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THE EFFECT OF PRESERVATION MAINTENANCE ACTIVITIES IN ASPHALT CONCRETE PAVEMENT SUSTAINABILITY

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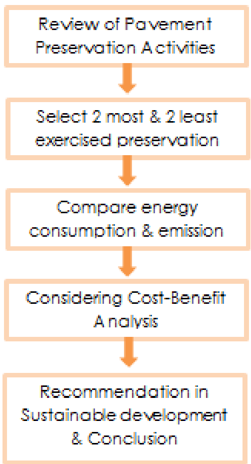
Graphical abstract



Abstract

Pavement infrastructure is crucial to quality lifestyle and affluence of society. Since the pavement structure deteriorates after a while, appropriate pavement preservation maintenance is essential to attain a superior performing, safety, and economic pavement network for the users. Nowadays, within a modern society resources and budget are restricted that make it necessary for transportation agencies to discover approaches to use the resources to optimize benefits included in daily operation. Simultaneously, focus on the idea of environmental sustainability has increased substantially. Pavement preservation assists environmental sustainability by preserving energy, raw materials, and mitigating greenhouse gases (GHG) by maintaining good roads in the perfect condition. Thereby, a sustainable pavement maintenance program should look into allocating budget and resources to pavement preservation. Various types of pavement preservation treatments use different levels of energy and produce GHG emissions. Preservation treatments considered in this study included thin hot-mix asphalt (HMA) overlay, chip seal, slurry seal and crack seal. This research states the methodology in sustainable pavement preservation maintenance. Its focus is on quantifying and recognizing which of these pavement preservations practices minimize environmental impacts. As the economic is one of the components in triple bottom-line in sustainability, the next step is focusing on cost-benefit of preservation maintenance activity and comparing by rehabilitation activity. This research aims to persuade pavement organization to apply correct perseverance activity on the right time and proper manner to enhance sustainable development.

Keywords: Pavement; preservation; maintenance; sustainability; energy consumption; hot-mix asphalt (HMA).

1.0 INTRODUCTION

Enhancing societal understanding of the environmental impacts of constructing, operating, and maintaining the highway infrastructure has resulted in new requests on transportation organizations to conduct their business inside a more sustainable method. The initial concept of environmental Sustainability has been defined in 1987 by Bruntdland [1]. Recently, the FHWA defined sustainable transportation as "providing exceptional mobility and access in a manner that meets development needs without compromising the quality of life of future generations. A sustainable transportation system is safe, healthy, affordable, renewable, operates fairly and limits emissions and the use of new and non-renewable resources" [2]. The foundation of sustainability includes the three components: economic, social, and environmental. Sustainable pavement preservation maintenance is a part of sustainable transportation where the effects of the treatments on the economy, environment and social equity are delineated and appraised. The Federal Highway Administration (FHWA) distinguishes between pavement preservation and pavement maintenance and uses this to spend federal resources appropriately. The various trigger of preservation, rehabilitation and reconstruction has been illustrated in Figure 1. Pavement preservation maintenance treatments usually provide the most affordable pavement management strategy entirely on a life cycle cost analysis [3].

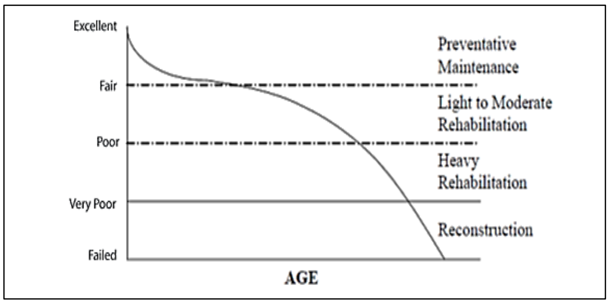


Figure 1 Trigger of preservation, rehabilitation and reconstruction

2.0 ENVIRONMENTAL SUSTAINABILITY

Computing environmental sustainability is an emerging area within the transportation industry, and much more so with regards to select the pavement maintenance treatment process. The literature appears filled with newly created terms to explain a given treatment's effect on the environment [4-7]. "The terms 'Green', 'Sustainable Development', 'Environmental Impact', 'Energy Efficiency', 'Global Warming', 'Greenhouse Gases', and 'Eco-efficiency', are becoming more widely recognized" [8]. Nevertheless, each study or guideline concentrates its assessment of environmental effect on a various set of impacts. Therefore, it is not easy to consider a unit, globally recognized term to distinguish the process of evaluating competing pavement preservation maintenance treatment options based on relative environmental sustainability.

