Shrinking the carbon footprint with sustainable pavement

By Susan Trulove

Weighing energy use and pollution as factors in road maintenance decisions is something we can do immediately.

Consider the carbon footprint — the sum total of greenhouse gases — created by the paving process.

About the only binder used in asphalt pavements is bitumen, which is made of heavy oil, and the asphalt itself is usually heated to more than 200 degrees before it is applied. The power equipment used to produce the materials and pave the roads requires fuel to manufacture as well as operate. Space to dispose of removed pavement materials is becoming scarce, to say nothing of the real concern about pollution of soil and ground water; yet, reuse and recycling of paving materials has not reached its full potential in the U.S.

It probably amounts to a footprint that even T. rex can't touch, but precisely quantifying the greenhouse effects has been problematic.

"In Blacksburg, the public works department is doing a lot of things with sustainability, such as climate action planning, energy management, green fleets, and recycling. But pavementwise, we haven't done that," said Kelly Mattingly, director of the Blacksburg, Va., public works department. "It is not an easy area to determine the environmental footprint."

Researchers at the Virginia Tech Transportation Institute are working to change that.

"Pavement is an important target for sustainability, not only because of the large area of the earth surface that is covered by pavements but also because of the impact on transportation cost and emissions," said Gerardo W. Flintsch, director of the institute's Center for Sustainable Transportation Infrastructure and professor of civil and environmental engineering at Virginia Tech.

Flintsch and his colleagues have measured energy use and emissions from three common processes for maintaining pavement to determine the most eco-friendly approach, and have created a decision-support tool that compares environmental variables, including emissions and energy, as well as cost and performance.
Flintsch's student, Filippo Giustozzi, based his thesis research on the development of a decision-support tool. Giustozzi is the first candidate to complete a dual Ph.D. in civil engineering from Virginia Tech and the Politecnico di Milano.

"Pavement is 60 to 70 percent of the cost of roads, so in the U.S., we focus on cost of maintenance and the services provided to auto and truck drivers," said Flintsch. "Filippo brought the European perspective; they have been paying attention to the environmental impact of pavement longer than we have in the U.S. More sustainable pavements must eventually be based on more sustainable materials and processes, such as efficient reuse of materials. In the meantime, weighing energy use and pollution as factors in road maintenance decisions is something we can do immediately."

**Sizing the carbon footprint**

Giustozzi, advised by Maurizio Crispino, a professor of civil engineering at Politecnico di Milano, and Flintsch, have determined the carbon footprint of three common preventive maintenance treatments — microsurfacing, slurry seal, and thin overlay.

If the ingredients used in microsurfacing were listed on a box, it would show a mixture of polymer-modified asphalt emulsion; aggregates, such as granite dust collected at quarries; mineral filler, such as hydrated lime or cement; other additives; and water. It's combined and spread on a paved surface, primarily to extend the service life of heavy traffic highways to address rutting, loss of friction, and damage from water and sun.

Slurry seal is the same sort of mixture but without polymers, uniformly spread over the pavement. It is usually used to restore pavement texture, providing a skid-resistant surface while improving waterproofing properties and sealing. "It's the same kind of mixture you would use on your driveway," said Flintsch.

Thin asphalt overlays, less than 1.25 inches thick, are usually applied when a more consistent method of intervention is needed. It can be placed with or without milling the existing asphalt surface layer, depending on the condition of the surface, such as the severity of cracks and ruts.

For comparison purposes, the researchers assumed the traffic volume and the pavement structure were the same for each process. Based on 50-year performance deterioration models, two maintenance schedules were set up at years 8 and 16 for overlay, at years 6 and 13 for microsurfacing, and at years 5 and 12 for slurry.

Costs were evaluated over the life cycle of each maintenance strategy using a standard price list for road materials and construction.
Emissions were determined based on cradle-to-grave analysis of materials, processes, and construction procedures to compute each alternative's "carbon footprint," referring to the manner, materials, and machinery used.

For example, to compute emissions attributable to bitumen, the researchers included emissions from the oil extraction, transport to the plant, refinement of crude oil into bitumen, and transport to the road work site.

Flintsch said the findings from previous, well-regarded research were averaged to provide final reasonable values for emissions and energy use from the manufacture of raw materials as a resource for road planners.

Road construction equipment was analyzed to determine emissions and energy spent; again, no small task. Roadbuilding equipment is wonderfully diverse. Complex road miller machinery gnaws asphalt off the road and spews the chunks into dump trucks, while massive but simple rollers do one job — iron new, hot pavement.

