug 2015

Ground Anchor Inspector's Manual, Aug 2015

Design and Construction Guidelines for Full Depth Reclamation of Asphalt Pavement, Aug 2015

Cold In-Place Recycling Construction Inspection Guidelines, May 2003

Paver-Placed Surface Treatment Construction Inspection Guidelines, May 2003

Independent Assurance Sampling and Testing Manual, May 2011

Materials Inspection Manual, Dec 2005

Materials Procedure: Micro-Surfacing and Slurry Guidelines, Nov 2009

Materials Procedure: Quality Assurance Procedure for Standard Specifications, Construction and Materials, Aug 2005

Materials Procedure: Quality Control and Quality Assurance Procedures for HMA Production, May 2013

Materials Procedure: Warranty Requirements for HMA Top Course, Sep 2010

Materials Procedure: Calibration of Metering System for Recycling Equipment, June 2015

Requirements for the Design and Construction of Underground Utility Installations Within the State Highway Right-Of-Way, Feb 1997

New York State Supplement to the Manual on Uniform Traffic Control Devices, Mar 16 2011

Comprehensive Pavement Design Manual, last updated May 14 2014

The Environmental Manual, 2010

Geotechnical Design Manual, last updated Feb 29 2016

Project Development Manual, last updated July 5 2016

Design-Build Procedures Manual Volume I, last updated Dec 2011

Design-Build Procedures Manual Volume II, Sep 2005

Work Zone Traffic Control, Feb 2015

Approved List of Warm Mix Asphalt Technologies, last updated Sep 21 2015

Projects in Your Neighborhood, https://www.dot.ny.gov/projects

E.7 ODOT-Oregon

Table E.7 Sustainability Practices of ODOT-Oregon under PSIM Indicators

As of 07/29/2016			
Management	Project Team	partially	Construction Manual Section 1-4~1-5, Chapter 9, Section 11-2, 12A-1; Standard Specifications for Construction Section 150, 180.42
	Budget Plan	partially	Estimating Manual; Highway Design Manual Section 15.5; Pavement Design Guide Chapter 9; Project Delivery Guide
	Quality Management	partially	Construction Manual Chapter 10, 34, 36; Estimating Manual Section-Quality Control; QCCS Manual
	Emergencies	partially	Construction Manual Section 12A-6; Archaeology Guidance for Hazardous Material Spill and Emergency Situations; Emergency and Urgency Maintenance of Cut or Fill Slope Failures; REC Manual & Guidance Chapter 9; Traffic Manual Section 6.33; Maintenance Guide Chapter 3, 8
	Maintenance Schedule	partially	Construction Manual Phase 2 and 3, Section 11-4, 13-6~13-11; Estimating Manual Section-Construction Schedules; Routine Road Maintenance Section-Monitoring; Standard Specifications for Construction Section 180.41, 180.85
	Project Record	yes	Construction Manual Chapter 12~12A, 37; Routine Road Maintenance Section-Documentation and Reporting; Environmental Baseline Report Guidance; Geotechnical Design Manual Chapter 21; Pavement Design Guide Section 4.1; Standard Specifications for Construction Section 170.07; Project Tracking Map; Highway Projects
	Work Zone Management	yes	Highway Design Manual Section 10.11.11; Inspector's Manual Part 200; Traffic Manual Section 6.43
	Crew Training	partially	Estimating Manual Section-Training Information; Routine Road Maintenance Section-Training; Field Staff Training Curriculum Guide
	Project Interaction	partially	Construction Manual Section 13-10; Right of Way Manual Chapter 12
Technique	Technique Selection		
	Distress Reason	partially	Pavement Design Guide Section 4.3
	Standard Procedure	yes	Routine Road Maintenance; Survey Policy and Procedure Manual; Construction Surveying Manual For Contractors; Highway Design Manual Section 11.3; Inspector's Manual Part 300, Section 758, 746, 748, 758; Standard Drawings and Standard Details; Pavement Design Guide Chapter 7; Standard

			Specifications for Construction Section 600~700; Traffic Signal Policy and Guidelines Section 2.4; Maintenance Guide Chapter 15
	Disturbance and Repair	partially	Inspector's Manual Section 1050, 1070; Standard Specifications for Construction Section 170.80, 170.82, 170.89, 310.60
	Uneven Surface		
	Preservation	no	Contract Plans Development Guide, Volume I Chapter 15; Contract Plans Development Guide, Volume II Chapter 15; Highway Design Manual Section 1.4.2.3~1.4.2.4
Material	Quality Certification	yes	Construction Manual Chapter 12B~12D, 41, Section 22-6; HMAC Supplemental Test Procedures; Manual of Field Test Procedures; Nonfield-Tested Materials Acceptance Guide; Standard Specifications for Construction Section 160.05, 165, 2000, 3000; Qualified Products List; Maintenance Guide Chapter 9
	Material Production	partially	Inspector's Manual Section 705~735
	Local Material	yes	Construction Manual Section 22-5
	Material Storage	partially	Construction Manual Chapter 12F; Standard Specifications for Construction Section 165.75
	Recycle Material	partially	Construction Manual Chapter 33
	Alternative Material	no	Standard Specifications for Construction Section 180.32
	Earthwork	partially	Geotechnical Design Manual Chapter 9, 10, 12; Highway Design Manual Section 10.4.2.5~10.4.2.6; Inspector's Manual Section 330; Standard Specifications for Construction Section 330
Energy& Water	Efficient Lighting	partially	Highway Design Manual Section 10.11.6; Inspector's Manual Section 970; Lighting Policy and Guidelines; Standard Specifications for Construction Section 950~960; Traffic Lighting Design Manual; Traffic Manual Section 6.13
	Energy Consumption I, Construction	partially	Maintenance Guide Chapter 10
	Energy Consumption II, Transport		
	Energy Consumption III, Asphalt Mixture	partially	Approved Warm Mix Technology
	Water Consumption	yes	Standard Specifications for Construction Section 290.11, 340
	Heat Island Alleviation		
Environment	Wastes	partially	Construction Manual Section 11-7, Chapter 33; Contract Plans Development Guide, Volume I Chapter 11; Contract Plans Development Guide, Volume II Chapter 9; Highway Design Manual Section 10.3.3.5, 10.3.3.9; Standard Specifications for Construction Section 170.32, 290.10, 290.20, 310.43; Maintenance Guide Chapter 7; Routine Road Maintenance Activity 125; Water Resources Specialist Manual; Hydraulics Design Manual Chapter 14

	Air Quality	partially	Air Quality Manual; Construction Manual Section 11-7; Routine Road Maintenance Section-Dust Abatement; Highway Design Manual Section 10.3.3.8; Standard Specifications for Construction Section 290.30
	Noise Control	partially	Geotechnical Design Manual Chapter 22; Highway Design Manual Section 10.3.3.1; Noise Manual; Standard Specifications for Construction Section 290.32
	Vibration Control		
	Erosion and Sediment Control	partially	Construction Manual Section 11-6, 12A-3; Contract Plans Development Guide, Volume I Chapter 10; Contract Plans Development Guide, Volume II Chapter 8; Erosion Control Field Manual; Erosion Control Manual; Routine Road Maintenance Activity 122; Geotechnical Design Manual Chapter 7, 15, 19; Highway Design Manual Section 10.10; Inspector's Manual Section 396, 398; Standard Specifications for Construction Section 280, 331, 344, 396, 398; Maintenance Guide Chapter 7
	Ecology Conservation	partially	Construction Manual Section 11-8; Biological Assessment Guidance Manual; Biology Manual; REC Manual & Guidance Chapter 6, 8; ECTS Guidance; Highway Design Manual Section 10.3.3.4, 10.3.3.6, 10.3.3.7; Standard Specifications for Construction Section 290.34~290.51; Maintenance Guide Chapter 7, 15
Safety	Traffic Control	yes	Construction Manual Section 11-5, 12A-2; Contract Plans Development Guide, Volume I Chapter 7; Contract Plans Development Guide, Volume II Chapter 7; Highway Design Manual Section 4.4; Inspector's Manual Part 900; Oregon Supplement to the MUTCD; Temporary Traffic Control Handbook; Standard Specifications for Construction Section 225; Traffic Control Plans Design Manual; Maintenance Guide Chapter 6
	Construction Safety	yes	Construction Manual Chapter 17, 30, 31; Survey Safety Manual; Standard Specifications for Construction Section 170.61, 270; Maintenance Guide Chapter 6, 11
	Pavement Marking	partially	Inspector's Manual Section 850~867; Oregon Supplement to the MUTCD Part 3; Pavement Marking Design Guidelines; Traffic Line Manual Section B; Traffic Manual Section 6.24
	Appurtenances	partially	Contract Plans Development Guide, Volume I Chapter 12; Contract Plans Development Guide, Volume II Chapter 12; Routine Road Maintenance Activity 142, 143, 151, 153, 154; Roadside Development Design Manual; Geotechnical Design Manual Chapter 16; Highway Design Manual Section 4.6, 10.9; Inspector's Manual Section 810~840, 855, 857; Standard Specifications for Construction Section 800~900; Traffic Line Manual Section C~D; Traffic Manual Section 6.7~6.8, 6.28, 6.32
	Pedestrian and Bicyclists	partially	Highway Design Manual Chapter 12~13; Bicycle & Pedestrian Design Guide; Traffic Manual Section 6.1, 6.3, 6.6; Traffic Signal Policy and Guidelines Chapter 5, Section 6.4; Guidelines for Maintenance Activities and their impact on ADA requirements; Consideration for Bicycle Use of Shoulders in Maintenance Pavement Preservation Projects
	Drainage	yes	Contract Plans Development Guide, Volume I Section 9.2.5; Routine Road Maintenance Activity 120, 121, 123, 124; Highway Design Manual Section 4.7, 10.5; Hydraulics Design Manual; Inspector's

