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Carbon footprint cost index: a pavement case study

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Abstract

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. The capitol budget limitation causes an issue for the owner. The municipality must construct projects with a focus solely on initial cost and cannot include sustainability requirements due to the perceived additional cost. 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. A case study illustrating a carbon footprint cost index is presented.

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

1. Main text

The airport industry has exhibited a determined interest in sustainability. The needs of aviation are different than those of other industries. Airports traditionally have terminal buildings and immense quantities of paved areas for tarmacs, taxiways and even automobile parking. A case study on sustainability for pavements was performed on a built project at Will Rogers World Airport in Oklahoma City.

The financial analysis of airport pavement construction and maintenance projects is typically based solely on minimizing initial cost. 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

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(RAP) "reduces production cost and conserves diminishing resources of aggregates and petroleum products" [1]. Slurry seal extends the life of the pavement [2]. 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) [3], Greenroads [4], Green Leadership In Transportation Environmental Sustainability, termed "GreenLITES" [5], and Federal Highway Administration's (FHWA) INVEST 1.0 [6]. 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 incorporated into Table 1 and 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. Table 1 also includes sustainable practices that were not evaluated for the carbon footprint.

Table 1. Sustainable Practices for Pavement

Paving Options	
	Permeable Low Albedo (light color) Recycled Content Asphalt – reduced emissions, warm mix Low VOC Admixtures/Cut-backs/Emulsions
Reduction Options	
	Construction Waste Virgin Materials Haul Distance
Production Options	
	Clean fuels, biofuels Minimize haul distances 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.

- Shotblasting / Lithium Hardener – Lithium silicate is used as a hardener on the surface of Portland Cement Concrete pavement [7]. The shotblasting process retextures pavement surface a process that relies on a machine that propels some form of abrasive particle onto the pavement surface [8].
- 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 [9].
- 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 [10].
- Slurry Seal is a mixture of well-graded, fine aggregate and unmodified asphalt emulsion [10] providing a seven-year extension of life of pavement [2].

- Cleaning and Filling Joints and Cracks includes crack sealing with sealant [9].
- Reduce Hauling limits the haul distance.

Chehovits and Galehouse [9] 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 of their table is illustrated in Table 2.

Table 2

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

The table 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.

A variety of example projects dating from 2006 through 2012 were used for cost data. Bid tabulations are posted on the COKC website [11]. Twenty-three projects were used for the cost data comparison basis 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.

This Taxiway Reconstruction and Realignment project utilizes both asphalt and concrete paving. 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.

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 in Table 3.

Table 3

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 [12]. Using the ENR Cost Index [13], 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 in Table 4.

Table 4

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 [14]. The NPV is evaluated at minimum, average and maximum life cycles and using the following equation:

$$NPV = \text{initial cost} + \Sigma \text{rehab cost}*[1/(1+i)^n] \quad [15]$$

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 in the table below.

Table 5

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). The alternatives are defined and then the values are prioritized. 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 6 illustrates the use of AHP. 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. The priorities are set based on the owner or user preference. There is some subjectivity involved, but for many government entities cost and performance will outweigh sustainable options. However for airports sustainability is often a higher priority based on federal funding.

Table 6

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

Based on the matrix shown, priority values are calculated by squaring the matrix and computing the eigenvectors. 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. The priority values are shown in Table 7.

Table 7

Value	Priority
Cost	0.34
Sustainability	0.24
Performance	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.

For a public owner like a municipal airport, 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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