Improving America's Road Infrastructure by Embracing Uncertainty

CSHub Topic Summary | March 2022

MIT CONCRETE SUSTAINABILITY HUB

Proven Perspectives. Modern Tools.

Projects like the U.S. Interstate System gave America a reputation for building world-class infrastructure. Yet, the nation's current infrastructure spending as a percentage of GDP today is the lowest since the 1960s, falling by roughly 25%.[1] Not surprisingly, as spending has fallen so too has the quality of our roads, of which 43% are in poor condition as of 2021.[2]

These spending patterns are now beginning to change. The recent passage of the Infrastructure Investment and Jobs Act promises to revive America's commitment to robust investment in world class infrastructure projects. But for this 1.2 trillion-dollar investment to yield lasting results will require long-term planning and perspectives that maximize every dollar spent.

The challenge is that today's asset management tools

Key Takeaways:

- New risks and challenges have made effective budget allocation essential.
- Modern allocation tools, however, struggle to manage uncertainties in cost and deterioration—which leads to inefficient infrastructure spending.
- MIT CSHub has developed a budget allocation model that better anticipates these uncertainties and allows DOTs to future-proof their pavement spending.
- This allocation model has been paired with three innovative management strategies: decision-making flexibility, a long-term planning horizon, and a mix of materials.
- When coupled, the CSHub allocation model and management strategies can reduce pavement network emissions by 21% while achieving the same performance at a 32% lower budget.

Credit: Aleksejs Bergmaniz | Pexels

often struggle to predict and meet future needs. In particular, they avoid measuring complex but essential uncertainties in cost and deterioration. In the era of COVID-19 and, moreover, climate change, such uncertainties have become more pronounced and problematic. Failing to account for them in our planning decisions will lead to plans that don't deliver.

The MIT Concrete Sustainability Hub has developed a tool, known as Adaptive Allocation Planning Tool (ADAPT), that gives agencies an unprecedented ability to factor the impacts of uncertainty into their asset management decisions.

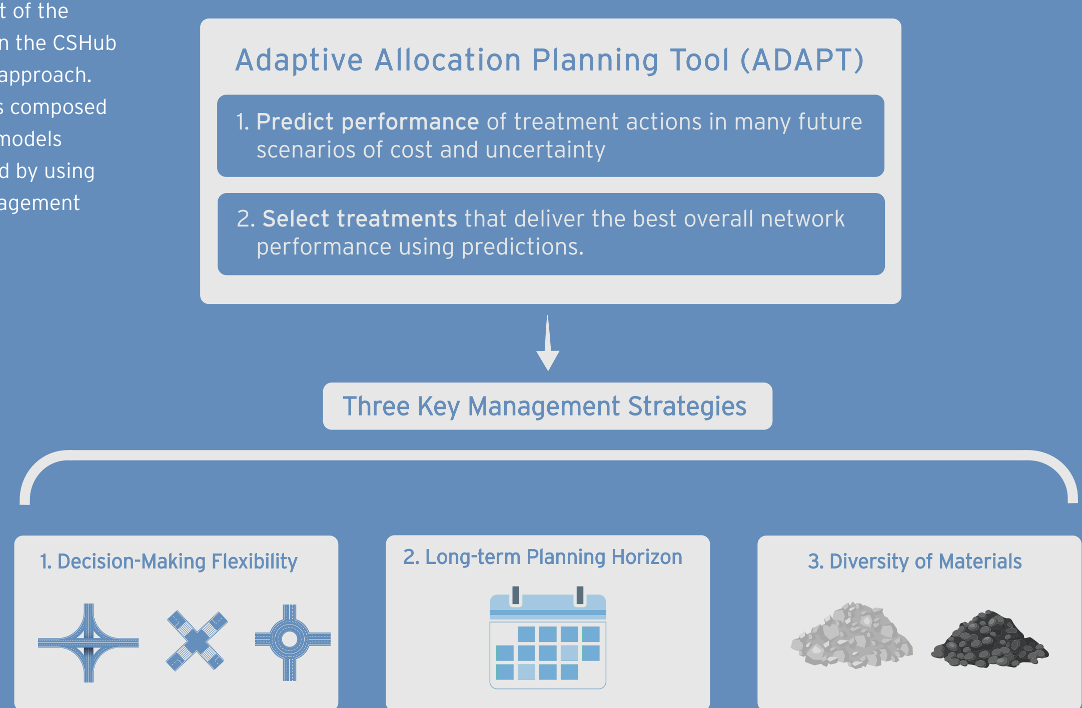
Applying the ADAPT approach uncovers three critical management strategies that agencies can deploy to respond to an uncertain future. These are: flexible practices, long-term planning horizons, and material diversity. CSHub analyses show that **the ADAPT approach employing these three strategies could lower costs by 32% and GHG emissions by 21% while maintaining the same performance.**

Allocating with (Un)Certainty

Currently, Departments of Transportation (DOTs) tend to simplify their approach to asset management through prescriptive methods. This can mean that they maintain a road the same way, with the same materials, and with the same timing criteria and performance trigger values over its lifespan.

