Carbon Footprint Cost Index: Measuring the Cost of Airport Pavement Sustainability

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Abstract: The airport pavement design process for construction and maintenance projects is typically only considered pavement alternatives on a basis of initial cost. With recent concern for the impact of these projects on the environment, airports are seeking to include sustainability into their pavement maintenance treatment selection decisions. The paper proposes a new decision criterion that integrates sustainability with initial cost, essentially quantifying the “bang for the buck” and permitting airport pavement managers to justify investing in higher cost treatments on a basis of enhanced sustainability. The metric is termed the carbon footprint cost index and measures the relative cost of reducing a pavement project’s carbon footprint. The paper also presents a methodology based on the analytical hierarchical process for integrating the index into the typical airport pavement construction/maintenance project design process and demonstrates the utility of the new metric by applying it to a case study project at the Will Rogers International Airport in Oklahoma City. The paper concludes that the carbon footprint cost index provides a simple way to enhance pavement sustainability at airports across the nation.

Utilizing an Analytical Hierarchical Process (AHP) can guide the decision as well. The AHP allows weighting of cost, performance and sustainability. Additionally, a framework for determining when to increase the budget for pavement preservation and sustainability requirements is presented to assist owners in the decision making process, using initial cost, life cycle cost, and carbon footprint.

INTRODUCTION

“The need to preserve our airfield pavement infrastructure is paramount to insuring the viability of transportation of people and goods” (Hein and Aho 2011). Increasing societal awareness of the environmental effects of pavement infrastructure has led to new demands on transportation agencies to provide environmentally responsive infrastructure. Pavement preservation and maintenance practices are applied to restore the pavement condition and extend service life. In the highway sector, the Federal Highway Administration (FHWA) considers pavement preservation as one of the three types of activities that restores the pavement serviceability: pavement maintenance, pavement rehabilitation, and pavement reconstruction and authorizes federal-aid highway funding for preservation projects. Fifteen years ago, those very same projects would have been the state’s financial responsibility for operations and maintenance. The change came as FHWA found that pavement preservation and maintenance treatments usually provide the least expensive pavement management strategy available (FHWA 2005).

The Federal Aviation Administration is also “the major source of preservation funding” (Hein and Aho 2011) and requires implementation of a formal pavement management program to be eligible for Airport Improvement Program (AIP) grants. Additionally, FAA Advisory Circular 150/5320-6E – “Airport Pavement Design and Evaluation” mandates the use of life cycle cost analysis (LCCA) as part of the pavement type/treatment selection process (FAA 2009). Minimizing life cost as the decision criterion permits a more expensive alternative to compete with the low cost option and while many current pavement sustainability rating systems include LCCA as an essential component, it still only measures the difference between alternatives in financial terms. Thus, the incremental cost of a highly sustainable option rather than the environmental impact remains a significant barrier to implementing a truly green pavement preservation program.

The very concept of pavement preservation is inherently sustainable. “Keeping good roads [and runways] good” (Galehouse et al 2001) means maintaining the network in a manner that does not require consumption of new material. When one compares the environmental impact of allowing a runway to deteriorate to the point where it must be removed and replaced to the impact of pavement preservation treatments like crack sealing, shotblasting or microsurfacing, the difference is so great as to make the surface treatment seem trivial. Thus, the next step is to invest in the treatment types themselves and take pavement preservation and maintenance to an even higher level of sustainability by selecting treatments that minimize the impact to the environment. However, to do so will require the ability for airport pavement managers to justify the added incremental cost, if necessary, of high-sustainability options. Therefore the objective of this paper is to propose a metric, the carbon footprint cost index that will fill that need.
BACKGROUND

There is currently a wide variety of research on sustainability for airports and aviation. The existing research includes operations, maintenance, and even a strong focus on tenants. However, little, if any, existing research has addressed sustainability through preservation practices for the taxiway, runway and landside pavement. Airport authorities require an objective comparison of sustainable pavement preservation alternatives to justify their cost. Sustainable pavement options in aviation are the same as those in other heavy civil construction projects. Airports must be able to estimate the cost of sustainability in addition to understanding the alternates. Currently there are many benchmarks in use for sustainability including Leadership in Environmental and Energy Design for New Development (LEED-ND) (USGBC 2009) and Greenroads (Muench et al 2010). The airport industry has not yet come to consensus on a standard for sustainability. However, some airports have tried to compile their own standards. The Chicago Department of Aviation published the Sustainable Airport Manual (SAM). The SAM focuses on Planning, Design & Construction, Operations & Maintenance and Concessions/Tenants (CDA 2011).

