Improving pavement networks by predicting the future

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CSHub researchers are modeling the future of pavements to help departments of transportation maintain their pavement networks while lowering costs. Credit: Luo Chris/Pexels

With around 4.18 million miles of roads in the United States, planning

pavement maintenance can seem like a daunting process.

Currently, departments of transportation (DOTs) tend to rely on past practices or expert opinion to make maintenance decisions. But with a $420 billion backlog of repairs for U.S. highways, these conventional methods are becoming less effective. Instead, DOTs require more quantitative approaches to manage their tight budgets and fix their aging roadways.

In a recent paper in *Transportation Research Part C: Emerging Technologies*, MIT Concrete Sustainability Hub (CSHub) researchers Fengdi Guo, Jeremy Gregory, and Randolph Kirchain propose one such approach, known as Probabilistic Treatment Path Dependence (PTPD). PTPD performs better than conventional models, which would require a 10 percent additional annual budget to reach the same level of network performance in the given case study.

CSHub researchers achieved this by confronting a fundamental concern that many conventional models shy away from: uncertainty.

Comfortable with uncertainty

Paving is fraught with uncertainty. From the deterioration of pavements to the price of materials, DOTs cannot be sure of what things will look like in five, 10, or 20 years. What's more, predicting and incorporating these kinds of uncertainties can prove challenging—enough so that many models discount it altogether.

Traditionally, most models weigh the costs and benefits of maintenance decisions for each segment of a network to choose the best one. Their analyses tend to calculate the cost and benefit based on the current year or for a fixed set of future maintenance treatments, without considering uncertainties during the analysis period.

"This may mean that they plan to maintain a new segment of pavement the same way each time over the course of its life," says Guo. "The problem is that this is often not possible. Over time, changes in the price of materials, the deterioration rates of pavements, and even the changes in treatment paths—which are the sequence of maintenance actions taken—will demand treatments not specified in the original model."

For DOTs to manage their networks efficiently, then, they had better adapt to treatment path dependence and uncertainty.

CSHub research sought to create a new model that offers them the most adaptability. To do this, they considered thousands of treatment schedules under future scenarios.

Their model takes a bottom-up approach, looking at each segment in a pavement network. For each segment, it evaluates every possible initial treatment and future scenario of material price and deterioration. From there, an optimal treatment path and its total cost are identified for each combination of scenario and initial treatment.

With all of these possibilities laid out in front of them, CSHub researchers then calculated the likelihood of certain outcomes in pavement performance—the pavement's surface quality—for each combination of initial treatment option and future scenario. This allows them to capture which treatments will likely have the best outcomes given all the possible changes that might occur. For each segment, the model then identifies the two treatment options with the best likely outcomes.

"To select between these final two options," says Guo, "our model considers the risks associated with each and the available budget, as well."

In this case, risk refers to how the actual performance of a treatment might deviate from its average expected performance. The more the variance and the more extreme the outlier scenarios, the greater the risk. However, it's a tradeoff—a riskier treatment may also yield better performance.

So, it's up to the DOT to determine how much risk they are willing to take. And it's that level of risk that determines which of the final two options they will select for each segment in the pavement network.

Paving in practice

In several case studies discussed in their paper, CSHub researchers analyzed how levels of risk affected the selection of treatments within their models, as well as how their model compared to conventional models. They found that when DOTs were less averse to risking unexpected outcomes in a segment's performance, their model favored thin asphalt overlays for that segment, which is a cheaper treatment option. As risk aversion increased, however, the opposite occurred. The model instead favored more expensive concrete overlays and complete reconstructions of the segment.

How come?

It boils down to the price of materials.

"Unlike asphalt, concrete tends to have lower price volatility," explains Guo. "That means DOTs can reliably predict how much concrete treatments will cost. This prevents the kind of cost overruns that might occur due to an unexpected increase in asphalt prices."

The same tradeoff occurs with pavement performance.

"While riskier treatments might offer better performance outcomes, it's more likely those outcomes will vary," explains Guo. "On the other hand, less-risky treatments will offer more consistent performance—though that performance could be slightly lower."

Ultimately, the researchers found that models with moderate risk aversion and a mix of asphalt and concrete had the best outcomes, since they could optimize average performance and performance variability.

The researchers then compared their PTPD model with moderate risk to conventional cost-benefit approaches currently used by DOTs.

Over a 20-year analysis period, they found that their PTPD model performed better than the conventional model.

While the conventional model could optimize cost and performance in the short term, it didn't anticipate future uncertainties. This led to more frequent, less-expensive treatments that initially improved outcomes but resulted in worse performance and higher costs over time.

The PTPD model instead took a long-term perspective. It accounted for uncertainties and, as a consequence, better anticipated and adapted to future changes.

This meant it invested more heavily up front in a few key, heavily used segments of a network. As a result, the performance and cost benefits throughout the network didn't manifest until later in the analysis period. By that time, the network required simpler, cheaper treatments less frequently.

In fact, for the cost-benefit model to perform as well as the PTPD model, DOTs would have to spend 10 percent more over 20 years in the given case study.

In the future, Guo and his colleagues hope to extend their analysis to the entire U.S. roadway system. In addition to cost and performance, they intend to measure the environmental footprint of paving decisions, as well.

Facing uncertainty is difficult. But with their latest model, CSHub researchers do just that. Instead of discounting uncertainty, they confront it head-on. And consequentially, DOTs may soon expect reduced backlogs and better roads.

More information: Fengdi Guo et al. Incorporating cost uncertainty and path dependence into treatment selection for pavement networks, *Transportation Research Part C: Emerging Technologies* (2019). DOI: 10.1016/j.trc.2019.11.015

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