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Life-Cycle Cost Analysis of Surface Retexturing with Shotblasting as an Asphalt Pavement Preservation Tool

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This paper explores the economics of replacing chip sealing and thin hot-mix asphalt overlays for highways with surface retexturing using the same shotblasting technology that is used on airport pavements. This technology is able to restores both the microtextured and macrotextured pavements that have skid resistance due to polishing. An economic analysis of a typical highway lane is conducted to determine the life cycle costs of using various options for the hypothetical project. The study utilizes the Federal Highway Administration pavement life cycle cost methodology and reports the results in Net Present Value basis to compare each skid restoration alternative. The analysis is conducted on two levels. First a traditional deterministic life cycle cost analysis is completed and it is followed by a stochastic analysis of life cycle cost using a Monte Carlo simulation. The paper concludes that shotblasting is an economically viable alternative to traditional methods for restoring lost skid resistance. It also allows the desired engineering objective to be achieved without the consumption of additional asphalt binder or aggregate thus making it an environmentally sustainable alternative as well.

With the decline in the condition of the nation’s transportation infrastructure, pavement preservation has become an essential component in every state Department of Transportation’s (DOT) program. Construction budgets cannot keep up with the demand of an aging infrastructure and as a result, preserving the nation’s highways is doubly important. Pavement skid resistance is perhaps the most important engineering component of the road from a safety standpoint. During the period 1995-2001, nearly a half a million injuries and over 6,000 fatalities were attributed to roadway accidents caused by slippery pavements (1). Slippery pavements are the result of several causes chief of which is the loss of both pavement surface micro and macrotextures. A recent European study found that increasing the pavement’s macrotexture not only reduced total also accidents under both wet and dry conditions but reduced low speed accidents (2). As a result, pavement managers must not only manage the structural condition of their roads but also their skid resistance (3). In fact it is possible for a structurally sound pavement to be rendered unsafe due to a loss of skid resistance due to polishing of the surface aggregates or in the case of chip seals, flushing of the binder in the wheel paths (4). This results in a safety requirement to modify the pavement surface to restore skid resistance. Many of the possible tools for restoring skid resistance, like chip seals, are also used for pavement preservation. Thus, it seems that maintenance of adequate pavement skid resistance is also a pavement preservation activity (3). This intersection of two requirements creates a technical synergy that a public highway agency can leverage to stretch its pavement maintenance budget. To do so it must have the necessary technical and financial information to assist decision-makers in selecting the appropriate surface treatment tool for a given situation.

The Federal Highway Administration requires each state DOT to establish its own standards for skid resistance (6). Skid resistance standards are expressed in a dimensionless index called the skid number (SN). This unit measures the composite effect of pavement surface microtexture (> 0.5mm (0.2 in)) and a sand patch or outflow meter is used to measure pavement macrotexture (0.5 to 50 mm (0.2-2.0 in)) (7).

Polishing of the aggregate is a loss of microtexture and flushing or bleeding of the binder creates loss of macrotexture. Kokkalis et al (8) divides pavement surface into five categories and furnishes an average SN value for each category:

1. Rough and harsh pavements- having both micro and macrotexture: ~SN 65;
2. Rough and polished pavements- having macrotexture but no microtexture: ~SN 25;
3. Smooth and harsh pavements- having microtexture but no macrotexture: ~SN 55;
4. Smooth and polished pavements- having neither micro nor macrotexture: ~SN 20; and

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5. Typical pavements- having average values of micro and macrotexture: ~SN 40

There is no national standard to construe a road’s relative safety from skid data. Guidelines vary from state to state. For instance, the New York DOT interprets skid numbers below 32 as poor requiring correction and above 32 as acceptable. Whereas, the Michigan and Vermont DOTs have set 30 as the lowest acceptable skid value (9). A study of wet-pavement accidents found that SNs of 30 or less had a strong correlation with accident rates (10).