There are two sustainable benchmarks that may be applicable for comparison of airport criteria. Although these benchmarks are not specifically indicated for airports, they will provide a basis for determining what sustainability should include. The benchmarks are LEED-ND (USGBC 2009) and Greenroads (Muench et al. 2010). LEED-ND is one of a family of sustainable benchmarks for architectural projects but is the only one that includes paving. Greenroads conversely is focused on highway projects. Neither was developed for airports and both primarily focus on new construction with mere passing references to the facility/infrastructure maintenance process in their rubrics. However, it is possible to use them to provide a foundational outline of sustainable pavement preservation practices.

The aviation industry’s goals are primarily operational. Therefore, to be valuable beyond construction or maintenance project completion, they must also account for operational impact (Berry et al 2008). Airports worldwide are at different levels of sustainability (SAGA 2012), so a decision-making tool to replace minimizing life cycle cost to increase sustainability is necessary. A framework is required to justify exceeding the minimum cost while increasing sustainability for pavement construction, preservation, and maintenance projects. The remainder of the paper will be devoted to explaining such a framework.

UNDERSTANDING PAVEMENT SUSTAINABILITY

Hajek et al describes state of the practice in airport pavement maintenance (2011). Types of paving maintenance for runways and taxiways include controlled shot blasting, slurry seal, microsurfacing and hot mix overlay. There are several areas on which airports have started their focus including; recycling/reusing existing materials, reflectance and heat island effect, maintenance and life cycle cost analysis and life cycle assessment, pervious pavements and alternate materials and designs. Airport sustainability and pavement practices found during the literature review were incorporated into the following list to document the current state of practice.

- Postconsumer recycled content such as glass cullet and toner
- In-place reclaimed materials,
- Portland cement with supplementary cementitious material (SCM)
- Meet long life pavement design criteria
- Stone matrix asphalt
- Warm mix asphalt
- Cold in-place asphalt pavement recycling
- Shotblasting / lithium hardener
- Thin hot mix overlays
- Microsurfacing
- Slurry seals

Before going forward, the concept of enhancing airport pavement sustainability must be understood within the context of this research. For example, in some sustainability benchmarking programs, the use of a concrete rather than an asphalt surface would qualify for credit based on reducing urban heat island effect. However, since most major airports depend on concrete for a large portion of their pavement, selecting concrete over asphalt would not enhance the overall sustainability of the airport since that choice would have been made in the absence of a desire to enhance sustainability. This issue is similar to a building project claiming LEED credit for being close to a bus stop when there was no alternative site.
under consideration (Mosier and Gransberg 2013). Therefore, the remaining discussion will be limited to furnishing information to select among true alternatives based on sustainability.

CARBON FOOTPRINT COST INDEX DEVELOPMENT

To solve the need to measure the value of sustainability, the study turned to a variant of utility theory called cost index number theory (West and Riggs, 1986). As many pavement management information system utilize the pavement condition index, which is itself is based on utility theory (TxDOT, 2001), using cost index number theory is a logical choice for this type of analysis. The method seeks to combine cost and carbon footprint measurements into a single index that can permit the direct comparison of two or more alternatives simultaneously and thus provide a measure of cost effectiveness in the context of each alternative’s carbon footprint. This theory allows the research team to compare a more expensive technology with a less expensive technology to determine if the incremental cost difference between the two alternatives is offset by enhanced sustainability.

Carbon footprint is a widely accepted metric that seek to quantify sustainability based on the amount of energy used and greenhouse gas emissions that are produced during the production, transportation, and installation of common pavement construction materials (Chehovits and Galehouse 2010). Thus it provides a ready system to gauge relative sustainability among options and to furnish an input function to a cost index number analysis. The second component is the cost of each alternative and their respective service lives. Lastly, it should be noted that while the algebra in the forthcoming set of equations will yield a number with dimensional units, cost index number theory holds the dimensions to be meaningless and the difference between competing alternatives’ index numbers to be the meaningful comparison. Thus, the units are dropped and the decision is based on the incremental differences between alternatives (West and Riggs, 1986).