			Manual Part 400; Standard Specifications for Construction Section 240, 400; Maintenance Guide Chapter 15
	Glare Control		
	Snow and Ice Removal	partially	Routine Road Maintenance Activity 170, 176; Maintenance Guide Chapter 15
Community	Report the Problem		
	Landscape Maintenance	partially	Construction Manual Chapter 39; Roadside Development Design Manual Chapter VII~IX; Inspector's Manual Section 1040; Standard Specifications for Construction Section 1030~1040, 1120; Prioritization of Hazard Tree Removal/Tree Corridor Plans
	Aesthetic Design		
	Culture Conservation	partially	Archaeology-Procedures Manual; Construction Manual Chapter 32; Cultural Resources Procedural Manual; Archaeology Manual; Highway Design Manual Section 10.3.3.2~10.3.3.3; Traffic Manual Section 6.11
	Notification	partially	Construction Manual Phase 4, Section 4-1, 13-1~13-4, Chapter 40; Guidelines for the Operation of Highway Advisory Radio on State Highways; Guidelines for the Operation of Permanent Variable Message Signs; Standard Specifications for Construction Section 220.03; Traffic Manual Section 6.9; Traffic Signal Policy and Guidelines Section 7.3; Project Tracking Map; Highway Projects; Maintenance Guide Chapter 3
	Ease of Use	no	Highway Design Manual Section 10.11.8
	Community Adaption	partially	A Guide to School Area Safety; Routine Road Maintenance Activity 136, 137; Speed Zone Manual; Traffic Manual Section 6.25, 6.34; Construction Manual Section 4-4, Chapter 24; Right of Way & Rail/Utility Coordination Contractor Services Guide; Contract Plans Development Guide, Volume I Section 9.2.5; Highway Design Manual Section 4.5, 10.8, Chapter 8, Section 11.4.7; Right of Way Manual Chapter 10, 14; REC Manual & Guidance Chapter 5; LPIF Guidance; Maintenance Guide Chapter 2, 3
	Sustainability Promotion		
Innovation	Creative Idea	partially	Highway Design Manual Chapter 16
	Sustainability Representative		
	Certified Sustainable Pavement		

References

A Guide to School Area Safety, Feb 2009

Air Quality Manual, 2008

Archaeology-Procedures Manual, 2004

Construction Manual, Feb 2016

Cultural Resources Procedural Manual, 2006

Right of Way & Rail/Utility Coordination Contractor Services Guide, last updated Sep 2012

Contract Plans Development Guide, Volume I, last updated Sep 1, 2005

Contract Plans Development Guide, Volume II, last updated May 28, 2004

Estimating Manual, Oct 2010

Erosion Control Field Manual, June 2006

Erosion Control Manual, April 2005

Archaeology Guidance for Hazardous Material Spill and Emergency Situations, July 2006

Archaeology Manual, 2015

Emergency and Urgency Maintenance of Cut or Fill Slope Failures, April 2002

Routine Road Maintenance, last updated 2004

Biological Assessment Guidance Manual, Oct 2005

Biology Manual, June 30, 2009

Environmental Baseline Report Guidance, Feb 2006

Regional Environmental Coordinator (REC) Manual & Guidance, last updated Oct 1, 2012

Environmental Commitment Tracking System (ECTS) Guidance, Aug 2009

Roadside Development Design Manual, Sep 2006

Water Resources Specialist Manual, 2011

Survey Policy and Procedure Manual, Aug 14, 2015

Survey Safety Manual, Mar 2013

Construction Surveying Manual For Contractors, Feb 1, 2016

Geotechnical Design Manual, Nov 2015

Guidelines for the Operation of Highway Advisory Radio on State Highways, June 2006

Guidelines for the Operation of Permanent Variable Message Signs, May 2013

Highway Design Manual, 2012

Hydraulics Design Manual, April 2014

HMAC Supplemental Test Procedures, Jan 2009

Inspector's Manual, 2014

Lighting Policy and Guidelines, Jan 2003

Manual of Field Test Procedures, 2015

Nonfield-Tested Materials Acceptance Guide, last updated June 2016

Noise Manual, 2009

Bicycle & Pedestrian Design Guide, 2011

Standard Drawings and Standard Details, last updated Jan 2016

Oregon Supplement to the MUTCD, Dec 2011

Temporary Traffic Control Handbook, Dec 2011

Pavement Marking Design Guidelines, July 2015

Pavement Design Guide, Aug 2011

Project Delivery Guide, 2010

Quality Control Compliance Specialist (QCCS) Manual, 2012

Right of Way Manual, June 8, 2016

Standard Specifications for Construction, 2015

Speed Zone Manual, Jan 2014

Traffic Control Plans Design Manual, May 1, 2016

Traffic Lighting Design Manual, July 2009

2011 Traffic Line Manual, last updated June 2012

Traffic Manual, Jan 2016

Traffic Signal Policy and Guidelines, July 2015

Letters of Public Interest Finding (LPIF) Guidance, last updated Aug 2014

Qualified Products List, July 2016

Field Staff Training Curriculum Guide, June 2012

Project Tracking Map

Highway Projects, last updated summer 2016

Maintenance Guide, 2004

Guidelines for Maintenance Activities and their impact on ADA requirements, Jan 1, 2015

Prioritization of Hazard Tree Removal/Tree Corridor Plans, Dec 1, 2010

Consideration for Bicycle Use of Shoulders in Maintenance Pavement Preservation Projects, April 1, 2011

Approved Warm Mix Technology

E.8 WSDOT

Table E.8 Sustainability Practices of WSDOT under PSIM Indicators

As of 8/13/2016			
Management	Project Team	partially	Plans Preparation Manual Section 400.02; Consultant Services Manual
	Budget Plan	partially	Plans Preparation Manual Division 8; Cost Estimating Manual for Projects; Local Agency Guidelines Section 44.6; Maintenance Manual Chapter 10
	Quality Management	partially	Construction Manual Section 1-05; Local Agency Guidelines Section 52.3; Prime Contractor Performance Report Manual; Sign Fabrication Manual
	Emergencies	partially	Emergency Relief Procedures Manual; A Joint Operations Policy Statement Chapter 7; Local Agency Guidelines Chapter 33; Maintenance Manual Chapter 1, Appendix B
	Maintenance Schedule	yes	Maintenance Manual Chapter 10
	Project Record	yes	Design Manual Division 3; Construction Manual Chapter 10; Electronic Engineering Data Standards; Environmental Manual Chapter 490, 590; A Guide for Local Agency Pavement Managers Chapter 5, 6, 8; Traffic Manual Chapter 11; Projects Interactive Map
	Work Zone Management	partially	Design Manual Chapter 1010; Local Agency Guidelines Section 41.2; Maintenance Manual Chapter 2

