404LVT FOR YOUR LIGHTLY TRAVELED ROAD

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- Carbon Footprint: How Does HMA stack UP?
- Segregation: Causes & Cures, Part 3
- Ohio Interstate Asphalt Pavements Continue to Show Superior Value

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Recently, business took me to Hershey, Pa. Being a tourist type, I took the opportunity during my visit to nose around and learn a bit about Hershey. My adventures took me to THE HERSHEY STORY, a museum of sorts that wove a fascinating story of the exploits, benevolence and philanthropy of Milton S. Hershey. Yes, Milton Hershey was the founder of Hershey Chocolate Company.

At THE HERSHEY STORY, I learned that the Hershey Chocolate Co. was not Milton Hershey’s first venture into capitalism. Hershey was a man of perseverance. and only after four bankruptcies did he come into success. Through perseverance, Hershey discovered manufacturing techniques that made chocolate available to the masses. Chocolate once was a delicacy of the rich, but that all changed with the adoption of assembly-line techniques and introduction of a novel product, the Hershey Kiss!

As I wove my way through THE HERSHEY STORY, I learned of Hershey’s desire to manufacture the highest-quality confectionaries. He used only the best ingredients and settled his factory in Pennsylvania’s heartland to ensure access to such. This gave rise to opportunity for many farmers who now had an outlet to market their products. Hershey was a wise businessman who understood that a successful business venture could only be such if its employees prospered just as the company was prospering. Hershey instituted rewards for innovation, but also expected a fair day’s work. He taught the importance of ownership and provided low-rate loans for employees seeking to purchase a home. To Hershey, recreation for his employees too was important; keeping mind and body healthy was both good for personal welfare and business. His greatest achievement, as he would attest, came from his benevolent heart; the Hershey Industrial School for orphan boys, now known as the Milton Hershey School.

As I neared the end of my tour of THE HERSHEY STORY, I started to understand the essence of Milton Hershey’s success. Then I came upon it, a quote from Hershey himself: “Business is a matter of human service.”

Hershey’s words are pregnant with wisdom. To unpack all that can be understood of them would take more ink than I can put on this page, but I would like to extract something which I feel very much relates to the business we are in . . . asphalt. Now, you may be wondering what relevance there is between asphalt roads and human service. Please hear me out.

What is true of Milton Hershey’s philosophy is true of us in the asphalt business. Our business too is a matter of human service. For the sake of time (and ink) I’ll skip discussing how the owner-employee relationship relates to all of this — although much can be learned by earnest study. Rather, let me concentrate on the asphalt industry’s relationship to its customers.
When the engineers and scientists of the American Association of State Highway Officials (AASHO) set out in the late 1950s to develop a method of determining how thick pavements should be constructed, they developed a concept that was revolutionary (for the highway industry), and it is one to which we ought to hold tightly. How do you measure value? How do you measure success? What constitutes good performance and what constitutes bad? AASHO engineers needed a measuring stick, and their deliberations brought them to the same principle that Hershey so simplistically expounded, “Business is a matter of human service.” They would develop a measure of road users’ perceptions of the levels of “service” that pavements provide. Completely subjective was the measure, but from it engineers could develop a means of quantifying pavement performance. Engineers know this today as the “serviceability” measure of a pavement. Newly constructed pavements provide high levels of “service” (i.e. ride quality) for the simple reason that they have received little traffic. Over time, and the beating of a few million trucks, pavements decline in their serviceability.

“Serviceability” is something we in the asphalt business in Ohio have on our side. It is no secret that newly constructed asphalt pavements provide the highest level of ride quality of any pavement type, and that routine surface restoration allows our customers (i.e. motoring public) the enjoyment of high levels of “service” throughout the pavement’s life. “Service,” however, the likes of what Milton Hershey would espouse, I believe, would go beyond our providing a smooth ride.

When it comes to providing a human service, as Hershey put it, we need to appreciate what the customer wants and build our product around those “wants.” Only then can we provide the service they desire, and in so doing ensure our future success. Many years ago a survey of highway users was taken as part of the National Quality Initiative (NQI) to benchmark what users desire in a highway system. NQI was a “quality” movement aimed at improving performance of highways through improved contracting procedures, construction materials and project management. The survey results showed the following items to be high on the list of desires: safe roads, no delays, riding comfort. I suspect a more current survey result would include items such as sustainability (“green”) and resource preservation (i.e. reuse/recyclability).

Asphalt pavements are exemplary at meeting all these customer desires, and through technological advancements over the asphalt industry’s legacy of innovation we have served our customers well — a 98 percent market share testifies to such. There is yet room for improvement, however, for certainly we are yet to mine the full wealth of creativity the engineering community and the asphalt industry have to offer. When one considers the value of asphalt pavements for providing perpetual life, complete reuse as a raw material for new asphalt pavement and ensuring the finest riding experience of all pavement types, it is easy to recognize the lasting human service that asphalt pavements provide.
The Summer 2008 issue of Ohio Asphalt announced the reintroduction of Item 404 Asphalt Concrete. 404 was a staple of the asphalt industry since its origination in 1965, but was removed from the Ohio Department of Transportation (ODOT) Construction & Materials Specifications in 2002 due to ODOT’s move to Items 446 and 448 for all asphalt construction. 404LVT (Low Volume Traffic) is a thin asphalt overlay (1-inch). Thin asphalt overlays have been demonstrated to be a superior treatment over other surface treatments because of its longer life and better functional characteristics. The reintroduction is being made by the asphalt industry under a “Low Volume Traffic Mixes Initiative” of Flexible Pavements of Ohio (FPO). Driving the reintroduction was a need to provide agencies with an economical option to chip seals and microsurfacing on the LVT pavements, options that are longer lasting and improve the overall driving experience for motorists.
404LVT draws upon the substantial history of 404 mix performance. In the early days, 404 mixes were formulated and reformulated by ODOT plant inspection personnel. Project by project these mixes were honed to optimum composition. This permitted the accumulation of a history of successful mix performance for light-, medium- and heavy-traffic conditions. As traffic demands increased, however, and new aggregate sources came online, it became necessary for a systematic method to formulate new mix designs to handle even heavier trucks. Today, Superpave (ODOT Item 442) and Marshall Mix Design methods (Items 446 & 448) are the state of the practice in Ohio. Item 404, however, still has a place for pavements seeing lighter traffic, allowing agencies to draw on the rich history of excellent performance.