Since FAA Advisory Circular 150/5320-6E uses net present value as the basis of its airport pavement LCCA, the cost index number will also use that approach. 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 FAA pavement life recommendations (Navneet et al 2004). The NPV is evaluated at minimum, average and maximum life cycles and using the following equation (Pittenger et al 2012):

\[
NPV = I + R\left[\frac{1}{(1+i)^n}\right]
\]

Where:  
I = initial installation cost of a given alternative ($)
R = cost to rehabilitate the pavement at the end of an alternative’s service life ($)  
i = interest rate (%)  
n = service life (years)

\[
CF = \frac{E}{A}
\]

Where:  
CF = carbon footprint (British Thermal Units/Square Yard)
E = energy usage (BTU)
A = area of treatment (SY)

Because the metric is being developed to conduct comparative analysis and the incremental difference in alternatives, not the discreet value of each alternative is the information of interest, the index will be developed by looking at the percentage change in NPV compared to one another. Therefore, the equation for the carbon footprint index is as follows:

\[
CFCI = \frac{(NPV_b - NPV_a)/NPV_a \times 100) \times CF}{NPV_b - NPV_a}
\]

Where:  
CFCI = carbon footprint cost index (dimensionless)
NPV_a = NPV of lower cost alternative ($)
NPV_b = NPV of alternative of interest ($)

AIRPORT CASE STUDY

Research has investigated a number of types of sustainable pavement preservation (Riemer et al 2012). The following pavement preservation treatments will be evaluated for cost and service life extension of the base pavement course. All of the listed alternatives can be used as surface treatments that restore surface friction and slow underlying pavement deterioration (Galehouse et al. 2003):
Shotblasting/Lithium Hardener: The shotblasting process retextures pavement surface via special purpose a machine that shoots abrasive steel particles onto the pavement surface (Gransberg 2009). The pavement retexturing by shotblasting allows for deeper penetration of an applied surface hardener to create a concrete surface that is resistant to deterioration (Stokes 2010). Lithium silicate is used in conjunction with shotblasting and is a hardener placed on the surface of Portland Cement Concrete pavement (Nasvik 2008). The service life extension has been shown on average to be over 6 years (Riemer et al 2012).

2" HMA Overlay: 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). An HMA overlay is shown to extend life 5-10 years (Chehovits and Galehouse 2010).

Microsurfacing: 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 (ISSA 2011). The microsurfacing process adds 3-5 years of service life (Chehovits and Galehouse 2010).

Slurry Seal: A mixture of well-graded, fine aggregate and unmodified asphalt emulsion (ISSA 2011) providing up to a seven-year extension of life of pavement (Chen et al 2003).

Supplementary Cementitious Materials (SCM): This product is not a surface treatment, but an alternative to traditional Portland cement or can be used with traditional Portland cement (Type K). SCM was found to extend the service life of airport pavements up to as much as 60 times normal (Bescher et al 2012). For this comparison, a twenty-year life extension will be used and a 5% reduction in carbon footprint versus typical Portland cement can be expected (Bescher et al 2012).

To illustrate the development and use of the CFCl the paper will compare Shotblasting / Lithium Hardener, 2” hot-mix asphalt (HMA) overlay, microsurfacing and slurry seal as rehabilitation methods to extend the life of the pavement against conventional asphalt and Portland cement concrete paving. Supplementary cementitious material (SCM) will also be reviewed for its added initial cost and reduced carbon footprint, and an increased lifespan. Table 1 comes from a study by Chehovits and Galehouse (2010) who developed a list of the energy usage of several types of pavement preservation materials along with pavement preservation life extension estimates. It is supplemented with information from Riemer et al (2012) on the shotblasting with lithium hardener treatment. The shotblasting itself has a negligible impact on the carbon footprint (Rippman 2012), but has been added to the lithium hardener for comparison. SCM was added to the table with the life extension of 20 years and a carbon footprint of 5% less than the specified Portland cement with flyash based on calculations performed for this research.