	Crew Training	partially	Highway Surveying Manual; Environmental Health & Safety Manual Chapter 7; Environmental Manual Section 610.04; Local Agency Guidelines Section 27.2
	Project Interaction		
Technique	Technique Selection		
	Distress Reason	partially	Design Manual Chapter 610; Organizational Conflicts of Interest Manual
	Standard Procedure	yes	Plans Preparation Manual Section 700.05; Standard Plans; Construction Manual Chapter 5, Section 8-14; Standard Specifications Division 4~5; Maintenance Manual Chapter 3
	Disturbance and Repair	yes	Construction Manual Section 1-07.13~1-07.14, 1.07-16~1-07.18
	Uneven Surface		
	Preservation	no	Design Manual Chapter 1120
Material	Quality Certification	yes	Construction Manual Section 1-06.3, Chapter 9; Materials Manual; Standard Specifications Division 3, 9; Maintenance Manual Chapter 10
	Material Production	partially	Construction Manual Section 3-01
	Local Material		
	Material Storage	partially	Plans Preparation Manual Section 700.03; Construction Manual Section 3-02; Standard Specifications Division 3; Maintenance Manual Chapter 10
	Recycle Material	partially	Construction Manual Section 1-06.6; Construction Manual Section 3-03; Standard Specifications Division 9
	Alternative Material		
	Earthwork	partially	Plans Preparation Manual Section 700.02; Roadside Manual Chapter 700; Construction Manual Chapter 2; Standard Specifications Division 2; Geotechnical Design Manual
Energy& Water	Efficient Lighting	no	Design Manual Chapter 1040; Construction Manual Section 8-20; Standard Specifications Section 8-20; Maintenance Manual Chapter 9; Traffic Manual Chapter 4
	Energy Consumption I, Construction	partially	Environmental Manual Chapter 440
	Energy Consumption II, Transport		
	Energy Consumption III, Asphalt Mixture		
	Water Consumption	no	Standard Specifications Division 9
	Heat Island Alleviation		

Environment	Wastes	yes	Environmental Manual Chapter 430, 433, 447; Maintenance Manual Chapter 6, 10; Design Manual Division 8; Construction Manual Section 1-07.15, 8-01; Standard Specifications Division 8; Highway Runoff Manual; Hydraulics Manual
	Air Quality	partially	Environmental Manual Chapter 425
	Noise Control	partially	Design Manual Chapter 740; Environmental Manual Chapter 446; Geotechnical Design Manual Chapter 17
	Vibration Control		
	Erosion and Sediment Control	partially	Design Manual Chapter 630, 730; Roadside Manual Chapter 710~740; Construction Manual Section 8-01; Standard Specifications Division 8; Geotechnical Design Manual Chapter 7, 15, 20; Highway Runoff Manual Chapter 6; Temporary Erosion and Sediment Control Manual
	Ecology Conservation	yes	Roadside Manual Section 210.02, 220.03; Construction Manual Section 1-07.5; Environmental Manual; Local Agency Guidelines Chapter 24
Safety	Traffic Control	yes	Construction Manual Section 1-07.23(2), 1-10; Work Zone Traffic Control Guidelines for Maintenance Operations; MUTCD - Washington State Modifications; Traffic Manual Chapter 5
	Construction Safety	yes	Roadside Manual Section 310.06; Construction Manual Section 1-07.23(1); A Joint Operations Policy Statement Chapter 9; Safety Procedures and Guidelines Manual
	Pavement Marking	partially	Standard Specifications Division 8, 9; Maintenance Manual Chapter 8; MUTCD - Washington State Modifications
	Appurtenances	partially	Design Manual Chapter 900, 1020, 1030, 1230, Division 16, 17; Roadside Manual Chapter 310, 320; Roadside Policy Manual; Construction Manual Section 6-10, 8-04, 8-11, 8-21; Standard Specifications Division 8; Geotechnical Design Manual Chapter 17; Highway Advertising Control; Maintenance Manual Chapter 6; Maintenance Manual Chapter 8; MUTCD - Washington State Modifications; Traffic Manual Chapter 2, 3, 4, 8
	Pedestrian and Bicyclists	partially	Field Guide for Accessible Public Rights of Way; Design Manual Division 14~15; Local Agency Guidelines Chapter 29; Permit Desk Guide
	Drainage	partially	Plans Preparation Manual Section 700.07; Construction Manual Chapter 7; Standard Specifications Division 7; Hydraulics Manual Chapter 5, 6; Maintenance Manual Chapter 4
	Glare Control	partially	Roadside Manual Chapter 500; Standard Specifications Section 8-25
	Snow and Ice Removal	partially	A Joint Operations Policy Statement Chapter 8; Maintenance Manual Chapter 7
Community	Report the Problem		
	Landscape Maintenance	yes	Roadside Manual Chapter 120, 800~820, Section 220.04, 220.05; Roadside Policy Manual; Construction Manual Section 8-02~8-03; Standard Specifications Division 8; Environmental Manual Chapter 459; Ethnobotany and Cultural Resources; Maintenance Manual Chapter 6
	Aesthetic Design	yes	Design Manual Division 9; Roadside Manual Section 210.03, Chapter 500, 910; Environmental Manual Chapter 459; Highway Advertising Control

	Culture Conservation	partially	Environmental Manual Chapter 456; Maintenance Manual Chapter 6
	Notification		
	Ease of Use	no	Design Manual Chapter 1050; Standard Specifications Section 8-20; Local Agency Guidelines Section 41.3
	Community Adaption	partially	Design Manual Division 5, 13, Chapter 210, 1100~1102; Roadside Manual Chapter 200, 630, 910; Environmental Manual Chapter 431~432, 458, 530; Highways Over National Forest Lands; Scenic Byway Logo Signing Guidelines; Traffic Manual Chapter 7; Local Agency Guidelines Chapter 32; Techniques of Right of Way Plans Preparation; Utility Manual; Utility Accommodation Policy; Organizational Conflicts of Interest Manual
	Sustainability Promotion	no	Local Agency Guidelines Chapter 45, 46; Maintenance Manual Chapter 6
Innovation	Creative Idea		
	Sustainability Representative	no	Design Manual Chapter 225
	Certified Sustainable Pavement		

References

Field Guide for Accessible Public Rights of Way, Nov 2012

Design Manual, July 2016

Plans Preparation Manual, Nov 2013

Roadside Manual, Feb 2016

Roadside Policy Manual, Aug 2015

Standard Plans, Aug 1, 2016

Construction Manual, April 2016

Materials Manual, Jan 2016

Standard Specifications for Road, Bridge, and Municipal Construction, 2016

Consultant Services Manual, June 2015

Cost Estimating Manual for Projects, April 2015

Electronic Engineering Data Standards, Aug 2015

Highway Surveying Manual, Jan 2005

Emergency Relief Procedures Manual, Feb 2012

Environmental Health & Safety Manual, Dec 2008

Environmental Manual, June 2016

Ethnobotany and Cultural Resources, April 2016

Geotechnical Design Manual, May 2015

Highway Advertising Control, Jan 2015

Highway Runoff Manual, last updated Feb 2016

Highways Over National Forest Lands, June 2013

Hydraulics Manual, Jan 2015

A Joint Operations Policy Statement, 2014

Local Agency Guidelines, Apr 2016

Maintenance Manual, August 2013

Work Zone Traffic Control Guidelines for Maintenance Operations, Dec 2014

Manual on Uniform Traffic Control Devices (MUTCD) - Washington State Modifications, Nov 2005

Organizational Conflicts of Interest Manual, July 10, 2009

Pavement Surface Condition Field Rating Manual for Asphalt Pavements, April 1999

Permit Desk Guide, April 2016

Prime Contractor Performance Report Manual, May 2015

Safety Procedures and Guidelines Manual, July 2016

Scenic Byway Logo Signing Guidelines, Feb 2007

Sign Fabrication Manual, August 2006

A Guide for Local Agency Pavement Managers, Dec 1994

Techniques of Right of Way Plans Preparation, Oct 1999

Temporary Erosion and Sediment Control Manual, Apr 2014

Traffic Manual, July 2015

Utility Manual, May 2016

Utility Accommodation Policy, Mar 2016

Projects Interactive Map

E.9 Summary

Table E.9 PSIM Points Distribution Based on Sustainability Practices of State DOTs