Airport pavement managers have similar interests and more stringent skid resistance requirements (11). One of the major tools used by airport pavement maintenance managers is shotblasting to restore lost skid resistance. On an airport runway in Calgary, Alberta, this process was found to increase SNs from 15 to 50 points and remain above minimum levels (in Canada SN > 30 is acceptable) for up to 5 years (12). Shotblasting is a process that relies on a machine that propels some form of abrasive particle onto the runway surface and blasts away contaminants, such as excess bitumen, while restoring both micro and macrotexture. There are a number of different proprietary machines that range in pattern width from roughly 6 inches (15.2 cm) to 6 feet (1.8 m). The process involves a system that vacuums up the debris, separates the abrasive particles for recycling, and stores the resultant debris for disposal. This process is also referred to as “high velocity impact removal” and “shot peening.” This technology has also been successfully used in highway applications (13, 14). It is commonly applied to Portland cement concrete pavements and bridge decks to improve skid resistance or as a surface preparation prior to sealing, but the technology has also been successfully used on both hot mix asphaltic concrete (HMA) pavements and chip seals (15). An ongoing pavement texture research project in Oklahoma has registered average SN increases on two types asphalt pavement surfaces (hot mix and microsurfacing) from around 40 before shotblasting to over 55 after (16). Additionally, this project recorded increases in macrotexture of up to 50% over pretreatment texture.

SHOTBLASTING
Shotblasting equipment generally comes in two types. The first is a vehicle mounted, self-contained unit that contains the apparatus that propels the abrasive shot as well as the magnetic vacuum system that picks up the abrasive shot and residue, separates it and captures the residue and dust in a container for disposal. This type can be operated from the cab of the vehicle by the operator. The largest version of a vehicle mounted shotblaster has a cutting width of approximately 6 feet (1.8 meters), and Figure 1 is a picture of a smaller version with a cutting width of approximately 4 feet (1.2 meters). The second configuration consists of smaller ground-mounted version that is “capable of cutting six to twenty inches [15 - 51 cm] at a pass” (17). The smaller version has the capability of being mounted on a vehicle in a configuration where two shotblasters can be located over the wheel paths of a road to only shotblast the polished portions of the road to achieve a higher rate of production while reducing the overall unit cost of shotblasting per lineal unit.

FIGURE 1 Vehicular Mounted Shotblaster Showing Before and After Shotblasting (18).

The shotblasting system essentially consists of the following components:
- Shot propelling apparatus
- Vacuum system
- Magnetic separator
- Residue container
- Follow-on magnetic brush/broom to pick-up any debris that might have been left by the shotblasting system
Figure 2 is a schematic diagram of typical shotblasting equipment’s process. It shows how the abrasive shot is propelled by the impeller and is then retrieved along with the debris, separated and either returned to the shot hopper or fed into the residue/dust collection bin. This is a very sustainable technology. The only petroleum product that is consumed is the fuel to power the vehicle. Virtually all the abrasive shot is recovered and recycled for continued use by the system. The collected dust/debris is no more hazardous than the millings from typical asphalt or concrete pavements and can be disposed of in the same manner. The only constraint on the use of this process is that the pavement must be reasonably dry for the magnetic shot separator to operate at optimal performance. Thus, this technology furnishes public highway agencies with a pavement preservation tool to restore skid resistance during those times of the year when the temperatures are too low to apply bituminous surface treatments. Depending on the type of asphalt pavement, the process could also be constrained by surface temperatures being too high. However, airport runway retexturing practice has shown that this can be overcome by scheduling the work to take place at night after pavements have had a sufficient time to cool down. Much traditional highway resurfacing work is already conducted during the hours of darkness, especially in urban areas. So this should not pose a problem. Additionally, most of the shotblasting that is done at airports is also conducted at night to reduce the impact of aircraft operations. So the unit prices and production rates cited in this paper are applicable to night-time retexturing operations. The process is less noisy than chip sealing.

