Making roadway spending more sustainable

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The share of federal spending on infrastructure has reached an all-time low, falling from 30 percent in 1960 to just 12 percent in 2018.

While the nation's ailing infrastructure will require more funding to reach its full potential, recent MIT research finds that more sustainable and higher performing roads are still possible even with today's limited budgets.

The research, conducted by a team of current and former MIT Concrete Sustainability Hub (MIT CSHub) scientists and published in Transportation Research D, finds that a set of innovative planning strategies could improve pavement network environmental and performance outcomes even if budgets don't increase.

The paper presents a novel budget allocation tool and pairs it with three innovative strategies for managing pavement networks: a mix of paving materials, a mix of short- and long-term paving actions, and a long evaluation period for those actions.

This novel approach offers numerous benefits. When applied to a 30-year case study of the Iowa U.S. Route network, the MIT CSHub model and management strategies cut emissions by 20 percent while sustaining current levels of road quality. Achieving this with a conventional planning approach would require the state to spend 32 percent more than it does today. The key to its success is the consideration of a fundamental—but fraught—aspect of pavement asset management: uncertainty.

Predicting unpredictability

The average road must last many years and support the traffic of thousands—if not millions—of vehicles. Over that time, a lot can change. Material prices may fluctuate, budgets may tighten, and traffic levels may intensify. Climate (and climate change), too, can hasten unexpected repairs.

Managing these uncertainties effectively means looking long into the future and anticipating possible changes.

"Capturing the impacts of uncertainty is essential for making effective paving decisions," explains Fengdi Guo, the paper's lead author and a departing CSHub research assistant.

"Yet, measuring and relating these uncertainties to outcomes is also computationally intensive and expensive. Consequently, many DOTs [departments of transportation] are forced to simplify their analysis to plan maintenance—often resulting in suboptimal spending and outcomes."

To give DOTs accessible tools to factor uncertainties into their planning, CSHub researchers have developed a streamlined planning approach. It offers greater specificity and is paired with several new pavement management strategies.

The planning approach, known as Probabilistic Treatment Path Dependence (PTPD), is based on machine learning and was devised by Guo.

"Our PTPD model is composed of four steps," he explains. "These steps are, in order, pavement damage prediction; treatment cost prediction; budget allocation; and pavement network condition evaluation."

The model begins by investigating every segment in an entire pavement network and predicting future possibilities for pavement deterioration, cost, and traffic.

"We [then] run thousands of simulations for each segment in the network to determine the likely cost and performance outcomes for each initial and subsequent sequence, or 'path,' of treatment actions," says Guo. "The treatment paths with the best cost and performance outcomes are selected for each segment, and then across the network."

The PTPD model not only seeks to minimize costs to agencies but also to users—in this case, drivers. These user costs can come primarily in the form of excess fuel consumption due to poor road quality.

"One improvement in our analysis is the incorporation of electric vehicle uptake into our cost and environmental impact predictions," Randolph Kirchain, a principal research scientist at MIT CSHub and MIT Materials Research Laboratory (MRL) and one of the paper's co-authors. "Since the vehicle fleet will change over the next several decades due to electric vehicle adoption, we made sure to consider how these changes might impact our predictions of excess energy consumption."

After developing the PTPD model, Guo wanted to see how the efficacy of various pavement management strategies might differ. To do this, he developed a sophisticated deterioration prediction model.

A novel aspect of this deterioration model is its treatment of multiple deterioration metrics simultaneously. Using a multi-output neural network, a tool of artificial intelligence, the model can predict several forms of pavement deterioration simultaneously, thereby, accounting for their correlations among one another.

The MIT team selected two key metrics to compare the effectiveness of various treatment paths: pavement quality and greenhouse gas emissions. These metrics were then calculated for all pavement segments in the Iowa network.

Improvement through variation

The MIT model can help DOTs make better decisions, but that decision-making is ultimately constrained by the potential options considered.

Guo and his colleagues, therefore, sought to expand current decision-making paradigms by exploring a broad set of network management strategies and evaluating them with their PTPD approach. Based on that evaluation, the team discovered that networks had the best outcomes when the management strategy includes using a mix of paving materials, a variety of long- and short-term paving repair actions (treatments), and longer time periods on which to base paving decisions.

They then compared this proposed approach with a baseline management approach that reflects current, widespread practices: the use of solely asphalt materials, short-term treatments, and a five-year period for evaluating the outcomes of paving actions.

With these two approaches established, the team used them to plan 30 years of maintenance across the Iowa U.S. Route network. They then measured the subsequent road quality and emissions.

Their case study found that the MIT approach offered substantial benefits. Pavement-related greenhouse gas emissions would fall by around 20 percent across the network over the whole period. Pavement performance improved as well. To achieve the same level of road quality as the MIT approach, the baseline approach would need a 32 percent greater budget.

"It's worth noting," says Guo, "that since conventional practices employ less effective allocation tools, the difference between them and the CSHub approach should be even larger in practice."

Much of the improvement derived from the precision of the CSHub planning model. But the three treatment strategies also play a key role.

"We've found that a mix of asphalt and concrete paving materials allows DOTs to not only find materials best-suited to certain projects, but also mitigates the risk of material price volatility over time," says Kirchain.

It's a similar story with a mix of paving actions. Employing a mix of short- and long-term fixes gives DOTs the flexibility to choose the right action for the right project.

The final strategy, a long-term evaluation period, enables DOTs to see the entire scope of their choices. If the ramifications of a decision are predicted over only five years, many long-term implications won't be considered. Expanding the window for planning, then, can introduce beneficial, long-term options.

It's not surprising that paving decisions are daunting to make; their impacts on the environment, driver safety, and budget levels are long-lasting. But rather than simplify this fraught process, the CSHub method aims to reflect its complexity. The result is an approach that provides DOTs with the tools to do more with less.

More information: Fengdi Guo et al, Environmental and economic evaluations of treatment strategies for pavement network performance-based planning, *Transportation Research Part D: Transport and Environment* (2021). DOI: 10.1016/j.trd.2021.103016

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