The American Association of State Highway and Transportation Officials (AASHTO) Centre for Environmental Excellence (CEE) offers the general impact of infrastructure construction and maintenance activities to the environment that could be analyzed using the following seven sustainability impact factor areas: raw material consumption; use substitute material; monitoring and managing pavement; noise; air quality/emissions; water quality and energy utilization [9].

3.0 THEORY OF PAVEMENT PRESERVATION

Traditionally, the majority of transportation agencies would allow their pavements to degrade to fair or poor condition [10]. Due to the national centre pavement preservation (CNPP) initiative, funding agencies have become acquainted with the cost effectiveness of employing preventive maintenance to protect the infrastructure. Figure 2 shows the idea of pavement preservation, where every dollar allocated to maintenance prior to the age of speedy deterioration saves future rehabilitation costs and could certainly conserves much more when user delay and traffic control costs are included to the bottom-line [11].

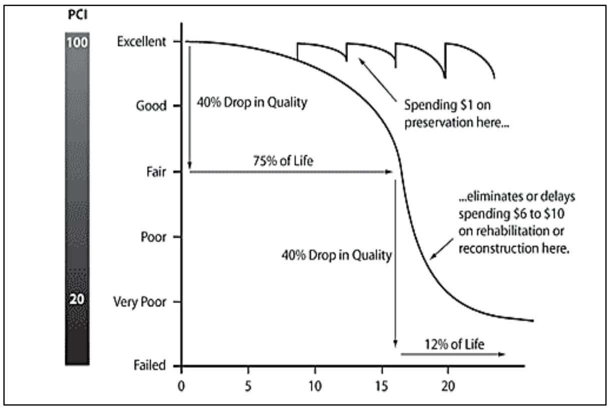


Figure 2 Economical theory of pavement preservation

By keeping the road in good condition, the overall sustainability of the network can potentially greatly enhanced by the reduction in the use of virgin materials and energy. The environment benefits from potential reductions in greenhouse gas emissions, hazardous material exposure, and deleterious construction operations that expose the soil to erosion. Society can benefit where preservation results in reduced times of traffic disruption, which translate into fewer work zone accidents and a drop in injuries and/or fatalities. In asset management terms, pavement preservation enhances the overall condition of the network and simplifies resource distribution decisions. Thus, optimization of pavement preservation practices and keeping them adequately funded has the potential to improve sustainability.

3.1 Previous Pavement Preservation Sustainability Studies

The literature is rich with information on practices that can improve sustainability that have been applied to highway design and construction. Each study represents an opportunity for maintenance engineers to potentially adopt aspects of the practices that can improve sustainability in maintenance and preservation. In other cases, the identified practices that can improve sustainability will likely need to be adapted or altered prior to their usage in pavement preservation and maintenance applications.

Table 1 illustrates that while fundamental research has been done on enhancing highway environmental sustainability through the use of recycled materials, alternative materials, and green construction technologies, the information necessary to extend these promising opportunities to pavement preservation and maintenance must still be developed through future research and field testing. A recent FHWA studies stated that the pavement preservation activities rarely considered in life cycle cost analysis method for new construction [12]. As a result, rigorous research would be needed in order to apply a life cycle cost analysis algorithm which goes beyond merely looking at treatment construction costs and provides a rigorous methodology to assign a valueto such things as carbon sequestration and resource renewability.

Table 1 Previous asphalt pavement preservation studies

References	Material/technique	Preservation uses	Remarks
Denevillers (2010)[24]	Bio-fluxing	Prime coat Chip seals Micro-surfacing	Trade name is Vege-flux
Denevillers (2010)[24]	Bio-binder	Chip seal Micro-surfacing	Trade name is Vege-col
ISSA (2010)[25]	Baghouse fines	Micro-surfacing Slurry seal	-
Benson & Edil (2009)[26]	Flue gas desulphurization gypsum	Micro-surfacing Slurry seal	-
Gardner & Greenwood (2008)[27]	Recycled concrete aggregation (RCA)	Full-depth patching Partial-depth patch	RCA acts to sequester CO_2 in addition to recycling
Pidwerbesky & Waters (2007)[28]	Ultra-high pressure water cutter	Restore macro-texture on chip seals	Uses no virgin material and the sludge can berecycled as pre-coatingfor chip seal aggregates.
Carpenter & Gardner (2007)[29]	Bottom ash	Micro-surfacing mineral filler	-
MnDOT (2005)[30]	Fly ash	Micro-surfacing Slurry seal	Widely used in a variety of products
Transportation Canada (2003)[15]	Shot-blasting	Restore microtexture on polishedHMA	Uses no virgin material and the steel shot is recycled for reuse inthe process
Chappat &Bilal (2003)[32]	CrushedSlag	Chip seal	-
Beatty *et al.* (2002)[10]	Recycled tire rubber	Chip seals Thin overlays	Also found to reduce road noise.