Category	Indicators	CA	CO	FL	KY	MN	NY	OR	WA	Average	Category Priority	Initial Points Distribution	Sectors involved under TBL	Modified Distribution
	Project Team	1	0	2	3	3	4	2	4	2.375		2.0	3	**2**
	Budget Plan	2	1	4	1	2	2	6	6	3		2.6	2	**3**
	Quality Management	6	6	9	3	0	9	6	6	5.625		4.8	3	**4**
	Emergencies	4	0	4	6	3	4	6	6	4.125		3.5	2	**3**
Management	Maintenance Schedule	4	3	2	3	0	6	6	3	3.375	28	2.9	2	**3**
	Project Record	1	4	6	4	4	4	9	9	5.125		4.4	3	**4**
	Work Zone Management	2	4	6	4	2	6	6	4	4.25		3.6	3	**3**
	Crew Training	2	4	2	2	0	1	6	6	2.875		2.5	3	**4**
	Project Interaction	2	4	2	2	0	4	2	0	2		1.7	3	**2**
	Technique Selection	0	0	0	0	0	2	0	0	0.25		0.4	3	**2**
	Distress Reason	0	3	6	1	4	2	2	4	2.75		3.9	3	**4**
Technique	Standard Procedure	3	6	9	9	9	9	9	9	7.875	20	11.2	3	**8**
	Disturbance and Repair	3	1	0	0	2	2	2	3	1.625		2.3	3	**2**
	Uneven Pavement	0	1	2	0	1	0	0	0	0.5		0.7	3	**2**
	Preservation	1	0	0	0	3	2	2	1	1.125		1.6	3	**2**
Material	Quality Certification	6	6	9	9	6	9	9	9	7.875	20	7.0	1	**5**
	Material Production	6	2	1	2	1	4	2	2	2.5		3.5	3	**4**

	Local Material	3	0	0	4	0	2	3	0	1.5		1.3	2	**2**
	Material Storage	2	2	0	1	0	3	2	4	1.75		1.6	3	**2**
	Recycle Material	2	2	4	2	6	3	2	4	3.125		2.8	2	**4**
	Alternative Material	0	4	2	2	0	0	1	0	1.125		1.0	2	**1**
	Earthwork	2	6	6	1	6	6	4	6	4.625		4.1	2	**2**
Energy& Water	Efficient Lighting	3	3	4	0	6	2	6	2	3.25	12	3.4	2	**3**
	Energy Consumption I, Construction	2	2	2	4	6	4	2	2	3		3.2	2	**3**
	Energy Consumption II, Transport	2	1	1	4	2	2	0	0	1.5		1.6	2	**2**
	Energy Consumption III, Asphalt Mixture	2	4	4	1	4	4	4	0	2.875		3.0	2	**2**
	Water Consumption	1	0	0	0	0	1	3	1	0.75		0.8	2	**1**
	Heat Island Alleviation	0	0	0	0	0	0	0	0	0		0.0	1	**1**
Environment	Wastes	6	4	6	6	6	6	6	9	6.125	26	5.8	3	**6**
	Air Quality	9	4	2	6	4	3	6	2	4.5		4.3	1	**4**
	Noise Control	6	2	4	6	2	2	6	4	4		3.8	2	**4**
	Vibration Control	1	0	2	0	4	1	0	0	1		0.9	2	**2**
	Erosion and Sediment Control	4	4	4	4	9	6	6	6	5.375		5.1	3	**4**
	Ecology Conservation	9	4	4	6	9	4	6	9	6.375		6.1	2	**6**
Safety	Traffic Control	6	6	9	9	9	9	9	9	8.25	62	13.2	3	**10**
	Construction Safety	2	4	4	6	3	9	9	9	5.75		9.2	1	**10**
	Pavement Marking	6	3	6	4	6	2	6	4	4.625		7.4	2	**7**
	Appurtenance	6	6	6	4	9	2	6	6	5.625		9.0	1	**10**
	Pedestrian and Bicyclists	2	4	6	2	9	4	6	4	4.625		7.4	1	**8**
	Drainage	6	2	9	4	9	6	9	4	6.125		9.8	2	**10**
	Glare Control	0	0	0	0	1	0	0	2	0.375		0.6	2	**2**
	Snow and Ice Removal	2	3	0	6	9	2	2	2	3.25		5.2	2	**5**
Community	Report the Problem	3	6	0	3	2	0	0	0	1.75	18	1.1	3	**1**
	Landscape Maintenance	6	6	9	9	9	4	6	9	7.25		4.5	2	**4**
	Aesthetic Design	6	2	4	2	4	1	0	9	3.5		2.2	1	**2**

	Culture Conservation	6	2	6	4	6	2	6	2	4.25		2.6	2	**3**
	Notification	2	4	6	2	2	4	6	0	3.25		2.0	1	**2**
	Ease of Use	2	1	2	0	6	2	1	2	2		1.2	1	**1**
	Community Adaption	9	4	6	6	9	6	6	6	6.5		4.0	2	**4**
	Sustainability Promotion	0	1	4	0	0	0	0	1	0.75		0.5	1	**1**
Innovation	Creative Idea	0	2	3	2	3	0	2	0	1.5	14	7.6	3	**8**
	Sustainability Representative	1	0	2	0	6	0	0	1	1.25		6.4	3	**4**
	Certified Sustainable Pavement	0	0	0	0	0	0	0	0	0		0.0	3	**2**

Appendix F: Comparison Charts of Pavement Maintenance Techniques, example for PSIM Indicator T-1 Technique Selection

There might be several pavement maintenance techniques available to fix one type of pavement distress, the project team might select one or more techniques base on its own judgements. Various manuals provided by State DOTs or local transportation agencies can be used to recommend appropriate techniques for certain distress according to the severity and extent. It is not appropriate to say a pavement distress is sustainable or not, while different pavement maintenance techniques that fix those distresses can be compared on their sustainability features.

If a pavement maintenance project has Technique Selection in its SIL, the available techniques and selection process must be provided by the project team to be eligible for earning points. In this appendix, different maintenance techniques will be compared based on their features or performance under the 10 sustainability factors, project team can refer to this appendix to select appropriate technique in term of sustainability. The weights of 10 sustainability factors for maintenance techniques were first determined based on how many sectors in TBL were involved and then modified by the importance of that factor, as shown in Table F.1.

Table F.1 Weights of the 10 Sustainability Factors For Pavement Maintenance Techniques

	Indicator	**TBL Reflection (1 economy; 2 environment; 3 society)**	**Explanation**	**points**			**Weight**
				-1	**0**	**1**	
1	**Performance Period**	1,3	How long is it before next treatment?	shortest	medium	longest	10
2	**Relative Cost**	1	How much is the average treatment cost?	high	medium	low	10
3	**Construction Difficulty Level**	3	Is the treatment process complicated or simple?	complicated	medium	simple	5
4	**Seasonal Effects**	3	Is the treatment affected by seasonal changes?	a lot	ordinary	no	5
5	**Weather Limits**	3	Are there restrictions on time of the year for treatment?	a lot	ordinary	none	5

6	**Traffic Disruption**	2,3	How about the traffic disruption during and after the treatment?	long	short	none	15
7	**Structural Benefit**	1	Does the treatment add structural strength to the pavement?	no	a little	yes	5
8	**Potential Negative Effects**	1,2,3	Are there any potential negative effects after finishing the treatment?	some	a little	no	20
9	**Roughness**	1,2	Is roughness improved after finishing the treatment?	negative	none	positive	15
10	**Friction**	3	Is friction improved after finishing the treatment?	negative	none	positive	10

F.1 Paved Surface (Asphalt or Concrete Surface)

Maintenance techniques used on asphalt/concrete surface pavement are collected from the preservation or maintenance manuals of four State DOTs (SDDOT, 2010; UDOT, 2009; NMDOT, 2007; NDOR, 2002), and then they are evaluated under the 10 sustainability factors. The evaluation score of each technique are calculated to reflect corresponding sustainability. The score ranges from -100 to 100 and serves the purpose of ranking each technique (sustainability ranking), as shown in Table F.4 and Table F.5.