The most comprehensive research on the use of shotblasting to retexture a variety of road surfaces that had lost their skid resistance was conducted in Australia (18). This project included retexturing of both polished HMA and flushed chip seals. Bennett (18) reports that:

[the shotblasting] system has shown that it is a fast and efficient means of reinstating texture to road surfaces. At each trial site, the treatment increased texture depth by at least 0.2 to 0.8mm ... The SCRM [Sideway force Coefficient Routine Investigation Machine] data clearly shows that an increase in microtexture can also be achieved using this technology… the trial has proven that the shotblasting technology is very effective in reinstating both macro and microtexture to a wide variety of road surfaces. The process has the added advantage in that it uniformly treats all areas of the road surface without excessively damaging surface integrity, and effectively improves both macro and microtexture. It is environmentally friendly in that it is a dust free process and recycles all materials used and generated by the process.

Unit costs for shotblasting are a function of the total area to be retextured and the production rate at which a given pavement can be retextured. Intuitively, as the total area increases, the unit cost decreases as mobilization costs are spread over a greater number of pay units. The production rate is determined by the forward speed of the shotblaster, which is established by doing a test section and measuring the change in macrotexture. The major factor is the relative hardness of the asphalt binder. As temperatures rise, asphalt binder softens and is able to absorb more of the force of the shot. This necessitates slowing down the forward speed and reduces the production rate, increasing the unit cost. Aggregate hardness does not affect production but it does affect the amount of microtexture gain. Unfortunately, though soft aggregates will gain a larger amount of microtexture than hard aggregates, they also lose their microtexture relatively quickly. Thus, the properties of the aggregate control the appropriateness of shotblasting for long term increase in SN.

ASPHALT PAVEMENT PRESERVATION TREATMENTS

While shotblasting can be used to retexture both asphalt and concrete pavements, the focus of this paper is only on asphalt. Also as this study looks at shotblasting as a potential pavement preservation tool, the comparison will be made to several common pavement preservation treatments for asphalt pavements. The Federal Highway Administration (FHWA) defines pavement preservation as including minor...
rehabilitation, preventive maintenance and routine maintenance actions that do not increase a pavement’s structural strength (20). Thus, thin hot mix asphalt (HMA) overlays with thicknesses less than 1.5 inches (3.81 cm) are generally included in this category (21). To make the analysis meaningful, shotblasting will be compared to the following four asphalt pavement preservation treatments:

1. Strip seals
2. Chip seals
3. Slurry seals
4. 1 inch (2.54 cm) HMA overlay

These four treatments were selected to furnish a representative set of alternatives against which the economic viability of shotblasting could be compared. It is not considered an exhaustive list of possible alternatives. They represent both ends of the pavement preservation spectrum in this area. A strip seal (i.e. chip sealing only over the wheel paths where skid resistance is the least) defines the minimum treatment and the 1 inch HMA overlay defines the upper limit. Other possible treatments would most likely fall somewhere between the two in terms of cost and consumption of bitumen and aggregate. Therefore, the results of the life cycle cost analysis should be representative in dollar terms illustrating shotblasting’s relative position in the pavement preservation surface retexturing spectrum.

LIFE CYCLE COST ANALYSIS

Life cycle cost analysis for highway projects is defined in the Federal Highway Administration’s (FHWA) Life-Cycle Cost Analysis in Pavement Design —Interim Technical Bulletin as: “...an analysis technique ... to evaluate the overall long-term economic efficiency between competing alternative investment options” (22). The fundamental model described in the FHWA technical bulletin is used to conduct the life cycle cost analysis of each of the previously described alternatives. To compare shotblasting to other pavement preservation treatment life cycle costs, one must first develop the basic life cycle cost model for the specific application. Thus, the following list describes the scenario used in the calculations of net present worth.

1. The substrate consists of a 4-year old 2 inch HMA overlay that has lost its skid resistance due to polishing in the wheel paths. This necessitates corrective maintenance to restore the skid resistance in year 5 of its service life.
2. The engineer has the following options to restore the skid:
   a. Shotblast the entire lane
   b. Strip seal over the polished wheel paths
   c. Chip seal the entire lane
   d. Slurry seal the entire lane
   e. Install a thin HMA overlay 1 inch thick.