FPO made several modifications to Item 404 in its introduction of the “LVT” specification. These were done to improve economy, ensure long-term durability and accommodate contemporary contract administration practices:

First, the LVT specification targets a blend of aggregates to ensure a fine-textured mix. Such mixes facilitate handling, uniform mat textures and long-term durability. A minimum of 50 percent of the virgin fine aggregate in 404LVT must be natural sand. This assists roller compaction, which is necessary for long-term mix durability. An added benefit, the finer gradation permits the placement of thinner layers (1-inch minimum) and 404LVT uses locally available aggregate, all of which helps the treatment’s economy — i.e. less cost per square yard of pavement. (Editor’s note: It is worth noting that where a roadway’s profile or crown is excessive, a variable-depth intermediate course is recommended.) Recent ODOT research conducted by Ohio University evaluated asphalt mixture characteristics of good performing pavements. Ohio University found that, in general, finer-graded mixes provided the greatest longevity. The report, “Forensic Investigation of AC and PCC Pavements with Extended Service Life Volumes 1-3,” can be viewed online at the ODOT Research & Development, Office of Innovations, Partnerships & Energy (www.dot.state.oh.us/Divisions/TransSysDev/Research/reportsandplans/Reports/2010/Pavement/134280_Vol1_FR.pdf).

Second, the aggregate gradation limits are narrowed to restrict mixture variability. Limiting variability enhances opportunity for successful and predictable performance on each and every project.

Third, target binder contents are set depending on coarse aggregate type (i.e. gravel, limestone) and a mechanism is provided for adjusting asphalt binder content based on field observance of the paving mixture. Pay is automatically adjusted for changes to asphalt binder content; adjustments are based on ODOT price indexing.

Fourth, the contractor is incentivized to ensure the 404LVT mixture is produced at the mix design binder content; if lower than the mix design, the contract unit price is adjusted (i.e. reduced) based on the actual binder content received. No adjustment in unit price is made for occurrences where the actual binder content exceeds the mix design formulation. The following table shows for comparison purposes the mixture proportions for 404LVT and 448 Type 1 mix:

<table>
<thead>
<tr>
<th>Mixture Proportions</th>
<th>404LVT</th>
<th>448 Type 1, Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve</td>
<td>Total Percent Passing</td>
<td>Total Percent Passing</td>
</tr>
<tr>
<td>1/2 inch</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3/8 inch</td>
<td>90 – 100</td>
<td>90 – 100</td>
</tr>
<tr>
<td>No. 4</td>
<td>72</td>
<td>45 – 57</td>
</tr>
<tr>
<td>No. 16</td>
<td>27 – 45</td>
<td>17 – 35</td>
</tr>
<tr>
<td>No. 50</td>
<td>10 – 22</td>
<td>5 – 18</td>
</tr>
<tr>
<td>No. 200</td>
<td>0 – 8</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total binder content (% by weight of mix)</th>
<th>Gravel coarse aggregate: 6.2%</th>
<th>Limestone coarse aggregate: 6.4%</th>
<th>Gravel/Limestone coarse aggregate blends: 6.3%</th>
<th>Slag: as determined by the Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Note 1: Increase binder content 0.2% for coarse aggregate having absorption ≥ 2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Note 2: The engineer may adjust binder content. Compensation will be made according to 404LVT.22</td>
<td></td>
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</tr>
</tbody>
</table>

The 2010 construction season saw the use of 404LVT by two Ohio counties, Fayette and Muskingum. Fayette County has now used 404LVT for two years. The finer texture and rich appearance of the LVT mixes are what attracted the county engineer to using it for low-volume pavements. The first use of 404LVT was in 2009, and was constructed as an experimental project. That experiment proved sufficiently successful to contract the paving of two additional low-volume roads in 2010.

Paving Ohio’s first 404LVT project was the John R. Jurgensen Co., an FPO member in Cincinnati. That first LVT project was constructed for the Fayette County Engineer and a marked difference was seen from traditional Type 1 mixtures. Most noticeable was the mat texture. Because of its finer texture and better knit, this mixture allowed for the complete elimination of mat segregation. Asphalt binder content sufficiency could...
be seen in the rich appearance of the mat. The Fayette County 404LVT paving program expanded to two projects in 2010. John R. Jurgensen Co. paved Greenfield-Sabina and Stafford roads. Cox Paving had its first experience with placing 404LVT by successfully paving Creek Road.

The Muskingum County Engineer took up the experimental specification and contracted two 404LVT projects. Doug Davis, county engineer, saw 404LVT as a potential solution to obtaining greater longevity on his rural routes and preferred the safety, pavement strength increase and smoothness of an asphalt riding surface.

Shelly & Sands, of Zanesville, and The Shelly Co., of Thornville, were the successful bidders. The combined quantity of the projects was approximately 20,000 tons. Placement of the material followed conventional paving practices. The mix readily compacted under the weight of the rollers. Mix composition was an approximate 50/50 coarse aggregate blend containing No. 8 limestone and gravel, with a manufactured and natural sand blend. Twenty percent recycled asphalt pavement (RAP) was reused into the new LVT mixture. Asphalt binder content was 6.5 percent—a healthy binder content for this blend of materials. To improve economy of the treatment the plans called for the 404LVT mix to be placed 1-inch thick.

Attracting specifiers to 404LVT is its VALUE as seen in economy and pavement attributes. Thin-lift asphalt mixtures facilitate lower-cost treatments without sacrificing the desired attributes of treatment longevity, safety and smoothness. 404LVT espouses to deliver more for the specifier’s investment dollar.
## Comparison of Value Attributes

<table>
<thead>
<tr>
<th>Feature</th>
<th>404LVT</th>
<th>Microsurfacing</th>
<th>Chip Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrects minor surface distress</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Can be applied in one pass</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Eliminates dust and loose aggregate</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Improves road profile and driver safety</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improves pavement drainage</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrects minor rutting</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improves ride quality</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facilitates re-use &amp; recycling</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greatest time between maintenance treatments</td>
<td>✓</td>
<td></td>
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</tbody>
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In the past, agencies and contractors determined pavement-type selection by evaluating performance and cost. In the near future, a new factor may be considered—sustainable development.