If the maintenance techniques being considered for paved pavement are not included in Table F.2 and Table F.3, they can be evaluated by the strategy described in this Section.

Table F.2 Sustainability evaluation of maintenance techniques for asphalt surface pavement

sustainability factor	**TBL reflection**	**crack treating**	**crack sealing**	**crack leveling**	**fog seals**	**scrub seals**	**rejuvenators**	**spray patching**	**microsurfacing**	**rut filling**	**chip seal**	**thin HMA overlay**	**cold milling**
roughness		may cause rougher surface when filler material is forced out	may cause rougher surface when sealant material is forced out	improve					improve minor roughness		correct minor roughness	improve ride quality	improve

	during warm months	during warm months										
friction	adversely affect friction/skid resistance	adversely affect friction/skid resistance		negative				improve		improve	improve	improve
structural benefit	no	no	no	no	no	no	no	no	yes	no	yes	no
preparation	minimal	more substantial		consideration of pavement markings and bump grinding	consideration of pavement markings and bump grinding			test section needed to determine characteristics and to set time			tack coat	
weather	cool, dry	cool, dry, moderate yearly temperatures			dry, moderate air temperature			avoid hot weather for flushing, cool weather leads to early raveling, do not place when freezing, spread only when surface is 50F/10C and above, avoid fog and rain, no placement if the finishing product will freeze within 24hrs		warm weather, temperature in the shade on surface is above 70F		
traffic consideration	not significantly affected by ADT or trucks	not significantly affected by ADT or trucks	all traffic levels	increased ADT or truck increases surface wear	lower traffic volume and low percentage of trucks	effective in all traffic conditions	all traffic levels	for low and high traffic volume, avoid areas of heavy truck turning or down grade locations	all traffic levels	high volume is OK with special design and proper placement	performance is not affected by ADT or percent trucks	all traffic level

traffic control				2 hours for curing		after the absorption time, traffic will be opened until adequate friction is restored		open to traffic after about 1 hour, but are least 7 days of drying weather before new markers or striping, so temporary markers needed		2 hours cure time, avoid premature placement of pavement markers and stripping		
construction difficulty level	*	*	*	**	**	**	*	**	*	**	***	*
potential negative effects	undesirable visual impacts (tracking of filling materials by tire action, obscuring lane markings)	undesirable visual impacts (tracking of filling materials by tire action, obscuring lane markings)		stripping in susceptible HMA pavements	susceptible to snow plow damage	do not directly correct distresses		accelerate the development of stripping in susceptible AC pavements		accelerate the development of stripping in susceptible AC pavements		generally not a stand-alone treatment unless implementation plan is approved
performance period	2-4 yrs	2-8 yrs	5-8 yrs	1-3 yrs	5-7 yrs	3-5 yrs	2-6 yrs	4-7 yrs	4-6 yrs	6-8 yrs	10-15 yrs	remaining life of the pvmt, does not extend life
relative cost	$	$	$$	$	$$	$$	$$	$$	$$	$$	$$$	$

Table F.3 Sustainability evaluation of maintenance techniques for concrete surface pavement

sustainability factor	**TBL reflection**	**crack sealing**	**joint sealing**	**diamond grinding**	**diamond grooving**	**full-depth repair**	**partial-depth repair**	**dowel bar retrofit**	**cross stitching**	**subsealing/under sealing**	**pavement jacking/mud jacking**
roughness		improve		smooth riding			improve ride quality			minimize	smoother ride

friction	adversely affecting skid resistance		increase surface friction	increase wet-pavement friction						
structural benefit										
preparation	clean and dry	clean and dry				properly determine repair boundaries, prepare patch area				
weather										avoid frozen ground
traffic consideration	performance is not significantly affected by varying ADT or truck levels	performance is not affected by different ADT or percent trucks		performance is not affected by varying ADT or truck levels		all traffic conditions	the higher the ADT and percent trucks, the greater the potential for DBR	performance is not significantly affected by varying ADT or truck levels	performance is not known to be affected by different levels of ADT or percent trucks	all traffic levels
traffic control	need to be cured before opening to traffic				cure needed	cure needed				
construction difficulty level	**	***	*	**	***	***	***	**	**	**
potential negative effects	roughness can be increased especially placed in an over band configuration or the sealant material is forced out during warm months, undesirable visual impacts (tracking of sealing material by tire action, obscuring lane markings)		should be used in conjunction with all restoration techniques including load-transfer restoration, full and partial depth repair, cross stitching, sub-sealing/under sealing, and pavement jacking	resealing of joints is required after grooving			performed in conjunction with diamond grinding and joint sealing			

performance period	4-8 yrs	4-15 yrs for hot-poured asphalt sealant; 10-20 yrs for silicone sealant	8-15 yrs	greater than 8-15 yrs	10-15 yrs	5-15 yrs	at least 15-20 yrs	15-30 yrs	variable	5-10 yrs
relative cost	$	$	$$	$$	$$$	$$$	$$$	$$$	$$	$$

Table F.4 Sustainability ranking of maintenance techniques for asphalt surface pavement

Sustainability Factor	**Weight**	**Crack Treating**	**Crack Sealing**	**Crack Leveling**	**Fog Seals**	**Scrub Seals**	**Rejuvenators**	**Spray Patching**	**Microsurfacing**	**Rut Filling**	**Chip Seal**	**Thin HMA Overlay**	**Cold Milling**	**White Topping**	**Slurry Seal**	**Cape Seal**	**Pothole Patching**	**Skin/Blade Patching**	**Nova Chip Overlay**	**Cracking Filling**	**Full Depth Crack Repairs**	**Spray-Injection Patching**	**HMA Patch**
performance period	10	-1	-1	0	-1	0	-1	-1	0	0	0	1	1	1	-1	0	1	1	1	-1	1	1	1
relative cost	10	1	1	0	1	0	0	0	0	0	0	-1	1	-1	0	-1	1	-1	-1	1	0	1	0
construction difficulty level	5	1	1	1	0	0	0	1	0	1	0	-1	1	-1	0	-1	0	-1	0	1	0	1	0
seasonal effects	5	1	0	1	1	0	1	1	-1	1	0	1	1	0	0	0	1	0	0	1	1	1	1
weather limits	5	0	0	1	1	0	1	1	-1	1	1	0	1	0	0	0	0	0	1	0	0	0	0
traffic disruption	15	1	1	1	0	1	0	1	-1	1	-1	1	1	-1	-1	-1	1	1	1	1	1	1	1
structural benefit	5	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	0	-1	1	-1	-1	-1	0	0	-1	1	-1	-1
potential negative effects	20	0	0	1	0	0	1	1	0	1	0	1	0	1	0	0	0	0	1	0	1	0	1
roughness	15	-1	-1	1	0	0	0	0	1	0	1	1	1	1	1	1	1	1	1	-1	1	1	1
friction	10	-1	-1	0	-1	0	0	0	1	0	1	1	1	1	1	1	1	1	1	-1	1	1	1
	Score	**-5**	**-10**	**60**	**-5**	**10**	**15**	**35**	**-5**	**50**	**10**	**60**	**70**	**30**	**-5**	**-10**	**60**	**35**	**65**	**-5**	**80**	**65**	**70**
	Rank	**16**	**21**	**6**	**16**	**14**	**13**	**10**	**16**	**9**	**14**	**6**	**2**	**12**	**16**	**21**	**6**	**10**	**4**	**16**	**1**	**4**	**2**

Table F.5 Sustainability ranking of maintenance techniques for concrete surface pavement

