

A Carbon Footprint Cost Index for Pavements

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Public projects for pavement and pavement maintenance are often based on budgets set by capital improvement budgets. A better way for determining the cost of sustainability in infrastructure costs is needed. This limitation causes an issue where the owner must construct projects with a focus solely on initial cost and cannot include sustainability requirements due to the perceived additional cost. A tool is required to assist owner's in the decision making process to justify spending additional funding for sustainable goals based on future savings. Sustainability can often be viewed as subjective. Utilizing the carbon footprint as the basis for the decision creates a much more objective evaluation of sustainability in pavements.

Keywords: pavement maintenance, pavement preservation, sustainability, project planning, carbon footprint

Introduction

Pavement preservation and maintenance techniques are considered more sustainable by increasing the lifespan of existing roadways through a variety of factors. For instance, Reclaimed Asphalt Pavement (RAP) "reduces production cost and conserves diminishing resources of aggregates and petroleum products" (Hajj et al. 2008). Slurry seal extends the life of the pavement (Chen et al 2003). A comparison of the cost factors and sustainability for pavement construction projects is required. A cost index that utilizes the carbon footprint to represent sustainability is an objective evaluation of sustainability in pavements.

Owners require an objective comparison on sustainable alternates for pavement preservation to justify the cost of sustainable pavement practices and to estimate the cost of sustainability in addition to understanding the alternates. Currently there are multiple benchmarks for sustainability including Leadership in Environmental and Energy Design for New Development (LEED-ND) (USGBC 2009), Greenroads (Muench et al 2010), Green Leadership In Transportation Environmental Sustainability, termed "GreenLITES" (NYSDOT 2010), and Federal Highway Administration's (FHWA) INVEST 1.0 (Bevan et al. 2012). The focus of the different benchmarks varies widely, including pre-project planning and operations and maintenance.

The sustainable pavement practices found in the benchmarks have been listed to illustrate the current state of practice. In order to increase sustainable pavement practices, the cost of the sustainability portion must be determined. There are several areas upon which a municipality can focus. Sustainable practices are listed below that were not evaluated for the carbon footprint.

- **Paving,**
- Permeable,
- Low Albedo (light color),
- Recycled Content,
- Asphalt – reduced emissions, warm mix,
- Low VOC Admixtures/Cut-backs/Emulsions,

- **Reduce,**
- Construction Waste,
- Virgin Materials,
- **Haul Distance,**
- Production Cycles,
- Clean fuels, biofuels,
- Minimize haul distances, and
- Minimize starts/stops of construction sequence.

Types of sustainable pavement preservation include: reclaimed asphalt pavement, warm mix asphalt, slurry seal, micro-surfacing, hot mix asphalt overlay and shot-blasting with lithium hardener. The research evaluates the following sustainability alternatives for pavement projects. Listed alternatives are typical pavement construction project bid items, not all of them are the actual paving.

- **Reclaimed Asphalt Pavement** (RAP) is produced by cold milling existing pavement and adding back into the production process.
- **2" HMA Overlay** is a mixture of asphalt binder and graded mineral aggregate, mixed at an elevated temperature and compacted to form a relatively dense overlay, or surface layer over existing pavement (Galehouse et al 2003).
- **Micro Surfacing** is a mixture of high-quality fine aggregates, which makes it cleaner and harder relative to slurry seal in addition to a polymer-modified emulsion for high-performance (Peshkin et al. 2004).
- **Slurry Seal** is a mixture of well-graded, fine aggregate and unmodified asphalt emulsion (Peshkin et al. 2004) providing a seven-year extension of life of pavement (Chen et al 2003).
- **Cleaning and Filling Joints and Cracks** includes crack sealing with sealant (Galehouse 2003).
- **Reduce Hauling** limits the haul distance.

Chehovits and Galehouse (2010) provide a list of the energy usage of several types of pavement preservation materials and also provide estimations of pavement preservation life extensions. An adaption follows (see Table 1)

Table 1

Pavement Preservation Material and Life Extensions

Sustainable Treatment Type	**Life Extension**	**Carbon Footprint BTU/yd^2**
*RAP (12")	0 years	-4,400
2" HMA Overlay	5 – 10 years	61,500
Micro - Surfacing	3 – 5 years	3,870-5,130
Slurry Seal	3 – 5 years	3,870-5,130
Cleaning / Filling Joints / Cracks	1 – 3 years	290-870
*Reduce Hauling	0 years	-1250

Table 1 includes only items applicable to the case study location. RAP is defined here as 50% aggregate replacement for a 12" deep section of asphalt. *RAP and Reduce Hauling do not increase lifespan, but can reduce the carbon footprint.

Case Study Project

A variety of example projects dating from 2006 through 2012 were used for cost data. Bid tabulations are posted on the City of Oklahoma City website (COKC 2011). Twenty-three projects were used for cost data from all types of paving construction, including trails, resurfacing, streetscapes and road widening projects, which include full depth replacement. Each of these types of projects has the potential for more sustainable construction. Even though asphalt resurfacing is already a preservation project and therefore sustainable, there is additional room for more sustainable practices. The cost data was used to build a database. A case study project was used for validity testing.