Sustainable development can be defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable development considers environmental impacts, such as greenhouse gas production and depletion of non-renewable resources, such as fossil fuels.

The term “carbon footprint” generally refers to the total amount of all greenhouse gas emissions (generally CO2) caused directly and indirectly by a given process, product or event. When looking at the carbon footprint of asphalt pavement, for example, one can envision summing the amount of CO2 emissions from the extraction of aggregate at a quarry and the production of bitumen binder at a refinery, plus those associated with transporting raw materials, processing raw materials into finished pavement, constructing the pavement and other miscellaneous activities associated with pavement production and maintenance.

A number of studies compare the energy consumption, waste produced and environmental impacts from different pavement materials. These studies use environmental lifecycle assessments to make meaningful comparisons over the design life, taking into account raw material acquisition, manufacture, transportation, installation and waste management.

Horvath and Hendrickson\textsuperscript{2} performed an economic input-output-based lifecycle assessment to compare an 11.8-inch-thick hot mix asphalt (HMA) pavement with an 8.7-inch-thick continuously reinforced concrete pavement (CRCP) placed on the same subgrade. The four-lane pavements were designed to carry 10 million equivalent single axle loads (ESALs). The study estimated that it takes approximately half of the energy per mile to produce the HMA pavements as compared to the equivalent CRCP pavement (0.93 million kW hr versus 1.85 million kW hr).\textsuperscript{2} Other studies have used the lifecycle approach recommended by the Society for Environmental Toxicology and Chemistry (SETAC) and the U.S. EPA. This method tracks environmental flows or impacts upstream. For example, HMA would be tracked to stone quarrying and asphalt binder production, and asphalt binder would be tracked to impacts from recovering and transporting crude oil.

A Swedish study using this method indicates that it takes 36 percent more energy to produce a PCC than a comparable HMA pavement.\textsuperscript{3} A similar study conducted in the U.S. found that using the same pavement sections used by Horvath and Hendrickson, the HMA pavement required 21 to 92 percent less energy than the CRCP pavement, depending on the estimate used for the energy required to produce the asphalt binder.\textsuperscript{4,5} Why the big deal about energy use? Simply put, the more energy that is used, the more greenhouse gases are produced and the bigger the carbon footprint. This is the same concept used with warm-mix asphalt (WMA), where fuel savings from lower temperatures result in reduced carbon dioxide (CO2) emissions.

The energy consumed to produce an HMA pavement deserves a closer look. Asphalt production consumes 39 percent (using the high estimate) of the energy used to produce an HMA pavement, while heating, drying and mixing the aggregates and binder uses 49 percent. All of the studies noted that a significant advantage of HMA pavements is the fact that they can be readily recycled. The use of RAP in a mixture reduces the virgin asphalt demand and therefore reduces energy consumption. Recycling rates for
CRCP pavements are much lower, in some part due to the difficulty in removing the reinforcing steel. WMA technologies also have the potential to significantly reduce the energy required to construct an HMA pavement.

The studies also cited the need for a method to make routine comparisons. One such method is BEES® – Building for Environmental and Economic Sustainability – developed by the National Institute of Standards and Technology (NIST).

BEES allows economic and environmental lifecycle comparisons for a variety of parking lot options. Figure 1 shows a comparison of the carbon emissions between HMA with conventional maintenance, PCC, and PCC with 15 percent of the cement replaced with fly ash. The comparison is based on typical PCC and HMA construction practices. The environmental impacts for the HMA are based on a 15 percent RAP content. Maintenance for the HMA parking lot includes a 1.5-inch overlay every 15 years. All comparisons used a haul distance of 20 miles.

Based on the figure at the top of the page, the PCC pavement options produce significantly more CO2, even when fly ash is substituted for cement. In the BEES analysis, HMA is preferred both economically and environmentally on a lifecycle basis.

Although the differences between HMA and PCC are significant during the construction of the pavement, construction impacts as a whole are dwarfed by the energy used and greenhouse gases emitted by traffic. One study determined that traffic levels of only 5,000 cars per day used 10 times more energy over a 40-year period than that used to construct the pavement. The inclusion of RAP and the potential fuel savings from WMA technologies allow for even greater reductions in the carbon footprint of HMA pavements.

References

“Carbon Footprint: How Does HMA Stack UP?” is a copyrighted article being reprinted with the permission of the National Asphalt Pavement Alliance (NAPA). This article originally appeared in the May/June 2010 NAPA publication HMA.
Expanding Implementation of Perpetual Pavement

Perpetual Pavement is the name given to an asphalt pavement that is designed not to fail. Construction is in layers whose properties serve a combination of different functions; they all add up to an extraordinarily long-lasting pavement. Surface distresses may occur eventually, but they do not penetrate deep into the pavement’s structure. Routine maintenance involves infrequent milling of the top layer for recycling, then placing a smooth, quiet, durable, safe, new overlay. A Perpetual Pavement never needs to be completely removed and replaced. In the world of pavements, this is the ultimate in economic and environmental sustainability.

Perpetual Pavements can mitigate climate change by reducing greenhouse gas emissions, both now and for generations to come. Perpetual Pavements reduce greenhouse gas production in several ways:

- Since only the surface is renewed, the base structure stays in place, thereby significantly reducing greenhouse gases associated with virgin raw materials acquisition and placement.
- Greenhouse gas emissions associated with complete removal and replacement of pavements that have reached the end of their useful life is avoided.
- Greenhouse gas emissions associated with construction delays are greatly reduced because maintenance and rehabilitation can be done quickly in off-peak hours, unlike the remove-and-replace option, which necessitates 24-hour road closures. Limiting closures to off-peak hours can reduce delays for road users by at least a factor of 12 (i.e., a 2 1/2-minute delay versus a 30-minute delay).

Perpetual Pavements are more cost-effective than traditional asphalt pavements while enhancing durability, performance and long life. Reuse/recycling is part of the maintenance and rehabilitation process. All these factors conserve construction materials and reduce greenhouse gases.