Sustainability Factor	Weight	Crack Sealing	Joint Sealing	Diamond Grinding	Diamond Grooving	Full-Depth Repair	Partial-Depth Repair	Dowel Bar Retrofit	Cross Stitching	Subsealing/Under Sealing	Pavement Jacking/Mud Jacking	Joint Spall Repair	Selective Slab Replacement	Surface Sealing	Thin HMA Overlay	White Topping
performance period	10	0	1	1	1	1	1	1	1	0	0	1	1	0	1	1
relative cost	10	1	1	0	0	-1	-1	-1	-1	0	0	1	-1	0	-1	-1
construction difficulty level	5	0	-1	1	0	-1	-1	-1	0	0	0	-1	-1	1	-1	-1
seasonal effects	5	1	1	1	1	0	0	1	1	0	0	0	0	-1	1	0
weather limits	5	0	0	1	1	-1	-1	0	0	0	0	0	0	0	0	0
traffic disruption	15	0	1	1	1	-1	-1	1	1	1	1	1	-1	1	1	-1
structural benefit	5	-1	-1	-1	-1	0	-1	0	0	1	1	-1	1	-1	0	1
potential negative effects	20	0	1	1	-1	1	1	0	0	1	1	1	1	-1	1	1
roughness	15	1	0	1	1	1	1	0	0	1	1	1	1	0	1	1
friction	10	-1	0	1	1	1	1	0	0	0	0	0	1	0	1	1
	Score	**15**	**50**	**80**	**35**	**20**	**15**	**15**	**20**	**55**	**55**	**60**	**30**	**-10**	**60**	**30**
	Rank	**12**	**6**	**1**	**7**	**10**	**12**	**12**	**10**	**4**	**4**	**2**	**8**	**15**	**2**	**8**

F.2 Unpaved Surface (Dirt and Gravel Surface)

As mentioned in Chapter 1, most of unpaved pavements have dirt and gravel surface, so only dirt and gravel pavement will be discussed in this section.

Over 1.6 million miles of dirt and gravel roads exist within the U.S (Bloser, et al., 2014), they are commonly built on low traffic routes or/and due to lack of funds, but they are able to serve users well as long as they meet traveling demands.

Since the unpaved surface is exposed, dirt and gravel pavement will lose its construction materials such as gravels and dirt due to the traffic and weather, and then could adversely affect driving comfortability and affect surrounding environment by erosion and moving sediments to sensitive ecosystems. So that dirt and gravel pavement requires more frequent maintenance than paved pavement, especially after raining or increased traffic volume.

Counties and federal agencies, not the state DOTs, manage the large majority of dirt and gravel pavements in the U.S. (Venner Consulting & Parsons Brinckerhoff, 2004). The management of unpaved pavements does not receive as much attention as that of paved ones (GTC, 2010). Proper maintenance of dirt and gravel pavement will improve serviceability, durability, safety, and runoff quality. Sustainable maintenance practices on dirt and gravel pavements should treat the causes of the distresses within natural landscape, meet travelers' expectations, and provide good enough performances.

As for the environmentally sustainable maintenance on dirt and gravel pavements, the goals include reducing erosion and sediment, maintaining subsurface hydrologic connectivity, restoring drainage density to more natural conditions, and eliminating diversion potential (Bloser, et al., 2014).

For socially sustainable maintenance on dirt and gravel pavements, travelers' visual field should be considered.

The economy part of sustainable maintenance on dirt and gravel pavements is mainly on the pavement smoothness after maintenance.

Commonly used maintenance techniques for dirt and gravel pavement are cited from CPYRWMA Guideline (CPYRWMA, 2000) and FHWA Report (FHWA, 1998) as following:

- blading and dragging
- reconstructive grading
- damping (water application)
- chemical additives
- road fill/patching (coarser aggregates, fines or other binder, or both)
- addition of courser aggregates
- compaction
- crowning
- rolling road surface
- drainage improvement
- geotextile fabric foundation
- scarifying
- material replacement

Due to the structural features and relatively low traffic demand of dirt and gravel pavement, the techniques listed above basically have the similar evaluation score under most of the sustainability factors described in Table E.1, except Performance Period, Relative Cost, and Construction Difficulty Level. These three factors have a total weights of 25 out of 100, so all the techniques listed above will be considered to have the approximately the same sustainability level.

Unpaved pavements can be paved with asphalt or concrete if properly designed and constructed. However, after paving those unpaved pavements, the sustainability of their maintenance activities will be discussed under asphalt/concrete surface section.

Appendix G: Summary Reports of Emerging Technologies that can be adopted in Pavement Maintenance Projects, examples for PSIM Indicator I-1 Creative Idea

One of most important features of sustainable pavement maintenance is that it is able evolve as the industry develops, which means some new technologies will bring sustainable benefits as long as the technologies agree with the concept of sustainable pavement maintenance and are applicable on pavement maintenance projects.

If a pavement maintenance project has Creative Idea in its SIL during PSIM evaluation, a summary report must be provided by project team to be eligible for earning points. In this Appendix, examples of emerging technologies will be discussed as examples of such summary report, including:

- Explore features and effects of those emerging technologies
- Explain their potential to apply on maintenance projects
- Discuss their benefits under PSIM indicators
- Search their successful implementation

G.1 PSIM Summary Report of Photocatalytic Pavement

Introduction (features, effects, and functions)

Vehicle emissions containing NO_x are the major source of air pollution. The emissions could cause acid rain and smog, which are harmful to human health, driving comfort, ecosystem, and the fabric of infrastructures. In urban and suburban areas, the pollutant concentration could be higher because the denser canyon conditions inhibit the emissions dispersal (Hassan, et al., 2013).

Some of the air pollutants within vehicle emissions can be decomposed by ultraviolet (UV) light, including NO_x. Although this natural oxidation process is extremely slow, it can be accelerated by photocatalysis, which is defined by Wikipedia as “the acceleration of a photoreaction in the presence of a catalyst”.

After the vehicle emissions were discharged, they will contact the pavement surface; therefore, photocatalytic application can be made practically by putting titanium dioxide (TiO_2) into pavement. During the photocatalysis, TiO_2 can convert certain types of air pollutants within vehicle emissions, such as NO_x, into less hazardous chemicals (nitrate). The mechanism of Photocatalytic Pavement is shown in Fig. G.1.

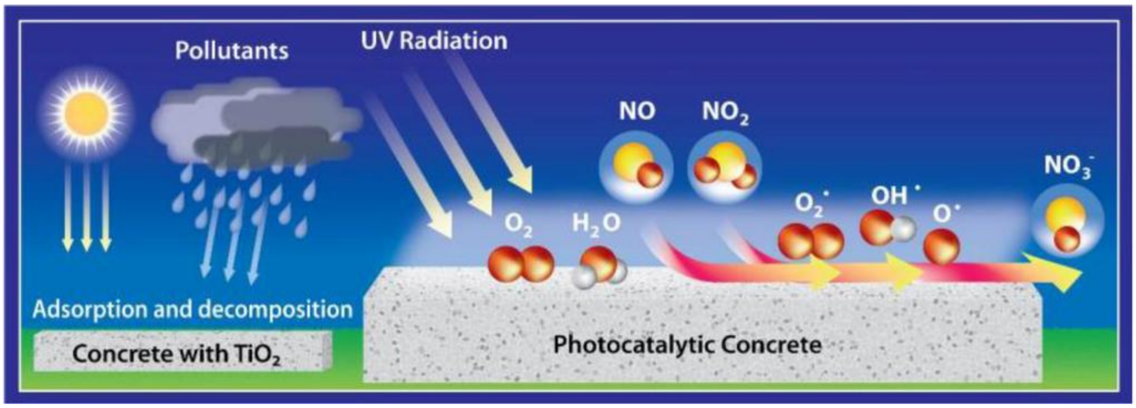


Fig. G.1. Illustration of Photocatalytic Pavement (Boonen & Beeldens, 2014)

Another advantage brought by TiO_2 is that it is hydrophobic and could break down algae and dirt so that the surface with TiO_2 coating becomes “self-cleaning”.

How to involve this technology during maintenance?

For paved pavement, photocatalytic materials can be sprayed on surface to make it able to “digest” vehicle emissions. If overlay or other rehabilitation is involved, photocatalytic materials can be added into the asphalt/concrete mixture to maximize the content of photocatalytic materials.

It is relatively impractical to apply photocatalytic technology on unpaved pavement, since unpaved pavement suffers from losing construction materials easily.

Besides, photocatalytic materials can be applied to other components of pavement system as coating. If the component is made of concrete, photocatalytic materials can be mixed into the structure, such as concrete barriers or concrete noise wall.

Sustainability benefits (TBL)

- Environment: reduce air pollution.

- Society: improve driving comfort by reducing smog.