Research has shown that the average service life of a US chip seal to be 5.76 years (23), and research in New Zealand indicates that the use of retexturing extended the service life of the chip seal by roughly two years (24). Using the US as the case study location for the life cycle cost analysis, the following assumptions are made to support the calculation:

1. The service life of a new chip seal and slurry seal will be five years.
2. The strip sealing option assumed that 30% of the lane width was covered by the wheel paths based a Texas DOT document (25) and unit costs were calculated as shown in Transportation Research Record 1989 (26). These include the cost of disposing of the residue material from the shotblasting.
3. In the strip seal option, a strip seal will be applied and that will restore the surface texture for two years when a full lane width reseal will be installed. The reseal will lose its skid due to flushing in the wheel paths at the end of its 4th year due to the amount of bitumen in the wheel paths from the strip seal.
4. In the shotblasting option, the surface retexturing in the fifth year will restore the surface texture extending the service life of the substrate by two years to year seven at which time it gets a full lane width reseal.
5. The overlay option will lose its texture in the same manner as the substrate and need to be redone every five years to maintain adequate skid resistance.
6. All alternatives will be analyzed over a period of 20 years and the patterns for each alternative described above will repeat throughout the period of analysis.
7. All other maintenance costs associated with the road are equal in all the alternatives.
8. A discount rate of 3% will be used in accordance with the FHWA technical bulletin (22).
9. To simplify the analysis, any user costs associated with traffic disruption during construction and maintenance operations will be ignored in the model as will all residual values. It should be noted that user costs of shotblasting would be considerably
10. The Net Present Value (NPV) of the life cycle costs for a single lane-mile of roadway will be calculated.

The life cycle cost analysis is presented in the two forms shown in the FHWA Technical Bulletin. First a deterministic life cycle cost analysis is conducted using the minimum, mean, and maximum possible values for each option. This provides information regarding where the life cycle costs will fall in each of three possible scenarios. Next, a stochastic version of the FHWA life cycle cost analysis model is run using the possible range in values as a probability density function to associate the probability of achieving a lower life cycle cost for each of the alternatives and to quantify the differences between each using a Monte Carlo simulation.

**Deterministic Life Cycle Cost Analysis**

Deterministic life cycle cost analysis compares alternatives using “minimize estimated life cycle costs” as the decision criterion. Thus, the economic dynamics of each alternative must be fully understood. In this case, the comparison is between four asphalt-based alternatives where material costs make up roughly one half of the total cost (27) and the shotblasting alternative that uses virtually no material (18). Thus, the actual cost of the asphalt-based alternatives will be sensitive to volatility in material prices, which in this case will be the cost of liquid asphalt and aggregate. Whereas, this volatility will be absent in the shotblasting option. The dynamics of material cost volatility can substantially impact the actual life cycle costs. The use of ranges to estimate life cycle costs for each alternative captures the impact volatility for past prices, but the analyst must remember that past volatility may not accurately model future volatility. This is the underlying reason for using stochastic estimating techniques and underscores the need to do the life cycle cost analysis using both deterministic and stochastic methods.

Unit prices for each alternative were taken from July 2008 bid tabulations from across the nation. The unit prices were then extended to calculate a cost per lane-mile assuming a standard 12-foot (3.7 meter) lane. Table 1 shows the values used for the various cost components to the life cycle cost analysis model. One can see that while the shotblasting has a lower estimated lane-mile cost than the other options at each possible value. However, the highest possible value of the shotblasting option is greater than the lowest possible values of the strip seal and slurry seal options. So it is theoretically possible that prices associated with the strip or slurry seals could put them at the low end of their possible ranges at the same time that the actual cost of shotblasting is at the high end of its range. Thus, it is impossible to conclude without further analysis that the shotblasting option is the preferred alternative.

For purposed of comparison, a second shotblasting alternative is added to the analysis. This is to shotblast the pavement every two years starting in year 5. This option is not technically viable because shotblasting removes a thin layer of pavement when it is applied and at some point in time it will have removed enough to adversely affect the structural cross-section. However, this is done to highlight the results for using shotblasting alone to restore skid resistance. Obviously, a polished pavement can be retextured using shotblasting more than once. Several major airports have their runways retextured several times a year using shotblasting (17).