Once the road is constructed, it becomes a permanent asset within the transportation infrastructure system. A Perpetual Pavement does not become a reconstruction problem for future generations.

The history of Perpetual Pavements goes back to the 1960s, although the term was not used until around 2000. Full-depth asphalt pavements first achieved wide acceptance in the 1960s as a way of minimizing materials use and construction costs. At that time, it was assumed that the design would result in a “20-year design life,” but experience has shown that such pavements have lasted for more than 40 years with no sign of structural failure. Engineering studies in the states of Kansas, Minnesota, Ohio, Oregon and Washington have validated these observations.

Beginning in 1999 and 2000, asphalt pavement researchers initiated efforts to understand the engineering features and performance characteristics of Perpetual Pavements. Research has been conducted at NCAT, the Asphalt Institute, the University of California at Berkeley, the University of Illinois and other leading institutions in the U.S. and around the world. The research has led to the development of materials, design methods and performance criteria to enable agencies to design pavements that ensure long life without wasting materials due to overdesign.

There are already many pavements around the United States that fit the Perpetual Pavement definition. In recognition of that fact, in 2001, the asphalt industry created a program to identify Perpetual Pavements and honor the agencies that have designed and maintained them. Fifty-nine Perpetual Pavement Awards have been presented through 2008.
In addition to working toward the full integration of Perpetual Pavement technologies into pavement design guides, the asphalt industry will continue to pursue research to advance Perpetual Pavement best practices.

There are currently two national studies on Perpetual Pavement through the National Cooperative Highway Research Program (NCHRP) focused on the engineering characteristics that will be critical to the design of long-life pavements. Pavements have been constructed with instruments embedded in the various layers to ascertain their responses to truck loadings at a variety of locations. These include the NCAT Pavement Test Track and the Minnesota Road Research Project, as well as in highways located in Kansas, Ohio, Pennsylvania, Wisconsin and other states. These will provide crucial information on the field behavior of Perpetual Pavements.

Significant opportunities for applied research on Perpetual Pavements include an investigation of high-stiffness base materials, which have the potential to reduce both costs and greenhouse gas emissions, and research on the impact of these long-life pavements on climate change, specifically greenhouse gases.

In summary, Perpetual Pavements conserve natural resources, reduce lifecycle costs, save fuel, and reduce fuel consumption and greenhouse gas emissions.

**Accelerating Appropriate Use of Porous and Open-Graded Pavements**

Porous and open-graded asphalt pavements have been shown to have a dramatic beneficial effect on water quality. These pavements have been used widely for more than 30 years with an excellent record of success. Open-graded pavement is made with same-size rocks, creating a web of interlocking pores that allow water to flow through the surface.

Open-graded pavements are used mainly in two types of applications. First, open-graded friction courses are widely used for surfacing roads and highways. The pavement layer directly beneath this is impermeable. During a rainstorm, instead of pooling on the surface or bouncing off it, rain drains through the surface and out to the sides. Splash and spray are greatly reduced, enhancing safety.

Second, porous pavement systems are stormwater management tools with an open-graded surface over a stone recharge bed. The system is designed and constructed to collect stormwater, which then infiltrates into the ground. Porous pavement systems are used mostly for parking lots, but they have also been used successfully for roads in communities like Pringle Creek in Salem, Ore.

Both applications can be used to improve water quality. Porous asphalt surfaces allow roads and highways to function as linear stormwater management systems. Porous parking lots store stormwater, reduce runoff, promote infiltration and groundwater recharge, allow evaporative cooling of the atmosphere, diminish erosion on stream banks, reduce particulates in stream water after storms and improve water quality.

Porous asphalt pavements are accessible and affordable. They can be produced and constructed by any qualified contractor. Open-graded
highway surfaces have additional environmental and safety benefits. They reduce road noise significantly. Texas DOT reported that replacing a conventional surface with open-graded friction course in a high-accident area reduced wet-weather accidents by 93 percent and reduced fatalities by 86 percent.

With respect to porous pavement systems for stormwater management, some local authorities may allow the construction of porous pavement systems but still require total redundancy with the use of conventional stormwater management structures. Applied research documenting the effectiveness of porous pavements, together with a program of continuing education, could be helpful in expanding the use of these pavements and avoiding using them inappropriately.

The industry and partners will use applied research, demonstration projects, open houses, web-based tools and other continuing education efforts to accelerate the deployment of porous asphalt solutions in the months and years to come. Industry will also assist federal and state agencies in developing design guidance for porous asphalt applications. And we will look for opportunities to document the environmental effectiveness and cost benefits of porous asphalt pavement, improve materials and mix designs and evaluate highways as linear stormwater management systems.

**Conclusion**

The engineers, scientists, contractors and managers who guide the development of asphalt pavement have made it one of the most environmentally advanced building materials in the world by constantly improving its cost effectiveness and safety.

By extending pavement life — by improving materials, designs or best practices — these professionals reduce the cost to the environment and to the taxpayer. By improving the desirability of reclaimed asphalt in new mixes, they have reduced the cost of the mix and the demand for virgin asphalt cement and virgin aggregates.

Going forward, the industry and its partners will pursue the same mandate. It is not enough that the asphalt industry is capable of cutting greenhouse gas emissions, or reducing energy usage, or enhancing the quality of stormwater runoff. Solutions must also make sense economically for the agencies and companies that buy them.

Going forward there will be more research, not less. As we conceive and prove new warm-mix technologies, more pavement managers will use warm mix in more applications. As we document the long life and long-term cost effectiveness of Perpetual Pavement, more engineers will adopt this design system for high-load, high-volume roads. As we test and verify new mix dynamics for porous asphalt, road managers will find more ways to use it.

That is how we will make warm-mix asphalt the primary pavement material — and reduce energy consumption and greenhouse gas emissions in the process. That is how we will double the reuse/recycling of asphalt pavements — and reduce energy consumption, emissions and the use of virgin natural resources. That is how we will make Perpetual Pavements the standard design method for roadways — and completely redefine the lifecycle expectations and economics of highways in America. And that is how we will make porous pavements accepted as a best-management practice for reducing stormwater runoff and improving water quality.

In responding to these challenges, the asphalt pavement industry and its partners will continue to improve the environmental performance of asphalt, already one of the most sustainable pavement materials on earth.