Sustainability Indicators List under PSIM

Management	Technique	Material	Energy&Water	Environment	Safety	Community	Innovation
Project Team	Standard Procedure	Quality Certification	Energy Consumption I, Construction	Wastes	Traffic Control	Aesthetic Design	Creative Idea
Budget Plan		Local Material	Energy Consumption II, Transport	Air Quality	Construction Safety	Notification	Sustainability Representative
Quality Management				Ecology Conservation	Appurtenances	Community Adaption	Certified Sustainable Pavement
Emergencies					Pedestrian and Bicyclists	Sustainability Promotion	
Maintenance Schedule							
Project Record							
Work Zone Management							
Crew Training							
Project Interaction							

Other indicators might be involved depending on the scale of the project.

Applicable scope

☑ Asphalt	☑ Concrete	☒ Unpaved

Existing projects to show benefits?

For concrete pavement, photocatalytic technology (mainly TiO_2) has been applied (Hassan, et al., 2013) by photocatalytic overlay, a thin exterior film of suspended TiO_2 nanoparticles within binding agent (such as cement), or sprinkling TiO_2 nanoparticles on curing concrete.

A so-called “smog-eating pavement” was constructed using “smart cement” in Hengelo, Netherlands (Bennett-Smith, 2013). Photocatalytic concrete blocks were paved over the entire width of the street (approximately 5 m) and approximately 150 m long. The blocks had a section size of 120 mm × 220 mm and had two layers with 70 mm of lower layer and with 5 mm of active upper layer containing TiO_2. According to the monitoring results, The NO_x concentration was 19% (during each day) and 28% (during afternoons) lower than the obtained values in the control street on average. A NO_x

concentration reduction of 45% could be observed under ideal weather conditions (high radiation and low humidity (Ballari & Brouwers, 2013)). The material used in Netherland was about 50% more expensive that normal concrete (Ford, 2010).

A photo-catalyst composite containing Nano-TiO_2 was sprayed on concrete bridge deck pavement surface at a toll station in Nanjing, China both during the pavement was being cast and during concrete curing. 10 g/L of photo-catalyst weight proportion was adopted, which was equal to 1 g of nano-TiO_2 per square meter. The NO concentration at control area was considerably higher than the one with photo-catalyst composite (Li & Qian, 2009).

Some other field studies of concrete photocatalytic pavement were provided by Iowa State University (Cackler, et al., 2012) as shown in Table G.1.

Table G.1. List of Studies on Concrete Photocatalytic Pavement

Location	Pavement type	Surface area (m^2)	NO_x concentration reduction
Antwerp, Belgium	Paving blocks	10,000	20%
Via Morandi, Segrate, Italy	Thin mortar overlay	7,000	50%~60%
Calusco dAdda, Bergamo, Italy	Paving blocks	8,000	45%
Porpora Street, Milan, Italy	Ceiling paint	728	23%
Borgo Palazzo, Bergamo, Italy	Paving blocks	7,000/12,000	20%~66%
Rue Jean Bleuzen, Vanves, France	Overlay	6,000	20%

Asphalt photocatalytic pavement has been studied much less compared to concrete one, probably because photocatalytic materials were initially introduced to concrete buildings. Also, the porous micro-structure in concrete is able to trap more TiO_2. However, since approximately 94% of the paved pavement network in the U.S. has asphalt surface, it is necessary to study the application of TiO_2 on asphalt pavement.

Louisiana State University (Hassan, et al., 2013) built the first air-purifying photocatalytic asphalt pavement in the U.S. by a water-based spray coating of TiO_2. LSU found that the efficiency of NO_x reduction is affected by the flow rate of the pollutant, relative humidity, UV light intensity, wind speed, vehicle type, and temperature. By spraying “a mixture of TiO_2 anatase nanoparticles with an average size of 6 nm suspended in an aqueous liquid at 2% by volume” at a density of 1 mL/ft^2 on pavement surface, SO_2 could be removed with a maximum of at a 0.05 L/m^2 coverage rate with a reduction efficiency of 19.8%, and there was evidence of photocatalytic degradation of

NO_x occurring. LSU estimated the cost of the photocatalytic coating is USD1.88/yd^2 (in year 2012 dollars) and the cost of 3.5 in. of asphalt paving surface is USD16.39/yd^2.

Scholars from Italy (Venturini & Bacchi, 2009) applied TIO_2 emulsion on asphalt pavement by two methods: spraying the emulsion during paving while pavement temperature is over 100°C or on pavement at normal temperature. Depending on the type of TiO_2 nanoparticles used, the NO_x reduction ranged between 20%~57%.

Potential Problem

The photocatalytic durability is affected by pavement contaminants and traffic abrasion.

The runoff quality should be monitored to avoid high concentration of the product of photocatalysis (NO_3^-).

The photocatalytic materials might be removed, reduced, or covered after future pavement maintenance, such as milling, slab replacement, and overlay.

G.2 PSIM Summary Report of Road Power Generator

Introduction (features, effects, and functions)

Different types of road power generators have been studied, the most common used one involves piezoelectric materials. Piezoelectric effect is one type of energy harvesting that transforms mechanical strain energy into electrical energy. The energy of vehicle movement and vibration on pavement commonly go to unused and can be such a resource for piezoelectric materials to be road power generator.

Normally the amount of electric energy generated from piezoelectric unit is small, but if enough piezoelectric materials are installed and enough traffic volume can be expected, the road power generator can provide electricity for street lights, electric signals, and even lighting/heating of transit stations within adjacent pavement system. And probably this is one of the greenest power that can be obtained on pavement. The mechanism of Road Power Generation is shown in Fig. G.2.

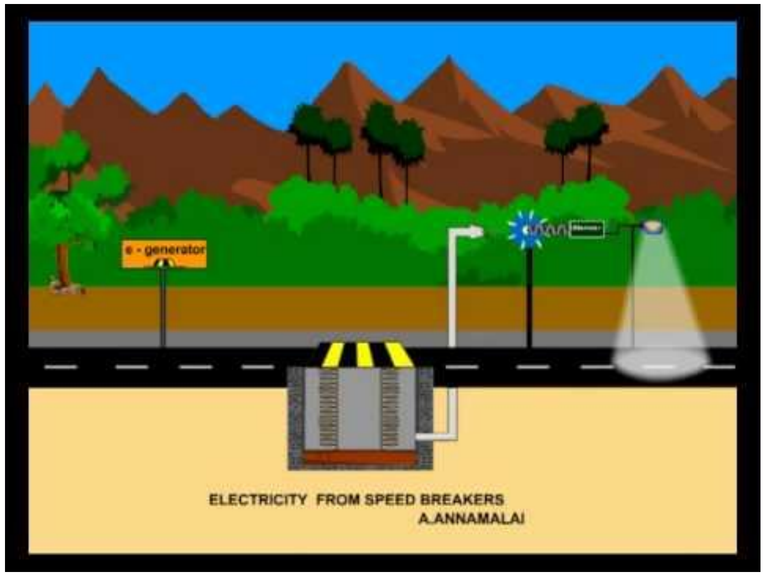


Fig. G.2. Illustration of Road Power Generation (TechVideoCollection, 2011)

The piezoelectric energy harvesting device can be configured in different ways depending on the application, including "modification of piezoelectric materials, altering the electrode pattern, changing the poling and stress direction, layering the material to maximize the active volume, adding prestress to maximize the coupling and applied strain of the material, and tuning the resonant frequency of the device" (Anton & Sodano, 2007).

The mostly commonly used piezoelectric materials are lead zirconate titanate (piezoceramic), poly(vinylidene fluoride) (PVDF), and piezofiber (Anton & Sodano, 2007).

Piezoelectric material has tremendous scope for future energy solution within transportation system towards sustainability, since piezoelectric energy is non-polluting. Piezoelectric road power generator also can be applied under other different scenarios, such as speed bumps, railroad, runway, etc.

Piezoelectric material also can be used for monitoring the traffic and the stress within pavement structure.

Other models of road power generators have also been tested, such as flip plate model (Ashtankar, et al., 2014), electro-mechanical model (Islam, et al., 2013), roller model (Sarma, et al., 2014), speed breaker model (Reddy, et al., 2015), and magnetic model (Partodezfoli, et al., 2012).

How to involve this technology during maintenance?