**TABLE 1 Life Cycle Cost Analysis Input Values**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Minimum $/lane-mile</th>
<th>Mean $/lane-mile</th>
<th>Maximum $/lane-mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shotblast Full Lane</td>
<td>$2,112.03</td>
<td>$4,488.05</td>
<td>$7,392.10</td>
</tr>
<tr>
<td>Strip Seal 30% Lane</td>
<td>$6,234.62</td>
<td>$11,447.46</td>
<td>$18,426.78</td>
</tr>
<tr>
<td>Slurry Seal Full Lane</td>
<td>$7,040.00</td>
<td>$10,326.27</td>
<td>$20,979.20</td>
</tr>
<tr>
<td>Chip Seal Full Lane</td>
<td>$8,312.83</td>
<td>$15,263.28</td>
<td>$24,569.04</td>
</tr>
<tr>
<td>1&quot; Overlay</td>
<td>$74,907.85</td>
<td>$78,325.35</td>
<td>$86,638.18</td>
</tr>
<tr>
<td>Substrate all options:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2&quot; Overlay</td>
<td>$127,740.52</td>
<td>$133,559.50</td>
<td>$147,876.04</td>
</tr>
</tbody>
</table>
The primary alternative that will be compared to the traditional alternatives envisions shotblasting being used as a tool to extend the service life by two years whereupon a chip seal would be applied.

Table 2 shows the results of the deterministic life cycle cost analysis. The ranges of the shotblasting, strip seal, slurry seal, and chip seal alternatives overlap once again. This leads to the conclusion that shotblasting to restore skid resistance is at very least a competitive alternative to strip and chip sealing and seems to be clearly more economical than the thin asphalt overlays. As a result, the two overlay options are dropped at this point in the analysis. Note that the strip seal cost is higher than the chip seal cost. This is because the strip seal is followed by a chip seal after two years. The same relationship is true for the shotblasting. So effectively, both processes are merely extending the pavement’s service life by two years each time they are applied.

**Stochastic Life Cycle Cost Analysis**

The FHWA life cycle cost model was built in a spreadsheet program and another commercial simulation software package was used to perform the Monte Carlo analysis to conduct the stochastic life cycle cost analysis. The input variables shown in Table 1 were modeled as having stochastic values, and each was assigned a triangular probability distribution using the minimum, maximum and mean values shown in Table 1. 10,000 iterations of the simulation were run, and the resulting probability distribution for shotblasting is shown in Figure 3.

### TABLE 2 Deterministic Life Cycle Cost Analysis Output

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Minimum $/lane-mile</th>
<th>Mean $/lane-mile</th>
<th>Maximum $/lane-mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shotblast</td>
<td>$144,503</td>
<td>$165,640</td>
<td>$199,873</td>
</tr>
<tr>
<td>Shotblast on 2 year cycle</td>
<td>$108,127</td>
<td>$124,671</td>
<td>$150,383</td>
</tr>
<tr>
<td>Strip Seal</td>
<td>$153,302</td>
<td>$180,493</td>
<td>$223,424</td>
</tr>
<tr>
<td>Slurry Seal</td>
<td>$147,468</td>
<td>$162,496</td>
<td>$206,665</td>
</tr>
<tr>
<td>Chip Seal</td>
<td>$151,035</td>
<td>$176,331</td>
<td>$216,724</td>
</tr>
<tr>
<td>1&quot; Overlay</td>
<td>$337,650</td>
<td>$353,046</td>
<td>$390,657</td>
</tr>
</tbody>
</table>

The FHWA life cycle cost model was built in a spreadsheet program and another commercial simulation software package was used to perform the Monte Carlo analysis to conduct the stochastic life cycle cost analysis. The input variables shown in Table 1 were modeled as having stochastic values, and each was assigned a triangular probability distribution using the minimum, maximum and mean values shown in Table 1. 10,000 iterations of the simulation were run, and the resulting probability distribution for shotblasting is shown in Figure 3.