* NAPA’s “Black and Green, Sustainable Asphalt, Now and Tomorrow” report can be read in its entirety digitally at www.sustainableasphalt.turn-page.com. Reprinted with permission of NAPA.
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SEGREGATION: CAUSES & CURES, PART 3

(Editors note: This is an update of the third part of a three-part series of articles that originally appeared in the winter, spring and summer 2005 issues of Ohio Asphalt. Eradicating segregation is a primary goal of Ohio’s asphalt pavement industry. It is for this purpose “Segregation: Causes & Cures” is being reprinted. In “Segregation: Causes & Cures, Part 3,” Jim Scherocman discusses random and side-to-side segregation. Parts 1 and 2 of this reprint series appeared in the Spring/Summer 2010 and Fall 2010 issues of Ohio Asphalt, respectively. The winter, spring and summer 2005 issues of Ohio Asphalt, in which this series originally appeared, are archived for viewing at http://www.flexiblepavements.org/ohio_mag.cfm.)

INTRODUCTION

Segregation in a Hot Mix Asphalt (HMA) mixture can be defined as the separation of the coarse aggregate particles in the mix from the rest of the mix. The segregation can take one of three forms: random, side to side, or longitudinal, and truckload to truckload. Each type of segregation is caused by a different problem or problems. Each type of segregation, however, affects the long-term durability of the asphalt concrete pavement structure.

Segregated areas in the surface of the pavement have a rougher texture than the surrounding pavement area. In addition, the density of the mix is much lower in the segregated locations compared to the density of the HMA mix in non-segregated areas. Pavement deterioration of the segregated areas in the form of raveling typically occurs quickly under traffic. With more time and with traffic loading, the raveled areas can increase in both size and depth and can result with a pothole forming in the pavement surface. With additional time and traffic, it is possible for the raveling to progress completely through the pavement layer.

Parts 1 and 2 of this three-part article discussed the problem of truckload-to-truckload segregation. This third article will briefly describe the various causes for each of two other types of segregation, random and side-to-side segregation. In addition, it will describe the most-efficient means to prevent each of these two types of segregation from occurring.

RANDOM SEGREGATION

Areas of random segregation, shown in Figure 14, occur at irregular intervals in the surface of the roadway. These locations are indeed random, both transversely and longitudinally. In general, there is not any consistent pattern to the occurrence of the segregated areas.

Random segregation is primarily caused by the handling of the coarse aggregate materials as they are stockpiled and then fed into the asphalt plant. If a stockpile of coarse aggregate is built using a conveyor and a conical pile is formed, the largest aggregate particles typically roll down the sides of the pile and collect at the bottom of the pile (see Figure 15). If the operator of the front-end loader at the asphalt plant picks up a bucket-full of the aggregate from the bottom of the pile and delivers the large aggregate particles into the cold feed bins at the plant, random segregation may occur on the roadway behind the paver, depending on the type of asphalt plant being used.

If a batch plant is employed to produce the asphalt concrete mix, the use of screens and hot bins at the top of the plant tower will normally partially re-blend the segregated coarse aggregate. In addition, the mixing of the different size aggregates and the asphalt cement binder in the plant pugmill will also aid in re-blending the segregated large, coarse aggregate particles. If the front-end loader operator fills the cold feed bins with several consecutive bucket loads of large aggregate pieces from the bottom of the stockpile, random segregation may still occur on the roadway even when a batch plant is used to manufacture the HMA mix.

Figure 14: Random segregation
If a parallel-flow drum mix plant is used to produce the mix, there is a significantly greater chance to obtain random segregation on the roadway if only large aggregate particles are delivered into the cold feed bins by the front-end loader operator. remixing of the aggregate particles in a parallel-flow drum mix plant is limited before the asphalt cement binder material is added to the coarse and fine aggregates. It is often said that this type of plant operates on a segregated-in-segregated-out principle. If segregated, large aggregate particles are in the cold feed bin, segregated mix will come out of the discharge chute of the plant.

If the HMA mix is manufactured in a counter-flow drum mix plant, there is a greater opportunity for the large, coarse aggregate particles to be re-blended inside the aggregate drying portion of the length of the drum. This is because the asphalt binder material is not added to the combined coarse and fine aggregates until the aggregates reach the rear mixing portion of the length of the drum. Although not as efficient in remixing the large aggregate particles together as the pugmill on the batch plant, the amount of random segregation that may be produced through a counter-flow drum mix plant is usually much less than the amount of random segregation that may be produced in a parallel-flow drum mix plant.

Once the segregated mix is produced in the plant, it is very difficult, if not impossible, to remix the segregated material during the temporary storage, loading, hauling, unloading or paving processes. Thus the solution to a random segregation problem is found in the proper management of the coarse aggregate stockpiles at the asphalt plant. If conical aggregate stockpiles are used, the front-end loader operator must be aware that the largest aggregate particles within each coarse aggregate stockpile will roll down to the bottom of the pile. The loader operator then needs to do two things: The first is to rework the pile, re-blending the large aggregate pieces at the bottom of the pile with the rest of the aggregate; the second is to fill the loader bucket with non-segregated aggregate taken from the pile several feet above the ground level. It is obviously very important to consistently put uniformly graded, coarse aggregate into the cold feed bins on any type of asphalt plant. In general, however, random segregation is not a major problem on most asphalt paving projects.

**Side-to-Side or Longitudinal Segregation**

Side-to-side or longitudinal segregation, shows up on the paved surface as a very rough texture on only one side of the paver (Figure 16). This type of segregation is not caused by the mismanagement of the coarse aggregate stockpiles, by the loading of the aggregate into the cold feed bins, or by the passage of the aggregate through the plant. Further, this type of segregation is not caused by the discharge of the mix from a parallel-flow or a counter-flow drum mix plant, or the discharge of the mix from the pugmill from a batch plant.

In order for the segregated coarse aggregate material to end up on only one side of the paving lane, the asphalt concrete mix must roll downhill. The largest aggregate particles will separate from the rest of the mix, similar to what happens in a conical aggregate stockpile. This process can occur when the HMA mix is delivered into a surge silo from a drag slat conveyor, a bucket elevator, or from a conveyor belt.