The future, however, cannot be prescribed. Uncertainties in material costs and pavement deterioration can make prescribed maintenance activities less effective and more expensive over time. To future-proof the

Figure 1. A flowchart of the methodology used in the CSHub asset management approach. The ADAPT model is composed of four component models that are then applied by using three different management strategies.



nation's infrastructure investment, then, DOTs must explicitly consider future uncertainties.

The MIT CSHub's ADAPT approach anticipates and manages these uncertainties in cost and deterioration to inform treatment activities and improve outcomes. The ADAPT model is composed of two steps. First, it simulates the performance of each treatment alternative for each segment in many (hundreds) of possible future scenarios of cost and deterioration. Then using that information, it selects the best set of treatments that balances expected performance and future risk for the network. The latest machine learning tools are critical to both steps in the ADAPT approach: they enable the numerous simulations and calculations required to first predict outcomes and then inform treatment decisions.

When applied to an entire pavement network, the ADAPT model shows promising results. Compared to the ADAPT approach, **a traditional cost-benefit approach with a fixed treatment sequence would require a 17% larger budget to achieve the same performance over 20 years.**

Putting Predictions into Practice

To maximize the potential of the ADAPT model, CSHub has tested it using three key management strategies: flexible paving practices, a long-term planning horizon, and a diverse materials portfolio (See **Figure 1**). Together, these strategies give DOTs the agility and foresight to respond to the uncertainties predicted by the model—and reap sizable benefits.

With this portfolio of tools, DOTs can realize higher network performance more affordably using fewer, more targeted treatment actions. This would have the added benefit of minimizing emissions from construction and excess vehicle fuel consumption generated from poor road quality. Such savings are often overlooked—but significant. A CSHub case study found that poor road quality on California's highways generated 5 billion gallons of wasted fuel over five years.

The ADAPT model and associated management strategies offer numerous opportunities to mitigate such excess emissions and improve road network performance. The CSHub team explored these opportunities in a peer-reviewed case study[3] of Iowa's U.S. route network.

The study predicted outcomes over a 30-year analysis period using the ADAPT approach and a typical budget (one that would allow DOTs to maintain the current level of the network using the prescriptive and short-term business-as-usual approach).

Iowa was chosen as it currently applies the three strategies discussed above (which allowed the team to model them more effectively) and because the State has published extensive data on its pavement networks. All life cycle emissions reductions presented in the study factor in the initial, embodied impact burdens of materials production and construction.

Strategy 1: Decision-Making Flexibility

The traffic levels across one pavement network can vary drastically. In Iowa, for instance, Johnson County sees roughly 12 times as much daily truck traffic as Osceola County. To respond to this variation—and inevitable uncertainties in cost and deterioration—requires an