![Distribution for Shotblast Full Lane Life Cycle Cost](figure3.png)

**FIGURE 3** Shotblasting Probability Distribution from Monte Carlo Simulation
Figure 4 consolidates the stochastic output and shows the maximum, minimum, and mean expected values for each alternative. One can see that once again the full-lane shotblasting alternative is shown to have a lower mean life cycle cost than slurry or chip sealing. It is comparable to strip sealing. Importantly, when the 5% to 95% probability range is considered, the shotblasting’s 95% probability life cycle cost is slightly less than the mean expected life cycle cost calculated for the chip seal alternatives. Thus, this furnishes evidence that on a purely economic basis that the use of the shotblasting to retexture the pavement and restore skid resistance is a better alternative than the traditional use of the slurry or chip seal and it is competitive with strip sealing.

**Sustainability – Qualitative Life Cycle Analysis**

The nation is moving toward putting a much greater value on environmental sustainability than it has in past years. In the alternatives analyzed in this study, the major items of interest would be the consumption of raw materials, i.e. aggregate and bitumen for the surface treatments and diesel fuel for the machinery required to install each treatment. Figure 5 shows a comparison of raw material consumption of shotblasting with three other common surface treatments. The figure for shotblasting assumes that only diesel fuel is consumed and is calculated from information regarding the consumption of raw materials in the production and distribution of diesel fuel in a report by Sheehan et al (28). The other consumption rates are taken from a report by Takamura et al (29). One can see that shotblasting is clearly the more sustainable option in this category. Other typical measures of sustainability like carbon emissions should favor shotblasting as well because its emission load is again related only to the diesel engines on the machinery. Whereas, all the resurfacing options that have an asphalt component all contribute additional carbon emissions in from the material as it is processed and placed on the road. Finally, both the large and small versions of shotblasting equipment only require the shotblasting machine, a vehicle that follows the shotblaster with a towed magnet to pick up and recycle any lost shot, and a self-propelled broom to sweep trash and debris in front of the shotblaster. A typical chip seal equipment crew will contain a distributor, a chip spreader, 3 to 5 dump trucks, 2 to 4 pneumatic rollers, 2 self-propelled brooms, as well as a loader to load the chip trucks and a diesel tractor to transport the heated binder. Thus, shotblasting uses 3 to 4 diesel engines and chip sealing uses between 11 and 15 diesel engines. Considering the eco-benefits of shotblasting makes it the preferred alternative over strip sealing in that its life cycle costs are roughly equal and it leaves a smaller carbon footprint as well as consumes no new aggregate or asphalt products.
CONCLUSIONS
This study has shown that the use of shotblasting to retexture a polished asphalt pavement’s surface and restore skid resistance is both technically and financially feasible. The assumptions used in the analysis were fairly conservative in that it made no effort to model the additional benefits that the shotblasting alternative would accrue due to the fact that it requires no additional materials and its lower impact on the traveling public. This gives it a high degree of environmental sustainability. Additionally, the fact shotblasting requires no asphaltic material makes it virtually immune to volatility due to fluctuating asphalt prices. The lack of aggregate also makes it attractive for use in those locations where quality aggregate is scarce. These factors increase the credibility of the results of the analysis. Finally, the technology is being used successfully by major US airports to restore runway skid resistance on a routine basis, which demonstrates its technical viability.

In addition to restoring pavement macrotexture, research has shown that this technology has the added ability to improve surface microtexture as well (18). Thus, an agency that invests in the machinery would be able to use it to restore skid resistance on both concrete and asphalt roads that have lost their skid resistance due to the polishing of the aggregate on the pavement’s surface. Returning to the safety theme of the introduction, this type of pavement preservation operation can be conducted in cold weather where minimum ambient air temperatures are too low to permit asphalt operations. Thus, the agency would have a tool to react to and correct unsafe situations virtually year-round, needing only relatively dry surface conditions to shotblast.

REFERENCES
6. Federal Highway Administration (FHWA). “Surface Texture for Asphalt and Concrete