4.0 PAVEMENT PRESERVATION PRACTICE

A variety of different treatments are available to transportation agencies, and their use is determined according to factors of traffic, climate, available materials, etc. Criteria of environmental criteria do not currently play a part in treatment selection. Normally the agency will consider many factors when determining which treatments should be used. These factors may comprise: cost of treatment, type of distress and extension, traffic volume, weather, pavement type, expected life, availability of qualified contractors, availability of quality materials, time of year, pavement noise, facility downtime (user delays) surface friction, anticipated level of service and other project specific conditions [13]. Gransberg *et al.* [14] issued the most common preservation activities in 42 US DOTs and 7 Canadian provincial MOTs. Figure 3 illustrates the percentage usage of each practice on asphalt concrete pavement.

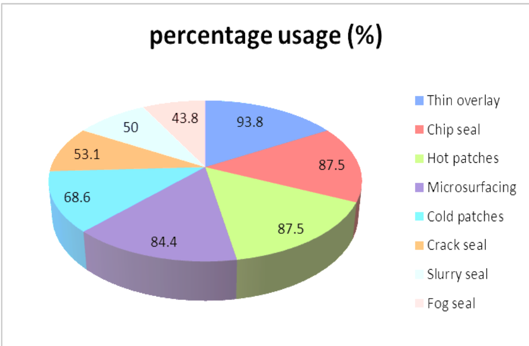


Figure 3 Preservation maintenance activities on asphalt concrete pavement [14]

Additionally, the research sought to evaluate the awareness of pavement preservation maintenance practitioners regarding the environmental sustainability of their existing practices [14]. The trend for asphalt preservation sustainability is shown in Figure 4.

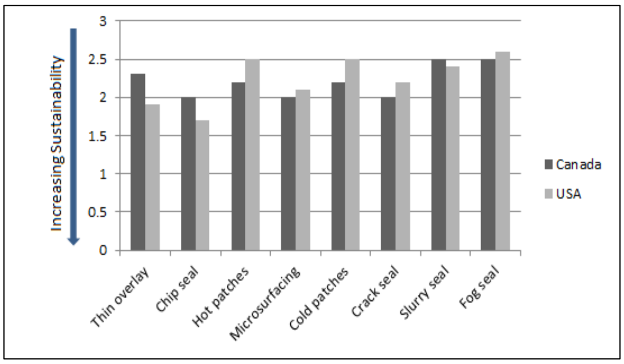


Figure 4 Rated sustainability of asphalt pavement preservation in USA & Canada [14].

4.1 Pavement Preservation Assessment

There are numerous factors to be considered when evaluating pavement preservation maintenance activities for a particular pavement. In general, the expected service life of the treatment is a function of the traffic loading, subgrade soil and design thickness. Several elements can be viewed as such as the pavement condition, roughness, skid resistance, structural adequacy and the associated effect on the level of serviceability. Another essential efficiency measure would be the computation of the environmental sustainability impact factors of each activity and the following total environmental sustainability impact of the remedy.

An extremely environmentally effective pavement preservation measure is using of shot-blasting on asphalt pavement which has dropped their skid resistance with time [15]. This technique uses simply no materials since it recycles the steel abrasives used to recover macrotexture and micro-texture on the pavement surface. Conversely, micro surfacing is frequently used to recover skid resistance to sound asphalt pavements with polished aggregate. When it is on comparison to thin (less than 2" or 5 cm) hot-mix overlays, it uses 50% the energy and raw materials, gives off about 60 % of the CO2, and cuts down the possibility of work-related illnesses and accidents by 63 % [16]. For instance, another factor which could be focused in environmental sustainability is the study of photo chemical ozone creation data and related reductions in CO2 and NO2 emissions regarding treatments same as micro surfacing [17].