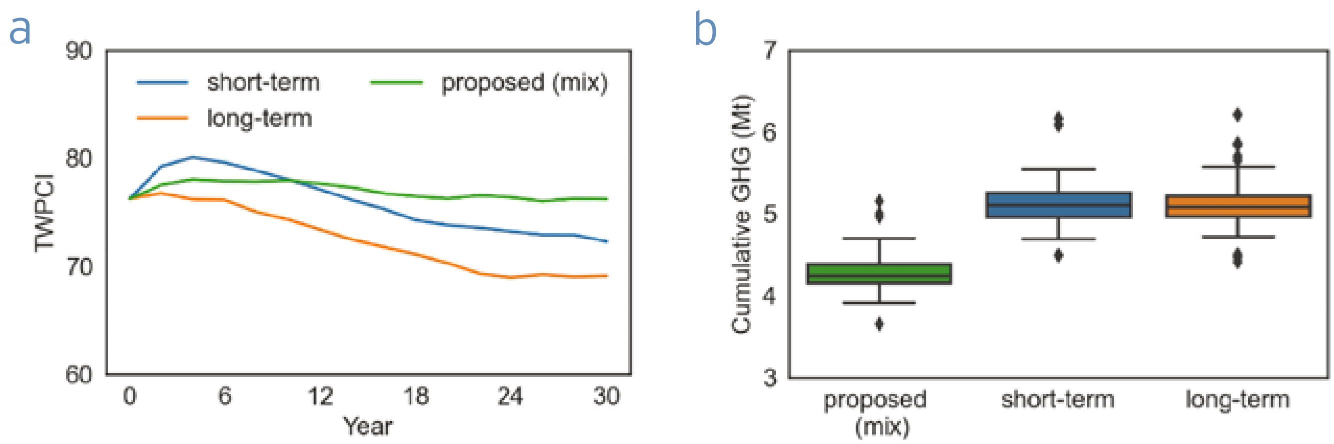


Figure 2. Iowa U.S. Route network (**a**) Traffic-weighted Pavement Condition Index (TWPCI) and (**b**) cumulative greenhouse gas emissions (GHG) over the analysis period when different treatment actions are considered. High TWPCI values indicate better road conditions. Green indicates the proposed MIT scenario that employs both short- and long-term solutions while blue and orange indicate scenarios that use solely short- and long-term solutions (including reconstruction), respectively.

array of paving activities.

Paving activities can be roughly grouped into three categories: minor, major, and reconstruction. Minor activities can include diamond grinding and asphalt overlays of up to 4". Major activities include concrete overlays, asphalt overlays in excess of 4", and complete concrete and asphalt reconstruction.

Despite the options available, it's common to rely heavily on minor maintenance activities that minimize initial cost. Solely utilizing these minor practices, however, tends to result in only short-term gains in performance. Major and reconstruction practices instead offer medium- and long-term benefits by sustaining better performance and minimizing road quality-induced vehicle fuel consumption—but they are also more expensive.

CSHub has found that striking a balance is important. A mix of minor, major, and reconstruction activities (a 'mix of fixes') provides decision-makers with the flexibility to manage uncertainty and meet the specific needs of each pavement segment. CSHub's ADAPT case study of Iowa found that, with a typical budget, **a mix of fixes offers 5% higher performance and 20% less GHG emissions over 30 years** than a strategy that would have used solely minor treatments (See **Figure 2**).

Strategy 2: Long-term Planning Horizon

Currently, many DOTs plan their maintenance on a year-to-year basis, conducting cost-benefit analysis for treatment actions over shorter periods. This is done, in part, to manage the challenges associated with predicting and managing long-term uncertainties. CSHub, however, has found that planning maintenance over far longer periods—as long as 20 years—is not only feasible but also improves performance and cost outcomes.

In the Iowa case study, the CSHub ADAPT model found that increasing the segment analysis period—the period over which potential treatment actions are evaluated and then selected on lowest cost—would generate numerous long-term benefits. Compared to a 5-year analysis period, **a 20-year analysis period improves performance by 6% and reduce GHG emissions by**

20% through better road quality. The 20-year analysis period quickly eclipses the other two analysis periods to demonstrate superior performance throughout the majority of the 30-year case study (See **Figure 3**).

A longer planning horizon introduces opportunities for more long-term paving activities—and that is why its benefits are so marked. With the strategic use of long-term activities, DOTs can eliminate repeated spending on minor paving activities, resulting in the lower total costs and superior road quality shown in the case study.

Strategy 3: Diversity of Materials

When investing, a diversified portfolio minimizes financial risk. The same is true when selecting paving materials: diversifying paving material selection can mitigate risk by protecting DOTs from fluctuations in any single material price.

The benefits of a diverse material portfolio extend far beyond risk reduction. Such a strategy also stimulates competition between paving industries, which can lower material unit costs, and gives agencies the flexibility to adapt to their projects' changing demands.

For most U.S. states, an opportunity exists to diversify paving material portfolios by introducing greater paving material competition. In fact, in several regions virtually no competition exists between paving industries, with most states spending a majority of their budget only on asphalt pavements.

A CSHub nationwide analysis of paving material diversification found that **if states spent 20% more of their paving material budget on concrete, unit costs of both asphalt and concrete could fall by 8% and 29%, respectively.** As a result, DOTs could **purchase 6% more material**, enabling them to improve more roads on a fixed budget.

Competition can also bring performance and environmental improvements. Iowa, which has the nation's most balanced paving market, presents an opportunity to measure such benefits by comparing the performance of a simulated competitive market (the current situation in Iowa) with those of simulated single-materials markets.