When the mix is carried to the top of the silo, it must be placed into the center of the silo. Although a conical shaped pile of mix may build up

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Ohio Asphalt

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inside the silo, the largest aggregate particles in the mix should roll downhill relatively equally all the way around the pile. As the silo is emptied, the coarse material will get mixed back into the remainder of the mix and longitudinal segregation will not occur.

Depending on the configuration of the silo and the type of conveying device employed, it is possible for the mix to be delivered into the top of the silo “off-center” (Figure 17). If this is the case, the pile of mix inside the silo will be higher on one side than on the other side of the silo. The higher side will be against the wall farthest from the discharge point of the mix from the conveying device. This provides the opportunity for the largest aggregate particles in the mix to roll downhill and collect at the side of the silo that is closest to the conveyor. These large aggregate particles will then be drawn down and through the silo and discharged into one side of the haul truck.

Side-to-side or longitudinal segregation can occur at the top of the silo even when a batcher is used to collect the mix coming up the conveying device and discharges the mix in a mass into the silo. If the mix delivered into the batcher is not placed into the center of the batcher (as illustrated in Figure 18) the largest aggregate particles in the HMA mix will roll to one side of the batcher. When the batcher is emptied, the segregated mix will be deposited on one side of the silo. This will result in side-to-side segregation of the mix behind the paver.

Longitudinal segregation can also occur when mix is delivered “off-center” from a transfer conveyor running horizontally across the top of several silos. If the mix is pushed off the side of the conveyor, the largest aggregate particles in the mix can again be thrown against the far side of the silo. This results in the largest aggregate particles running downhill to the near side of the silo. When the mix is discharged from the silo into the haul truck, the segregated material will be deposited on one side of the truck bed.

If the largest aggregate particles end up on one side of the haul truck they will be discharged into the paver hopper on the same side. The segregated material will then pass through the paver on that side and come out under the screed only on that same side of the paver. Side-to-side segregation is caused by how the asphalt concrete mix is delivered into the silo at the top of the silo. In general, however, side-to-side or longitudinal segregation is not a major problem on most asphalt paving projects.

**Segregation Series Summary**

Parts 1 and 2 discussed the causes and cures of truckload-to-truckload segregation. Truckload-to-truckload segregation is caused by the manner in which the haul truck is loaded. If the truck bed is loaded in one drop of mix and a conical pile is formed inside the bed, the largest aggregate particles in the mix will roll downhill and collect at the front of the bed, on the sides of the bed, and at the tailgate on the truck bed.

Truckload-to-truckload segregation can be eliminated by merely loading the haul truck correctly. One drop of mix should be deposited from the surge silo as close to the front bulkhead on the truck bed as possible. The truck driver should then pull the haul truck forward and the next drop of mix deposited as close to the tailgate on the truck bed as possible. The truck should then be backed up and additional drops of mix placed between the first and second amounts of mix. By loading the truck using the proper multiple-drop procedure, the distance that the coarse aggregate particles roll in the mix will be greatly reduced and segregation of the mix will be prevented.

In addition to loading the haul truck correctly, keeping the paver hopper half full between truckloads of mix, practicing rapid-stop-rapid-start paver operations and using fillets or cutoff plates in the corners of the paver hopper to eliminate the need to raise or fold the wings, will be very beneficial in reducing any amount of segregation that may have occurred during the truck-loading process.

In Part 3 of this series, two less-prevalent types of segregation, random and side-to-side segregation were discussed. The solution to a random segregation problem is found in the proper management of the coarse aggregate stockpiles at the asphalt plant. Side-to-side segregation must be solved through mechanical adjustments to the HMA plant. In either case, the key to eliminating the segregation is recognizing its pattern on the roadway and investigating and curing its causes at the production facility.

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*For questions regarding HMA segregation, James A. Scherocman, P.E. can be reached by telephone at (513) 489-3338, or by e-mail at jim@scherocman.com.*
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- Benjamin Franklin

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Ohio Interstate Asphalt Pavements Continue to Show Superior Value

When discussing value in a pavement, one of the facts often pointed to is the stellar performance of the original flexible pavements (i.e. asphalt pavements) on Ohio’s Interstate System (OIS). While Ohio is finding it necessary to replace its original Interstate’s rigid pavements (i.e. concrete pavements), no such expenditure has been found necessary of the OIS’s original asphalt pavements. In fact, there has been no need for major repair or reconstruction of Ohio’s Interstate asphalt pavements; rather, typical maintenance is best described as “preventive” or minor rehabilitation.

pavements were requiring less maintenance than their comparable concrete pavements. The experience since 1995 is even more compelling, as the original concrete pavements (turned composite) on the OIS are now systematically being replaced, while the original asphalt pavements continue to provide superior service with only the need for modest asphalt overlays.

The value of using an asphalt pavement is further illustrated by looking at the continuing performance of some of the original Interstate asphalt pavements that were examined in that 1995 Gibboney Study.

**AN UPDATE ON FOUR FLEXIBLE PAVEMENTS FROM THE GIBBONEY STUDY**

**Franklin -71-28.92 to Delaware -71-11.50**, a flexible pavement constructed under three 1958 construction projects was first overlaid in 1966 with 2.5 inches. In 1975, it was resurfaced again with 1.25 inches. Spot crack sealing and a slurry seal were the only contract maintenance activities between 1984 and 1989. Overlaid again between 1990 and 1992, the overlay thicknesses for two sections were 2.5 and 3.75 inches, respectively. Ever-increasing traffic eventually required the pavement be widened. The widening project included an overlay of the existing pavement area, a 2-inch milling and 5.75-inch structural overlay in anticipation of future traffic demands. Between 1999 and 2004, three projects were let to contract. While the true maintenance requirement of these original construction projects are now somewhat obscured by the various interchange and widening projects, the original pavement is still in service; having only the need for overlays. Project details:

- Original Construction (3 projects)
  - 12 (1958), DEL/FRA - 71-0.00/33.31
  - 29-(1958), DEL - 71-3.44
  - 50-(1958), DEL - 71-7.80

**Original Pavement Build-up**

![Original Pavement Build-up Diagram]

The following table provides a listing of FRA/DEL-71 contract maintenance projects:

<table>
<thead>
<tr>
<th>Project</th>
<th>Section</th>
<th>Treatment Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>126 (1966)</td>
<td>DEL/FRA-71-0.00/28.92</td>
<td>2.5-inch resurfacing</td>
</tr>
<tr>
<td>250 (1975)</td>
<td>DEL/FRA-71-0.00/28.92</td>
<td>1.25-inch resurfacing</td>
</tr>
<tr>
<td>809 (1984)</td>
<td>DEL/FRA-71-0.00/28.92</td>
<td>Spot slurry seal</td>
</tr>
<tr>
<td>5008 (1985)</td>
<td>DEL/FRA-71-0.00/28.92</td>
<td>Crack seal, spot slurry seal</td>
</tr>
<tr>
<td>200 (1989)</td>
<td>DEL/FRA-71-0.00/28.92</td>
<td>Crack seal, spot repair, spot slurry seal</td>
</tr>
<tr>
<td>8006 (1989)</td>
<td>DEL/FRA-71-0.00/28.22 from FRA - 28.22 to DEL - 0.20</td>
<td>Interchange construction, 3.75-inch resurfacing</td>
</tr>
<tr>
<td>619 (1992)</td>
<td>DEL-71-0.91 (to 11.50)</td>
<td>2.5-inch mill-and-fill</td>
</tr>
<tr>
<td>722 (1999)</td>
<td>FRA-71-17.3 to DEL-71-11.5</td>
<td>Add lanes, 2-inch milling, 5.75-inch overlay</td>
</tr>
</tbody>
</table>

**Hamilton -275-13.91 to 16.22**, is a flexible, asphalt-concrete base pavement built under a 1975 project. To date, the pavement has received a 3-inch overlay in 1990 and a 1.5-inch mill and fill in 2000. This constitutes 35 years of service, and it is still showing strong performance with just two resurfacings. Project details are:

- Original construction (1 project)
  - 461 (1975), HAM-275-13.91

**Original Pavement Build-up**

![Original Pavement Build-up Diagram (Hamilton)]
The following table provides a listing of HAM-275-13.91 contract maintenance projects.

<table>
<thead>
<tr>
<th>Project</th>
<th>Section</th>
<th>Treatment Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>663 (1990)</td>
<td>HAM-275-10.57</td>
<td>3-inch resurfacing</td>
</tr>
<tr>
<td>236 (2000)</td>
<td>HAM-275-10.57</td>
<td>1.5 inch mill-and-fill</td>
</tr>
</tbody>
</table>

**Hamilton and Clermont -275-32.27 to 10.98** is a flexible, asphalt-concrete base pavement built under five projects between 1968 and 1970. Over its performance life this pavement has seen the need for minimal maintenance. It first received a slurry seal (over a portion of the section) in 1982. The entire section received its first asphalt overlay between 1986 and 1992 under two projects. The entire section was later widened, and a second overlay placed under three projects between 2000 and 2002. Over the course of 40 years the pavement section received only two overlays. Project details include:

**Original construction (5 projects)**
- 3 (1968), HAM-275-29.03
- 2 (1970), CLE-275-0.00
- 660 (1970), CLE-275-4.53
- 13 (1970), CLE-275-6.68
- 668 (1970), CLE-275-5.61

**Original Pavement Build-up**

The following table provides a listing of CLE-275 contract maintenance projects.

<table>
<thead>
<tr>
<th>Project</th>
<th>Section</th>
<th>Treatment Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>479 (1982)</td>
<td>HAM-275-32.27 to 33.68</td>
<td>Slurry seal</td>
</tr>
<tr>
<td>211 (1992)</td>
<td>HAM-275-32.27 to 33.68</td>
<td>Pavement planing, 4.5-inch overlay</td>
</tr>
<tr>
<td>689 (1986)</td>
<td>CLE/HAM-275-0.00/34.91</td>
<td>Rut treatment (var. locations), 2.5-inch overlay</td>
</tr>
<tr>
<td>3012 (2000)</td>
<td>HAM/CLE-275-32.27/0.00 to 5.30</td>
<td>Pavement planing, 3.25-inch overlay</td>
</tr>
</tbody>
</table>

**Wood -75-5.06-14.91** is a flexible (i.e. asphalt) pavement built under two projects in 1966. The section was first resurfaced in 1976 with a 1.5-inch overlay. A second resurfacing occurred in 1990; 3 inches of asphalt was placed in two contiguous projects. Most recently, in 2002, a 1-inch thick Smoothseal (ODOT Item 424, Type B, Fine-graded Polymer Asphalt Concrete) overlay was placed. The WOO-75-5.06 section demonstrates a remarkable 44 years of service with minimal maintenance.

**Original construction (2 projects)**
- 177 (1966), WOO-75-5.06
- 474 (1966), WOO-75-9.90

**Original Pavement Build-up**
The following table provides a listing of WOO-75 contract maintenance projects:

<table>
<thead>
<tr>
<th>Project</th>
<th>Section</th>
<th>Treatment Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>751 (1976)</td>
<td>WOO-75-5.06</td>
<td>1.5-inch asphalt overlay</td>
</tr>
<tr>
<td>752 (1976)</td>
<td>WOO-75-9.92</td>
<td>1.5-inch asphalt overlay</td>
</tr>
<tr>
<td>712 (1990)</td>
<td>WOO-75-9.92</td>
<td>Pavement repair, 3-inch asphalt overlay</td>
</tr>
<tr>
<td>929 (1990)</td>
<td>WOO-75-4.81</td>
<td>3-inch asphalt overlay</td>
</tr>
<tr>
<td>340 (2002)</td>
<td>WOO-75-(5.06 to 14.91)</td>
<td>1-inch overlay, 854, Type B, Fine-graded Polymer Asphalt Concrete (a.k.a. Smoothseal)</td>
</tr>
</tbody>
</table>

**Conclusions**

The examination of the performance of Interstate asphalt pavements since the time of the 1995 Gibboney Study continues to demonstrate the advantages of using asphalt pavement construction. The original asphalt pavements constructed on the OIS have proven their long-term value by continuing to provide a high level of service to the public with just resurfacings. The original concrete pavements, on the other hand, are having to be completely replaced after extensive and expensive maintenance.