Uhlman [16] found that using micro-surfacing as a pavement preservation treatment leaves a much smaller ecological "fingerprint" than the hot-mix overlay. The ecological fingerprint concept involves comparing various ecological factors related to a product or process how it impacts the environment. Stakeholders select the factors that impact future generations and show it as a three-dimensional figure. Although this concept is still somewhat developmental, it provides a methodology for looking at multiple factors and how they impact the environment [18]. Many factors determine which preservation and maintenance treated is best suited for each agency, some of these factors include: traffic, climate, available materials, cost of treatment, type and extent of distress, expected life, time of year, and etc.

4.2 Energy and Emission of Pavement Preservation

Preservation activities are focused mainly on improving pavement functional performance and prolonging pavement life. In this study, four major treatment types of flexible pavements are considered. The HMA thin overlay and chip seal activities are chosen from the most interested practices while crack seal and slurry seal are least interested efforts [14]. However, fog seal is not considered in the least activities because this treatment is mostly use for shoulders preservation. Details of the preservation activities are discussed as the following:

i. HMA thin overlay is one of the most commonly used preservation treatments in pavement preservation. It prolongs pavement structure's life and adds more strength. It is applied in different thicknesses 0.5, 1.0, 1.5 and 2.0 inches [19]. Thin overlay is a popular approach in preservation of pavements as it reduces pavement distress, noise level, life cycle cost, improves ride quality, maintain surface geometrics and provide long lasting service. It can withstand heavy traffic and is easy to maintain. Thin overlays are expected to stay for seven years on a good low distress pavement surface [20].
ii. Chip seal is a surface treatment in which pavement surface is sprayed with asphalt and then immediately covered with aggregate and rolled by roller. Chip seals are used primarily to seal a pavement with non-load-associated cracks, and to improve surface friction. They are also common as a wearing course on low volume roads [20]. In chip seal, the adhesion of emulsion and aggregate is crucial and aggregates should be completely dry and clean to prevent the adhesion failure. Failure of chip seal occurs mainly because of two reasons: stripping and bleeding.
iii. Crack seal is one of the most common preservation treatments because it is cost-effective and can be easily applied. It extends the service life of the pavement by reducing the amount of moisture that can infiltrate a pavement structure. Crack sealing prevents intrusion of water and foreign material into the pavement surface [21]. This method requires a process of preparing cracks with cleaning and properly filling it with the filling materials. It's important to make it moisture free as this will make the material adhere to the crack surface effectively.
iv. Slurry seal is a mix of polymer-modified emulsion and fine crushed aggregate that is spread simultaneously in one pass over the road at a particular thickness. There are three types of slurry seal according to the size of the aggregate used. Slurry seal is very effective in sealing sound, oxidizing pavements, and restoring surface texture by providing an anti-skid surface and giving better water proofing

characteristics. Environmental conditions and temperature play an important role in curing and setting of the slurry. Slurry seal should not be applied at night or in rainy and cold conditions [21]. Type I aggregate is primarily used to correct minor surface defects like cracks and voids. It is mainly used for airfields and parking lots. Type II aggregate is used on pavements with medium textured surface and can correct surface voids and moderate surface defects. It can be applied to a surface which needs weathering correction and ravelling and surface prone to medium to heavy traffic. Type III the largest gradation is used to improve friction and skid resistance, increases durability and its best suited for higher traffic pavements like collectors, arterials and major highways and is best for rut filling and corrects minor surface irregularities.

All the consideration about resource consumption and transport distance to the site of these four treatments illustrated in Table 2. Meanwhile, Table 3 shows the calculated energy use and emissions at the construction stage for one lane-mile (each lane considered 3.6m) of surface area, respectively, for thin overlay, slurry seal, chip seal and crack seal. The energy consumption was summed up with the break-up of energy resources such as natural gas, oil, electricity, and coal fuel. The emission values were calculated for carbon dioxide (CO_2), sulphur oxide (SO_x), nitrogen oxide (NO_x), carbon monoxide (CO), nitrous oxide (N_2O), methane (CH_4), and volatile organic component (VOC).

Table 2 Characteristics of treatments

Process	Raw Material (ton)				Transportation (20 Mile)
	Asphalt	Emulsion	Aggregate	Sealant	
Thin Overlay (1.5 inch)	26 (5%)	-	492 (95%)	-	518
Chip Seal [a]	-	10 (10%)	87 (90%)	-	97
Crack seal [b]	-	-	-	1	16
Slurry Seal [c] (Type II)	-	11 (14%)	67 (86%)	-	78

a. With an application rate of 1.632 kg/m2 and 15 kg/m2 for emulsion and aggregate respectively.
b. With an application rate of sealant 0.37 kg/m2 and crack density of 0.37 m/m2.
c. With an application rate of 1.218 kg/m2 and 7.482 kg/m2 for emulsion and aggregate respectively.