Road power generators can be installed during overlay or other types of major rehabilitation that disturb pavement structure.

Sustainability benefits (TBL)

- Economy: save the costs of electricity and its transmission for transportation system.
- Environment: reduce emissions from electric power sector by generating green electricity.
- Society: possibly provide green electricity for neighborhoods; improve safety by installing nightlighting at relatively lower costs.

Sustainability Indicators List under PSIM

Management	Technique	Material	Energy&Water	Environment	Safety	Community	Innovation
Project Team	Standard Procedure	Quality Certification	Efficient Lighting	Wastes	Traffic Control	Aesthetic Design	Creative Idea
Budget Plan	Disturbance and Repair	Material Production	Energy Consumption I, Construction	Air Quality	Construction Safety	Notification	Sustainability Representative
Quality Management	Uneven Surface	Local Material	Energy Consumption II, Transport	Noise Control	Appurtenances	Community Adaption	Certified Sustainable Pavement
Emergencies		Recycle Material		Vibration Control	Pedestrian and Bicyclists	Sustainability Promotion	
Maintenance Schedule		Earthwork		Ecology Conservation			
Project Record							
Work Zone Management							
Crew Training							
Project Interaction							

Other indicators might be involved depending on the scale of the project.

Applicable scope

☑ Asphalt	☑ Concrete	☒ Unpaved

Road power generator can be used on pavements with asphalt surface or concrete surface (including composite ones). Since the traffic volume is relatively low on unpaved pavements, it is impractical to install road power generator on such pavements.

Existing projects to show benefits?

The world's piezoelectric pavement was built in Israel (Daily Mail Reporter, 2008) by Innowattech, a storage system to collect and store the generated electricity was also developed. The Innowattech piezoelectric Electric Generators (IPEG) (Henderson, 2009) was installed 6 cm under the pavement surface and at a distance of 30 cm. Innowattech declared that IPEG could be used on asphalt, concrete, and composite pavements. According to the project leader, "One truck can generate 2,000 volts, but to create useful electricity will require many IPEGs over hundreds of metres and a high volume of traffic". IPEG is capable of producing about 400 kWh of electricity from a 1 km stretch of generators along the dual carriageway assuming 600 vehicles per hour. Innowattech has also built similar road power generator system for railways and airports.

Treevolt has developed harvesters for both asphalt and concrete pavements, and applied them on real projects together with POWERleap. A 1 km length of roadway with 600 vehicles per hour and 6,000 Treevolt harvesters can yield approximately 720 kW. The harvesters will be installed under the top layer of asphalt pavement as the form of membrane; the harvesters will be partially embedded into the concrete pavement as the form of blocks that are directly exposed to the traffic (Hill, et al., 2014).

FHWA (FHWA, 2013b) is also interested in the idea of road power generator and launched a project with Virginia Tech Transportation Institute in 2013 to examine a piezoelectric energy harvesting system called "kinetic-electric conversion" (KEEC) system. The total system voltage ranged from 400~700 V and 0.2~0.35 mA per unit, with power pulses of 0.1~0.2 seconds. The project was tested under heavy truck traffic at about 40 mph, and traffic flow rate targeted 4,000 vehicle per day (Hill, et al., 2014).

Road power generator works properly even under human activities. Sponsored by Schneider, 2013 Paris Marathon used 178 Pavegen piezoelectric tiles that were laid on a 25 m stretch to produce electricity from runners. The energy was transported to a storage battery and then used for electric signs. A typical Pavegen tile was made of recycled polymer and recycled tires on the top. The Pavegen tiles generate electricity using piezoelectric effect and induction. "A foot stomp that depresses a single tile by 5 mm produces between one and seven watts" (Khadilkar, 2013). The marathon runners generated 4.7 kWh of electricity that could power a 5 W LED bulb for 940 hours, or 40 days (Khadilkar, 2013). One Pavegen tile costed over $76 (Zimmer, 2013).

Potential Problem

The layers of pavement structure become non-uniform after road power generator is installed, so cracking and other similar distresses should be paid attention to.

Appropriate construction materials should be selected to ensure desired performance.

The depth of road power generator installation should consider the future pavement maintenance needs, such as milling and overlay.

Appendix H: List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ADB	Asian Development Bank
AMRL	AASHTO's Materials Reference Laboratory
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BE^2ST	Building Environmentally and Economically Sustainable Transportation
BTS	Bureau of Transportation Statistics
Caltrans	California Department of Transportation
CCRL	Cement and Concrete Reference Laboratory
CDOT	Colorado Department of Transportation
CPYRWMA	Choctawhatchee, Pea and Yellow Rivers Watershed Management Authority
CRFB	Committee for a Responsible Federal Budget
DOT	Department of Transportation
EPA	Environmental Protection Agency
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GHG	Greenhouse Gas
GreenLITES	Green Leadership in Transportation and Environmental Sustainability

GreenPave	Green Pavement Design Rating System
GTC	Genesee Transportation Council
I-LAST	Illinois – Livable and Sustainable Transportation
ICO	International Code Council
IDOT	Illinois Department of Transportation
IJSG	Illinois Joint Sustainability Group
INVEST	Infrastructure Voluntary Evaluation Sustainability Tool
INVEST-VicRoads	Integrated VicRoads Environmental Sustainability Tool
IRI	International Roughness Index
ITS	Intelligent Transportation Systems
KYTC	Kentucky Transportation Cabinet
LCA	Life Cycle Assessment
LCCA	Life-Cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design
MCHD	Multnomah County Health Department
MnDOT	Minnesota Department of Transportation
MTO	Ministry of Transportation of Ontario
NAPA	National Asphalt Pavement Association
NCHRP	National Cooperative Highway Research Program
NCPTC	National Concrete Pavement Technology Center
NDOR	Nebraska Department of Roads
NEPA	National Environmental Policy Act
NICET	National Institute for Certification in Engineering Technologies

NMDOT	New Mexico Department of Transportation
NRMCA	National Ready Mixed Concrete Association
NYSDOT	New York State Department of Transportation
ODOT-Oregon	Oregon Department of Transportation
OSHA	Occupational Safety and Health Administration
PBOT	Portland Bureau of Transportation
PSIM	Pavement Sustainability Index for Maintenance
PSR	Present Serviceability Rating
QA	Quality Assurance
QC	Quality Control
RMRC	Recycled Materials Resource Center
SCCRTC	Santa Cruz County Regional Transportation Council
SDDOT	South Dakota Department of Transportation
STAR	Sustainable Transport Appraisal Rating
STARS	Sustainable Transportation Analysis & Rating System
STC	North American Sustainable Transportation Council
TBL	Triple Bottom Line
TRB	Transportation Research Board
UDOT	Utah Department of Transportation
UPH	Upstream Public Health
USCOE	U.S. Army Corps of Engineers
USDOT	The U.S. Department of Transportation
USNA	The U.S. National Arboretum

USGBC	The U.S. Green Building Council
VMT	Vehicle-Miles Traveled
VicRoads	Roads Corporation of Victoria
WSDOT	Washington State Department of Transportation

CURRICULUM VITA

NAME: Yibo Zhang

ADDRESS: Department of Civil and Environmental Engineering
218 Eastern Pkwy
University of Louisville
Louisville, KY 40208

DOB: Ruzhou, Henan, People's Republic of China - Aug 8, 1987

EDUCATION:

B.S., Civil Engineering
School of Civil Engineering
Zhengzhou University, P. R. China
2004-2008

M.S., Highway and Railway Engineering
College of Civil Engineering
Chongqing Jiaotong University, P. R. China
2009-2012

Ph.D. Civil and Environmental Engineering
Department of Civil and Environmental Engineering
University of Louisville
2012-2017

PROFESSIONAL SOCIETIES:

Member of
- American Society of Civil Engineers (ASCE)
- Greenroads
- International Code Council

PUBLICATION:

Zhang, Y. and Mohsen, J. P. (2016). Project-Based Sustainability Rating Tool For Pavement Maintenance, International Conference on Sustainable Infrastructure 2016, Shenzhen, China

INVITED PRESENTATION:

Zhang, Y. (2016). A Tool to Evaluate the Sustainability of Pavement Maintenance Projects. Pavement Design, Department of Civil and Environmental Engineering, University of Louisville