The lesson of history is clear: Asphalt-base pavement provides superior value, as measured by long life and low-maintenance cost.
Ohio Asphalt Plants Receive NAPA’s Diamond Achievement for Excellence

The National Asphalt Pavement Association (NAPA) annually recognizes excellence in asphalt plant operations by bestowing the Diamond Achievement Commendation for Excellence in Hot-Mix Asphalt Plant Operations. The Diamond Achievement Award process emphasizes continuous quality improvement and includes a review of items such as plant appearance, operation, environmental practices, safety, permitting and regulatory compliance and community relations.

In 2010, seven companies and 49 plants from across Ohio were recognized to receive this honor. The following is a listing of the Ohio companies and the plants which received this prestigious award:

Barrett Paving Materials Inc.
- Camden Asphalt Plant 1161
- Carthage Plant 1051
- Cleves Plant 1001
- Fairfield Plant
- Middletown Asphalt Plant 10057
- Moraine Asphalt Plant 10055
- Newtown Drum Plant 1011
- Reading Plant 1111
- River Road Plant 10058
- South Lebanon Hot Mix Plant
- Spring Valley Plant 10052
- W. Carrollton Plant 10050

Erie Blacktop Inc.
- Parkertown Plant

Kokosing Construction Co. Inc.
- Columbus Plant
- East Claridon Plant
- Fredericktown Plant
- Garfield Hts. Plant
- Mansfield Plant

Mar-Zane Inc., Division of Shelly & Sands Inc.
- Plants 2, 6, 13, 21 & 27

Terry Asphalt Materials Inc.
- Terry Asphalt Plant

The Shelly Co., an Oldcastle Materials Co.
- Allied Corp. Plants 5 & 79
- Allied Corp Streetsboro 72
- Allied Corp. Bedford Hts. 71
- Allied Corp. Downtown Plant 76
- Allied Corp. Kent Plant 75
- Shelly Materials Plants 2, 24, 25, 61, 63, 66, 80, 85, 90 & 94
- Stoneco Plant 110

Valley Asphalt Corp.
- Plant 14 Newtown
- Plant 17 Kilby Road
- Plant 19 Mehling Way
- Plant 23 Sharonville
- Plant 25 Troy
- Plant 5 Morrow
- Plant 6 Dryden Road

Asphalt Institute adds Moran, Rosenberger to Roll of Honor

The Asphalt Institute (AI) recently added Lyle E. Moran and Carlos E. Rosenberger to its Roll of Honor.

Since 1965, the AI Roll of Honor has been viewed as the highest level of recognition conferred by the institute. Individuals selected for the award have contributed to the asphalt industry through sustained technical achievement or substantial contribution of leadership.

Rosenberger is retiring this year after 42 years in the asphalt industry. He most recently spent 27 years as an AI senior regional engineer, based in Dillsburg, Pa. Before coming to AI in 1984, Rosenberger, a graduate of Shippensburg State University, served as a quality assurance engineer for the Pennsylvania Department of Transportation. He recently led a national research project to improve the way longitudinal joints are constructed, specified and accepted.

Moran and Rosenberger were announced as the 86th and 87th AI Roll of Honor additions last December at the institute’s annual meeting in Orlando.

Lyle E. Moran

Carlos E. Rosenberger
OBITUARY

Richard R. Stander, retired chairman of the Mansfield Asphalt Paving Company and national transportation leader, passed away Feb. 4, 2011, at the age of 92.

Stander served as chairman or president of several national transportation associations and programs, such as the American Road & Transportation Builders Association, the National Asphalt Pavement Association and The Road Information Program. He also served as president of the Ohio Contractors Association.

A life member of the American Society of Civil Engineers, Association of Asphalt Paving Technologies and National Society of Professional Engineers, Stander’s professional career spanned more than 50 years. He began with the Ohio Department of Highways as a bituminous test inspector. With Mansfield Asphalt Paving, Stander led the company to being an early adopter of the automatic paver screed, pneumatic and vibratory rollers and state-of-the-art asphalt plant production.

Stander is survived by his wife, Joyce, children Rick, Bill, Susan and Sally, grandchildren and great grandchildren. The family has requested that donations in Stander’s memory be made to help the engineering program at The Ohio State University, Mansfield Development Office.

Flexible Pavements of Ohio staff and members extend their sympathy to the Stander family and friends.
New Member

Flexible Pavements of Ohio would like to welcome seven companies as new members of the association. Please join in recognizing these new members:

Bucyrus Road Materials Inc. joins FPO as a Producer Member. Bucyrus Road Materials is a Hot Mix Asphalt producer and contractor located in Bucyrus.

Asphalt Shingle Grinding Services LLC joins FPO as an Associate Member. ASGS, located in Peru, Ind., is dedicated exclusively to providing onsite recycling of asphalt shingles or RAS.

GeoShack Ohio LLC joins the association as an Associate Member. With locations throughout Ohio, GeoShack is a distributor of leveling, alignment, measurement, guidance and grade control solutions to the construction, survey, agricultural, landfill and mining industries.

NuVention Solutions Inc. joins FPO as an Associate Member. NuVention Solutions specializes in the creation of new technologies and is currently developing a process which converts livestock solid waste into a bio oil that can be used as a value-added liquid asphalt extender. NuVention Solutions is located in Valley View.

Precision Laser & Instrument Inc. joins the association as an Associate Member. Located throughout Ohio, Pennsylvania and West Virginia, Precision Laser & Equipment provides sales, repair and technical support for advanced GPS measurement solutions to the construction, surveying and GIS mapping industries.

Rudd Equipment Company joins FPO as an Associate Member. Rudd Equipment is located in Columbus and provides complete equipment sales and service support to the mining, construction and associated industries.

Quality Control Inspection Inc. joins FPO as an Architect & Consultant Engineer Member. Headquartered in Bedford, with offices throughout Ohio, Quality Control Inspection provides comprehensive construction management and inspection services.
Dynapac is one of the world's most specialized and experienced manufacturers of high-performance compaction and paving equipment. With 75 years of experience worldwide, engineering expertise, and industry-shaping innovation, Dynapac routinely delivers pioneering solutions, keeping customers ahead of the competitive curve.

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