The proper equipment for each phase of the work was chosen. So, for applying a thin overlay, a tack coat sprayer, a paver, and a roller were selected. Energy and emissions were computed for a square meter of finished thin overlay. A similar procedure was used to estimate energy and emissions for microsurfacing and slurry seal.

"Engine exhaust was the main source of emissions analyzed, and there were many influencing factors, such as the work experience and behavior of the operator and the many kinds of engines and brands," said Giustozzi.

Different engines were analyzed to determine the fuel required for a square meter — 10 square feet — of a specific action, such as paving, where a machine as wide as a traffic lane accepts loose material at one end and spreads it at the other end as a steaming roadway material, only needing the roller before it is ready to be driven on.

The total amount of CO2e — short for equivalent carbon dioxide — and energy consumed were computed for each equipment model. For instance, one model of paver emitted 26.63 grams of CO2e per meter squared. "It was assumed that each engine was run at the rotation speed that provided the maximum torque while conducting the work, which is the most efficient from an environmental standpoint," said Flintsch.

After computing emissions and energy from materials and equipment, processes to convert raw materials into the final pavement treatments were investigated. Hot-mix asphalt production, reclaimed asphalt pavement processing, transportation from the plant to the construction site, and final disposal and recycling represent only some of the processes measured.

The result?
Microsurfacing was the optimal preventive maintenance strategy for the specific traffic level and pavement structure, Giustozzi, Crispino, and Flintsch reported in a 2012 article in the International Journal of Life Cycle. The polymer-enhanced asphalt mix applied twice over each life cycle will maximize performance and minimize costs and environmental impacts, according to the research project.

Creating a decision-support tool

"The decision-support tool Giustozzi created allows agencies to set up their own criteria and weights for each variable depending on their short-term needs and budget scenarios," said Flintsch.

For example, a greener plan can give a higher weight to the environmental variable. Or, a cost-effective strategy will base the decision on savings over the life cycle. "The environmental assessment should always be linked to performance and cost," said Giustozzi.

The decision tool resembles a geometry formula for the area of a cube, identifying the x-axis with the life-cycle costs, the y-axis with the performance, and the z-axis with the environmental features of carbon footprints and energy use. Data from each preventive maintenance alternative is entered in the software program MATLAB. The cube with the lowest volume represents the winning strategy, considering costs, performance, and environmental impacts.

"MATLAB is a research tool. For implementation, we need to develop a user-friendly tool," said Flintsch. "We are working on that."

A project headed by Flintsch and with his Center for Sustainable Infrastructure team and scientists from the departments of transportation in Virginia, Wisconsin, and Pennsylvania, and the Federal Highway Administration, are continuing this work to create a user-friendly decision-support tool and help implement it.

"A large amount of emissions and energy could be saved by adopting preventive maintenance plans on road pavements," said Flintsch.

Where the rubber meets the road

In Blacksburg, the challenge is which methods to use to keep the roads in top shape.

"There are all these pavement maintenance systems available to us and it is a challenge to know which is best for each road condition. I want to learn best practices and implement them," said Mattingly of the public works department.
More generally, it is widely believed that preventive maintenance saves money, but there is a gap in implementation, let alone consideration of the niceties of environmental impact.

"Operational decisions on pavement maintenance can certainly be influenced by the statewide recommendations, but available funding and local experience carry more weight," said Kevin McGhee, associate principal scientist with the Virginia Department of Transportation's Center for Transportation Innovation and Research. "Fortunately, the decisions at both levels tend to be very open to recommendations from sound research. Decision-makers are particularly receptive to ideas that will save money and/or stretch available funding as far as possible."

Mattingly agreed.

"We are just beginning to understand preventive strategies, instead of 'worst first' and 'mill and repave.' Blacksburg is trying to develop a preventive maintenance program right now with the help of Richard Ferron (head of business development) at Lanford Brothers. We are investigating slurry seals, chip seals, cold foam in-place recycling, pavement rejuvenators, etc. and we are trying to learn when best to apply these techniques."

Down the road, Salem has already had its roads rated, started crack sealing three years ago, and is starting to use asphalt rejuvenators to slow oxidation, reported Mike Tyler, director of the city's streets and maintenance department. "With the rising costs of the petroleum-based materials, overlay is not economically feasible, and probably has not been for 20 years," he said.

The traditional method for rehabilitation consists of milling off and disposing of all the existing asphalt layers and replacing them. An alternative is reclaimed asphalt pavement — RAP — a road material made from old asphalt pavements.