An airport taxiway reconstruction and realignment project was used as the case study because it utilize both asphalt and concrete paving. Taxiways act as connectors between the runway and the tarmac where a plane loads and unloads passengers. Pavement preservation types that can be utilized for this project include: shot-blasting with lithium hardener, slurry seal, micro resurfacing, and 2" hot mix asphalt overlay. The airport project consisted of 80 bid line items, however only the pavement items were used for validation.

For the purposes of reviewing pavement preservation costs only, the bids were reduced to the paving items only. At $3,296,272.44, the paving portion is significant and highlights why pavement preservation methods are so important. Items identified are included (see Table 2).

Table 2

Pavement Bid Items and Units

Item Description	Units
Cold Milling Asphalt Pavement	sy
Bituminous Surface Course	ton
Bituminous Surface Course (2")	sy
Structural Portland Cement Concrete	cy
Reinforcing Steel	lb
8" P.C. Concrete Drive	sy

The pavement preservation options were compared to the pavement items only for cost comparisons. Since the case study project includes both types of paving, it is assumed that both types will be installed even if pavement preservation is utilized. However, only one preservation type is compared at a time.

Cost data for the sustainable treatment options were obtained in 2008 (Riemer et al 2012). Using the ENR Cost Index (Grogan 2011), the full lane cost per square yard was converted to 2011 to match the bid year. The conversion factor is approximately 1.05. Index adjusted costs are illustrated (see Table 3).

Table 3

Annual Cost Index Adjustments

Sustainable Treatment Type	Additional Cost	Percent Increase
Shotblasting / Lithium Hardener	$22,034.13	0.67%
2" HMA Overlay	$346,269.33	4.44%
Micro - Surfacing	$38,396.53	1.16%
Slurry Seal	$18,266.31	0.55%

The Equivalent Uniform Annual Cost (EUAC) approach is not applicable when the dollar amounts are annualized over the same period. In this case, the period assumed for all alternatives was 20 years. Evaluating with a Net Present Value (NPV) approach using a 20 year life based on Federal Aviation Administration pavement life recommendations (Navneet et al 2004). The NPV is evaluated at minimum, average and maximum life cycles and using the following equation:

NPV = initial cost + rehab cost*$[1/(1+i)^n]$ (Pittenger et al 2012)

The additional costs of sustainable treatments are compared to project low bid of $3,296,272.44. Based on net present value, Lithium Hardener adds 1.58% or is $3,348,306.69 at the minimum life of 6.3 years, 1.48% or $3,345,200.20 at the average life of 6.7 years and 1.40% or $3,342,443.73 at a maximum life of 7.1 years.

Evaluating 2” HMA Overlay using net present value is an additional 25.19% or $4,126,621.75 at the minimum life of 5 years, 14.77% or $3,783,180.87 at an average life of 7.5 years and 9.56% or $3,611,460.42 at a maximum life of 10 years.

Using net present value, Slurry Seal adds 2.75% or $3,386,858.51 at a minimum life of 3 years, 1.65% or $3,350,624.30 at the average life of 5 years and 1.18% or $3,335,095.36 at maximum life of 7 years.

Micro-Surfacing would add 5.78% or $3,486,687.45 at a minimum of 3 years, 4.33% or $3,439,083.84 at an average life of 4 years and 3.47% or $3,410,521.67 at a maximum life of 5 years. The additional costs and the expected life are illustrated (see Table 4).

Table 4

Additional Costs and Expected Life Extension of Pavement Preservation Types

Sustainable Treatment Type	**Additional Initial Cost**	**Min. NPV / Life**	**Ave. NPV / Life**	**Max. NPV / Life**
Shotblasting / Lithium Hardener	$22,034.13	1.58% 6.3 years	1.48% 6.7 years	1.40% 7.1 years
2” HMA Overlay	$346,269.33	25.19% 5 years	14.77% 7.5 years	9.56% 10 years
Micro - Surfacing	$38,396.53	2.75% 3 years	1.65% 5 years	1.18% 7 years
Slurry Seal	$18,266.31	5.78% 3 years	4.33% 4 years	3.47% 5 years

Using this information, the owner can see that even though Slurry Seal has the least additional initial cost, the expected life causes the NPV to be higher. The Shotblasting / Lithium Hardener alternative has the higher initial cost, but has a longer life span. The 2” HMA Overlay has the highest initial cost even though it is illustrated with the longest expected life.

Comparing the carbon footprint, the Micro – Surfacing and Slurry Seal are very similar. When comparing to the other sustainable treatment options, constructing a 2” HMA Overlay has at least one order of magnitude greater carbon footprint. Shotblasting / Lithium Hardener has the smallest carbon footprint.

Another approach to the decision making process is Using an Analytical Hierarchical Process (AHP), we define the alternatives and then prioritize the values (see Table 5). For a municipality performance and cost are a higher priority than sustainability. Performance and cost may be equal, since higher performance products can cost more. Likewise, lower cost items may reduce the performance.