Table 1: Pavement Preservation Treatment Carbon Footprint and Service Information

<table>
<thead>
<tr>
<th>Sustainable Treatment Type</th>
<th>Life Extension</th>
<th>Carbon Footprint BTU/yd²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shotblasting / Lithium Hardener</td>
<td>6.3 – 7.1 years</td>
<td>1,290</td>
</tr>
<tr>
<td>2” HMA Overlay</td>
<td>5 – 10 years</td>
<td>61,500</td>
</tr>
<tr>
<td>Microsurfacing</td>
<td>3 – 5 years</td>
<td>3,870-5,130</td>
</tr>
<tr>
<td>Slurry Seal</td>
<td>3 – 5 years</td>
<td>3,870-5,130</td>
</tr>
<tr>
<td>SCM For 18” Reinforced Concrete</td>
<td>20 years</td>
<td>5,800</td>
</tr>
</tbody>
</table>

The Oklahoma City airport utilizes both concrete and asphalt pavements. As a result, routine construction, rehabilitation and reconstruction projects are advertised and built. During the period from 2008 to 2011 the airport contracts for asphalt sealing, pavement strengthening, and taxiway reconstruction projects. Each of these types of projects has the potential to be more sustainable. As previously stated, this paper’s methodology does not credit routine practices for increasing sustainability. For example, asphalt sealing is pavement preservation and the airport’s specification calls for flyash to be added to the Portland cement concrete. Both are examples of sustainable pavement maintenance and preservation practices, but neither is credited in the following analysis since they form the baseline against which sustainability enhancements will be measured.

The case study project bids were opened in 2011 with a low bid of $5,840,687.52. This taxiway reconstruction and realignment project utilizes both asphalt and concrete paving. The pavement preservation treatments shown in Table 1 extend the service life of the taxiway will be compared to the
option of permitting the pavement to deteriorate to a point where it must be reconstructed. Table 2 shows the 2011 bid prices for the three types of pavement constructed in the project. At $3,296,272.44, the paving portion is significant and highlights why pavement preservation methods are so important.

Table 2: Case Study Paving Costs and Carbon Footprint.

<table>
<thead>
<tr>
<th>Pavement</th>
<th>Units</th>
<th>BTU/yd²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous Surface Course</td>
<td>sy</td>
<td>61,500</td>
</tr>
<tr>
<td>18” P.C. Concrete Pavement (Reinforced)</td>
<td>sy</td>
<td>42,200</td>
</tr>
</tbody>
</table>

2008 cost data for the sustainable treatment options were obtained from Riemer et al (2012) and escalated to 2011 using the Engineering News Record Construction Cost Index (Grogan 2011. Costs with index adjustment are illustrated in Table 3.

Table 3: Increased Cost of Sustainable Treatment Types.

<table>
<thead>
<tr>
<th>Sustainable Treatment Type</th>
<th>Additional Cost</th>
<th>Percent Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shotblasting / Lithium Hardener</td>
<td>$22,034.13</td>
<td>0.67%</td>
</tr>
<tr>
<td>2” HMA Overlay</td>
<td>$346,269.33</td>
<td>4.44%</td>
</tr>
<tr>
<td>Micro - Surfacing</td>
<td>$38,396.53</td>
<td>1.16%</td>
</tr>
<tr>
<td>Slurry Seal</td>
<td>$18,266.31</td>
<td>0.55%</td>
</tr>
<tr>
<td>SCM For Reinforced Concrete</td>
<td>$51,200.00</td>
<td>1.55%</td>
</tr>
</tbody>
</table>

To calculate NPV, one must have a single service life. Since the available information was a range of values, the decision was made to utilize both extremes and the midpoint to provide a richer understanding of the sensitivity of the output to this input variable. Essentially, Table 4 provides best, worst, and average possible cases for each alternative and allows an airport pavement manager to evaluate each option over a range of possible lives rather than be fully dependent on a single service life assumption.