Table 3 Energy consumption and emission for pavement preservation treatment

Preservation Treatment	Thin Overlay (One lane-Mile)	Chip seal (One lane-Mile)	Crack seal (One lane-Mile)	Slurry seal (One lane-Mile)
		Energy (J)		
Natural Gas	2.27E+10	9.44E+09	1.79E+09	1.04E+10
Oil	5.22E+10	8.09E+10	4.93E+09	7.03E+10
Hydropower energy	2.87E+10	8.67E+08	-	6.67E+08
Electricity	1.86E+09	-	-	-
Fuel	2.28E+09	2.21E+09	5.71E+08	2.40E+09
Total	**5.95E+11**	**9.34E+10**	**5.71E+08**	**8.37E+10**
		Emission (Kg)		
SO_x	2.90E+01	8.63E+00	1.36E+00	6.89E+00
NO_x	3.42E+01	1.16E+01	2.10E+00	7.65E+00
CO_2	1.85E+04	2.52E+03	3.48E+02	1.79E+03
CO	2.04E +01	9.30E+00	6.81E-01	6.16E+00
N_2O	3.36E-02	1.21E-02	2.23E-03	7.25E-03
CH_4	2.94E+02	6.05E+00	8.73E-01	4.52E+00
VOC	1.64E+02	3.31E+00	3.93E-01	2.63E+00

4.3 Estimating Costs and Benefits of Pavement Preservation

Optimization of pavement preservation practices and keeping them adequately funded can potentially improve pavement sustainability. The costs and expected lives of the various treatments are summarized in Table 4 of the study. These values can vary depending on the project and its specifications and environmental surroundings [22]. To emphasis benefit of preservation maintenance activity two plans are considered as a case study as it is shown by Table 5. A basic life-cycle cost analysis was conducted, considering the preservation and rehabilitation activities after the initial construction (assuming that the initial construction will be the same, independent of the preservation plan). Then the total PSI-years are computed for each plan (with and without preservation activities, or when deciding on a specific activity or its timing). Finally, a comparison is made between the $/PSI-year/mile for each plan to determine its effectiveness. The discount rate is considered 4% and cost for Mill & Overlay is $50000, while other data comes from Table 4.

The cumulative performance provided by a pavement structure over its life can be computed as the accumulated area under the PSI curve. The performance is indicated by the units "PSI-years." As can be seen in the figures below, the pavement which has had performance activities to extend the life of the structure has performed better over its life than a pavement where preservation activities have not augmented the life of the structure.

From the condition index data in the curves shown in Figure 5 and 6, the overall PSI-year can be computed, by accumulating the area under the curves for the respective plans. In this case, with the terminal PSI set at 1.5, the area between the PSI curves and the terminal value is computed. By the end of the planned life, the Rehabilitation Only plan is estimated to provide a performance value of about 50 PSI-years. The Preservation plan provides about 60 PSI-years in performance. The last step is to divide the total life-cycle cost by the overall performance provided by the pavement.

For the preservation plan, the cost is:

$$\frac{\$171{,}810}{60\ \text{PSI}-\text{Years}} = \$2864\ \text{Mile/PSI} - \text{Year}$$

And for the rehabilitation plan, this cost is:

$$\frac{\$176{,}508}{50\ \text{PSI}-\text{Years}} = \$3530\ \text{Mile/PSI} - \text{Year}$$

Table 4 Typical unit costs and expected life of pavement maintenance treatments

Preservation Treatment	Expected Life of Treatment [min, max]	Expected Life of Treatment Average	Cost/m²	Cost (One lane-Mile)
Thin Overlay	[2, 12]	7	$2.09	$12100
Chip Seal	[3, 7]	5	$1.02	$5900
Crack seal	[2, 5]	3	$0.60	$3500
Slurry Seal	[3, 7]	5	$1.08	$6300

Table 5 Sample comparison between standard and preservation plans

Year	Plan 1 – With Preservation Activity	Plan 1 – Cost $/Mile	Plan 2 – Without Preservation Activity	Plan 2 – Cost $/Mile
1	Initial Construction	N/A	Initial Construction	N/A
2	Crack Seal	3640		
5	Chip Seal	6902		
10	Thin Overlay	17222	Mill & Overlay	71166
12	Crack Seal	5388		
15	Chip Seal	10217		
20	Mill & Overlay	105342	Mill & Overlay	105342
22	Crack Seal	7976		
25	Chip Seal	15123		
30	Reconstruction	N/A	Reconstruction	N/A
	Total	171,810	**Total**	176,508