"It can be reused in order to construct new pavements, therefore consuming less virgin material and a lower amount of bitumen, a non-renewable resource," said Giustozzi. "Typical percentages of RAP to be used in the mixture usually range between 10 and 30 percent; however, new research is being conducted using 100 percent of RAP material.

"An old pavement can theoretically be totally rejuvenated and live again," Giustozzi said.

"Yes!" said Ferron. He is a fan of an asphalt recycling technology called foamed asphalt, which is used widely in Europe, according to the Federal Highway Administration. When Lanford repairs a road using their mobile asphalt plant, you don't see a miller and a row of dump trucks. They rehabilitated a 3.7-mile section of
Interstate 81, rebuilding one lane to a depth of 24 inches using reclaimed asphalt on the spot, doing in 17 days what would usually take more than a year.

One massive piece of rolling machinery removed the pavement, applied foamed asphalt as a stabilizer, and then hotmix asphalt made from the removed material.

Giustozzi is happy to see the practice being tried, but said, "The eco-benefits from road materials recycling still have to be evaluated."

Ferron also champions some sustainable practices that his company does not offer.

"I have to prevent failures if we are going to succeed in what we do," he said. "There are a lot of products that have potential, such as the rejuvenator made from soybean oil that Salem is using. I want to prevent poor-quality work and promotion of poor products. It is a huge educational issue.

"The right product has to be applied correctly. Cracksealing is an example. Crack-sealing can prevent deterioration, but you can't crack-seal a road that has gone too far or you will have too much seal across the surface and that is dangerous."

Blacksburg and Salem are among a group of municipalities that belongs to a statewide sustainable pavement group started by Ferron that includes researchers from the Center for Sustainable Infrastructure at Virginia Tech Transportation Institute.

"Gerardo's group is a godsend to me," said Ferron. "They are doing a lot of work on how to get sustainability through maintenance and preservation. And we are starting a National Center for Recycled and Reclaimed Pavements that will be based at the Virginia Tech Transportation Institute."

Said Ferron, "The whole purpose of sustainability is that budgets are shrinking but the demands are the same; so public works departments are starting to operate wisely, to maintain roads, whereas they used to let them go to pieces then mill and repave. When I started the group, my concern was that they are so hungry for solutions, they are listening to anyone."

There have been ad hoc attempts to incorporate "green" materials into road maintenance, Giustozzi said. "But a strategy that appears environmentally friendly may not be the one with the highest performance."

Of course there are roadblocks to an eco-friendly focus and new technologies.
"In the U.S., current practices and financial restraints often discourage change and innovation in favor of established technologies, materials, and techniques," Flintsch said.

In Europe, while approaches to road maintenance differ by country, Giustozzi said, "Sustainability features of road projects and related activities are very common and often included even in the bid systems."

Meanwhile, in the U.S., Flintsch notes that "at times, decisions are focused more on short-term pressures than sustainable long-term effects.

Many areas have laws requiring the use of low-bid procurement in project level decision-making and do not allow sustainability to be considered alongside price."

"We run up against this in all areas," said Mattingly. "Environmental sustainability is a quality. If you buy a (brand name) computer, you are not asked what the payback is. Often green products are the only products that have a payback, and the only ones required to have a payback. I shouldn't have to justify additional cost for a lower carbon footprint. It drives me crazy."

Flintsch's research group has demonstrated that pavements can provide benefits, such as noise reduction and safety, as well as durability. "New paving materials also have the potential to act in a multifunctional way, such as drainage systems, to absorb air pollution, to generate energy, and to reduce urban heatisland effects," said Flintsch.

Giustozzi is now in Italy doing research on smart and sustainable road pavements.

"These are pavements that can generate energy using vehicle traffic loads," he said. "You can reuse that energy to heat the road during winter time, for instance, in order to keep the surface from freezing or you can simply reuse it to generate electrical power for road lighting."

The Center for Sustainable Transportation Infrastructure is looking at emissions and pollution by users' vehicles when they are being driven on various pavement types.

"Users create greater emissions and pollution than material extraction for pavement maintenance," said Flintsch. "If the road is in better condition, is stiffer, there is less resistance and that reduces energy and emissions. If there are no potholes, you don't have to change speeds and that saves energy. If you don't have to close the road for repairs, that reduces emissions."

Particularly on facilities that see heavy use, the slightest improvement in reduced rolling resistance or accident risk can quickly lead to societal savings that dwarf spending for materials and construction.
“Innovation may sometimes have higher initial cost, but is a prerequisite to the improvement of sustainability in the longer term,” said Flintsch.