Table 4: Net Present Value Calculations

<table>
<thead>
<tr>
<th>Sustainable Treatment Type</th>
<th>Additional Initial Cost</th>
<th>Min. NPV / Life</th>
<th>Ave. NPV / Life</th>
<th>Max. NPV / Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shotblasting / Lithium Hardener</td>
<td>$22,034.13</td>
<td>1.58%</td>
<td>1.48%</td>
<td>1.40%</td>
</tr>
<tr>
<td>2” HMA Overlay</td>
<td>$346,269.33</td>
<td>25.19%</td>
<td>14.77%</td>
<td>9.56%</td>
</tr>
<tr>
<td>Microsurfacing</td>
<td>$38,396.53</td>
<td>5.78%</td>
<td>4.33%</td>
<td>3.47%</td>
</tr>
<tr>
<td>Slurry Seal</td>
<td>$18,266.31</td>
<td>2.75%</td>
<td>1.65%</td>
<td>1.18%</td>
</tr>
<tr>
<td>SCM For Reinforced Concrete</td>
<td>$51,200.00</td>
<td>~</td>
<td>1.55%</td>
<td>~</td>
</tr>
</tbody>
</table>

Using this information, the owner can see that even though Slurry Seal has the least additional initial cost, the minimal expected life increase 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 costs even though they also have the longest expected lives.

Comparing the carbon footprint, the microsurfacing 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.

A cost index to simplify comparisons can be used. Using the average NPV and the carbon footprint, a cost index can be created. The carbon footprint number is multiplied by the percent increase of the average NPV. By creating this index, a valuation is created for the carbon footprint. As illustrated in the table below, the Shotblasting / Lithium Hardener alternative has the lowest footprint and percent increase in...
NPV. By using this index, a difference arises between in the percent increase in NPV. It is quite obvious that the microsurfacing has both a higher cost and higher carbon footprint.

Table 5: Carbon Footprint Cost Index Output.

<table>
<thead>
<tr>
<th>Sustainable Treatment Type</th>
<th>Low CFCI</th>
<th>Ave. CFCI</th>
<th>High CFCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shotblasting / Lithium Hardener</td>
<td>18.07</td>
<td>19.14</td>
<td>20.36</td>
</tr>
<tr>
<td>2&quot; HMA Overlay</td>
<td>5,880.60</td>
<td>9,084.46</td>
<td>15,492.19</td>
</tr>
<tr>
<td>Microsurfacing</td>
<td>155.97</td>
<td>194.96</td>
<td>259.95</td>
</tr>
<tr>
<td>Slurry Seal</td>
<td>53.00</td>
<td>74.20</td>
<td>123.67</td>
</tr>
<tr>
<td>SCM For Reinforced Concrete</td>
<td></td>
<td>574.89</td>
<td></td>
</tr>
</tbody>
</table>

METHODOLOGY FOR TREATMENT SELECTION DECISION

Once the information in Table 5 has been derived, the decision can be simplified by using the analytical hierarchical process (AHP) (Saaty 1987). To do so, the alternative variables are first defined and then prioritized. In the OKC airport case, performance and cost are typically a higher priority than sustainability due to availability of funding, and performance is twice as important as cost. Assuming that increased performance life also reduces cost as illustrated by 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 Table 6, priority values are calculated by squaring the matrix and computing the eigenvectors.

Table 6: AHP Analysis

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Sustainability</th>
<th>Performance</th>
<th>Priority Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>2/2</td>
<td>2/4</td>
<td>1/2</td>
<td>0.34</td>
</tr>
<tr>
<td>Sustainability</td>
<td>4/2</td>
<td>4/4</td>
<td>1/4</td>
<td>0.24</td>
</tr>
<tr>
<td>Performance</td>
<td>2/1</td>
<td>4/1</td>
<td>1/1</td>
<td>0.42</td>
</tr>
</tbody>
</table>

The value of 0.42 is the highest and therefore indicates the preference. The preference is to the highest performance, sustainability and best cost. By computing these values previously into a carbon footprint index, it is apparent the Shotblasting / Lithium Hardener preservation technique is the preference.

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 decision-making process is graphically illustrated in Figure 1.
CONCLUSIONS

A public owner like a municipal airport must be able to justify spending additional funding when necessary. As airports move towards integrating sustainability into all facets of their business models, it is imperative that the cost of enhanced sustainability is known. The costs of sustainable options are comparable to the less sustainable options, giving the owner the ability to construct more sustainably for an equivalent price. Using a cost index for comparison provide the owner with an easily identifiable difference in the NPV and carbon footprints. Using an AHP further illustrates the ease of the carbon footprint cost index for determining preference. This information will aid in making the decision to add sustainable pavement preservation into projects.
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