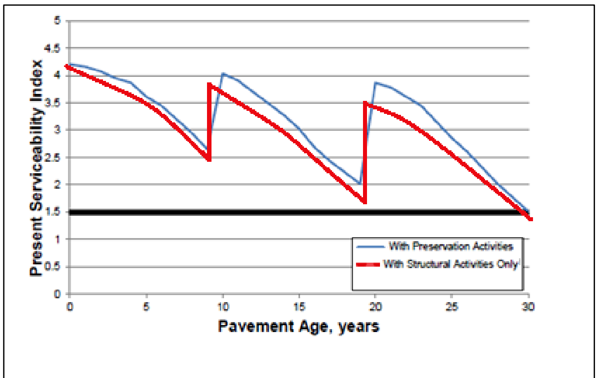


Figure 5 Preservation Serviceability Index

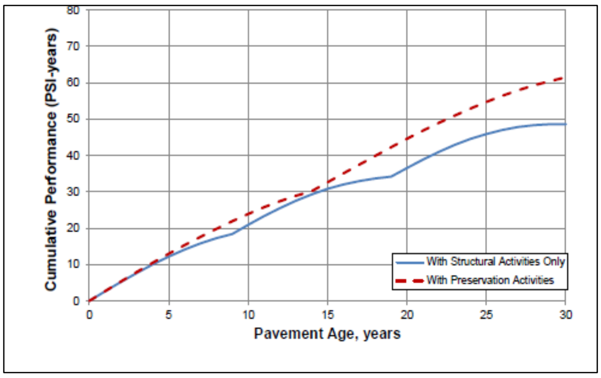


Figure 6 Cumulative pavement performance curve

5.0 DISCUSSION AND RECOMMENDATIONS

In this study, energy and emissions of four pavement preservation treatments were quantified at the construction stage. Also, the cost-effectiveness of preservation maintenance was examined. Programs for Pavement In-Service Monitoring and Management are required to alert agencies in a timely manner to pavement deterioration so that they can intervene with preservation treatments before the road becomes so bad that preservation is no longer an option. In short, they support putting the right treatment on the right pavement at the right time.

Although, the thin overlay was found to have the highest energy consumption and emissions among four preservation treatments during construction stage (If only construction stage is considered, energy and emissions are ruled by use of amount of material and manufacture process), should consider the effect of expected service life in calculation and frame-work design. For instance, the pavement segment needs just once thin overlay during 15 years serviceability while it requires chip seal minimum twice and crack seal around four times.

The crack sealing was found the least GHG emission and energy consumption and it is most eco-friendly treatment, however, the expected service life is just average 3 years.

Recycling, reusing, and reclaiming of existing materials is crucial to advance sustainable development [23]. Construction materials can be costly and some sources currently have restricted supply, making it crucial to make good usage of available materials.

The cost of adding several chip seals and only one thin overlay over the life of the pavement may be similar to applying two Mill & Overlay operations over the same life span. If the preservation activities serve the purpose of extending the life of the pavement structure, such a relative comparison is reasonable.

Some questions cannot be answered in this research, but that must be discussed and resolved at the local agency. Are the additional time and expense involved in extra preventive activities worth the increased pavement performance? How closely can costs and performance be estimated? How much will a change in prices affect the analysis? Will delaying preservation activities cause a pavement to deteriorate beyond the point where additional preservation would be useful?

6.0 CONCLUSIONS

Presently, public organizations have done hardly any to increase the information obtained from study and exercise in sustainable highway project over and above construction and into the pavement preservation maintenance of a road's life cycle. Therefore, there are lots of potential possibilities for long term study and enormous possibilities for organizations to collect benefits in this field. Treatments recognized in this study are mainly associated with preservation maintenance. However, these are not only at preservation maintenance and may be done in pavement rehabilitation.

Optimization of pavement preservation practices and keeping them adequately funded can potentially improve pavement sustainability. Thus, the next step is choosing investment in the preservation treatment or non-preservation to take pavement preservation and maintenance to an even higher level of sustainability.HMA thin overlay and chip seal activities are chosen from the most interested practices while crack seal and slurry seal are least interested efforts. In the economical point of view, by applying proper preventives activities the cost of pavement during its life cycle time reduces remarkably.

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