Table 5

Analytical Hierarchical Process Priority

	Cost	**Sustainability**	**Performance**
Cost	2/2	2/4	1/2
Sustainability	4/2	4/4	1/4
Performance	2/1	4/1	1/1

Assuming the performance reduces cost through net present value, priorities can be set. Performance is 4, cost is 2 and sustainability is 1, with importance doubling the priority. Based on the matrix shown, priority values are calculated by squaring the matrix and computing the eigenvectors (see Table 6).

Table 6

Prioritization Values

Cost	**Sustainability**	**Performance**
0.34	0.24	0.42

Using these priority values with alternatives of performance, cost and sustainability a preference for performance is shown. This method can be used to discriminate between two products and provide a tool, which does not make cost the only factor (see Figure 1).

With this simple case study a decision making tool is not necessary, however for more complex decisions a tool would be provide direction. Below is a decision making tool for a simple problem of budget, pavement preservation and sustainability requirements.

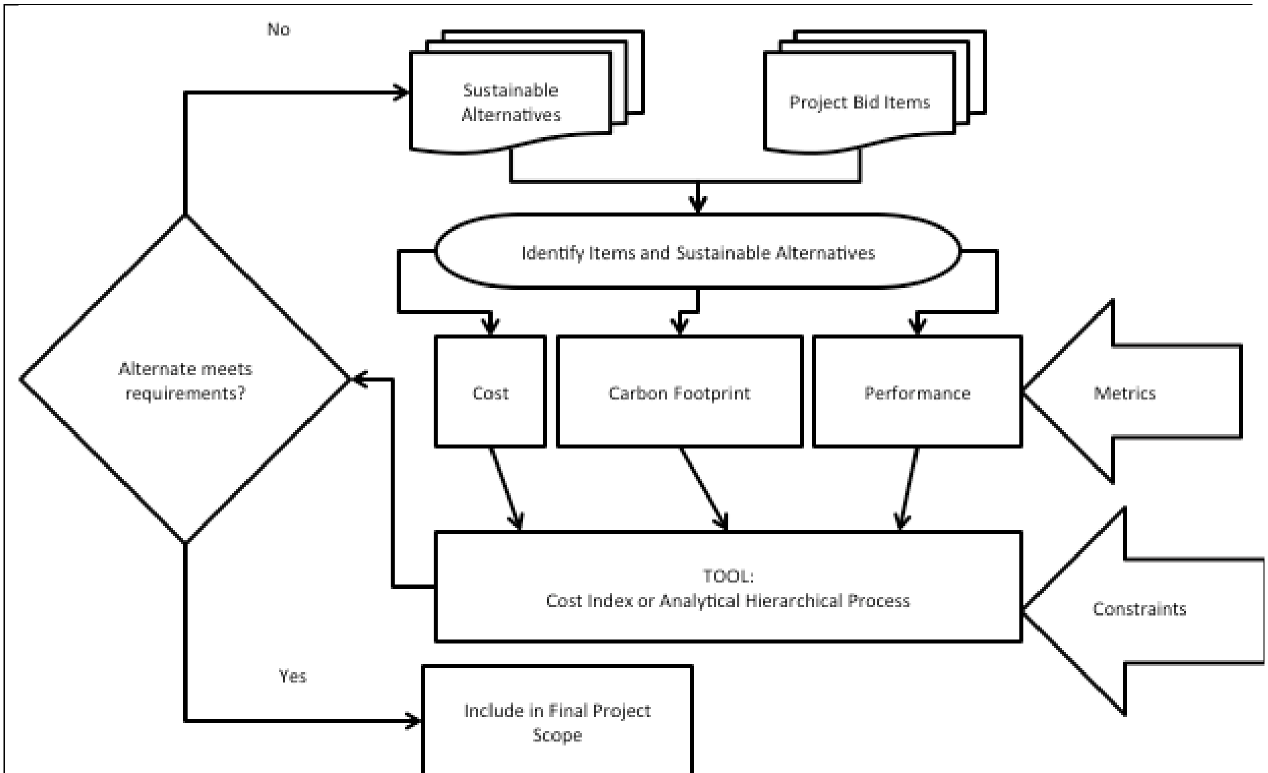

Figure 1: Carbon Footprint Cost Index Decisions Tool.

For a public owner like a municipality, being able to justify spending additional funding is often necessary. As agencies move towards integrating sustainability into all facets of public works construction projects, it is quite imperative that these costs are known. The costs of sustainable options are comparable to the less sustainable options, giving the owner the ability to construct more sustainable for an equivalent price. One advantage to the proposed process is that it segregates required features of work from the proposed preservation options.

Agencies should consider more sustainable paving types, which can be a minimal cost. However since pavement preservation can provide additional life, the additional costs need to be weighed against the benefits. Sustainable options should be investigated and can also be used for decision-making. Additional research should be performed, specifically about utilizing asphalt and recycled products in paving.

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