The CSHub Iowa case study found that **the combined use of asphalt and concrete performed**

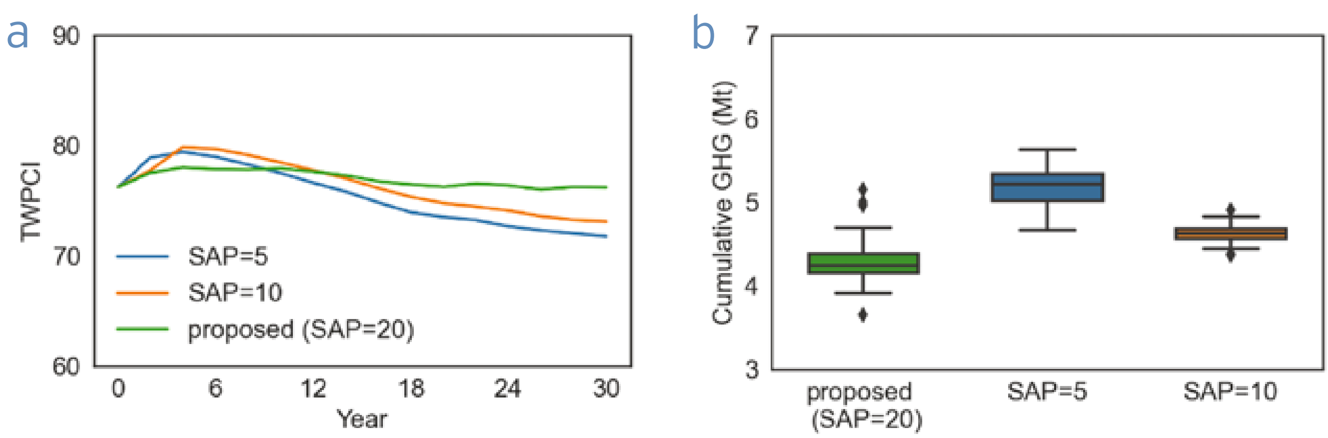


Figure 3. Iowa U.S. Route network (**a**) pavement condition (TWPCI) and (**b**) cumulative GHG emissions over the analysis period when different segmant analysis periods (SAP) are considered. Green indicates the proposed 20-year MIT scenario while blue and orange indicate 5-year and 10-year scenarios, respectively.

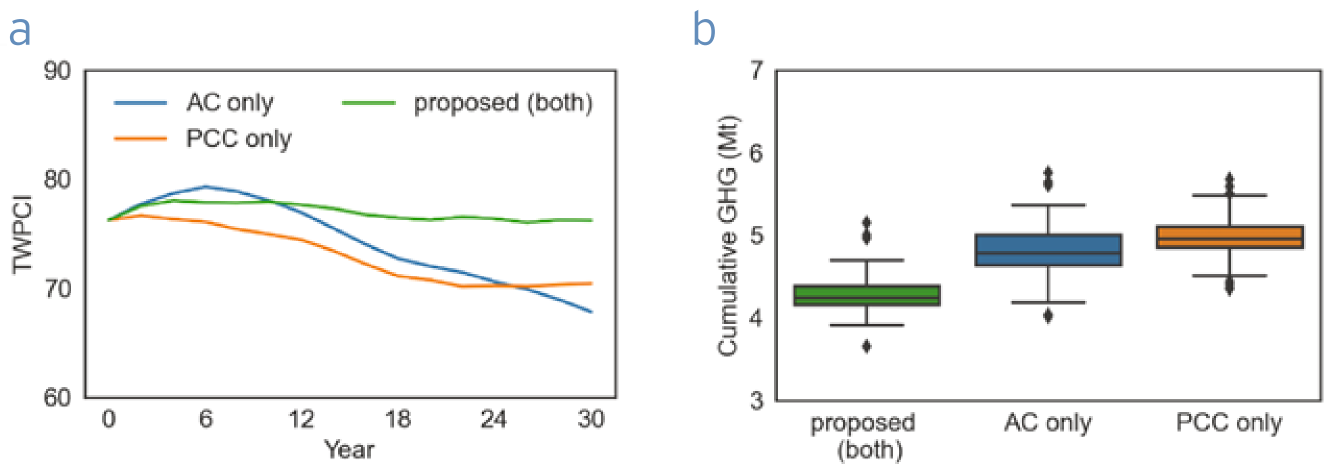


Figure 4. Iowa U.S. Route network (**a**) pavement condition and (**b**) cumulative GHG emissions over the analysis period when using different material selections. Green indicates the proposed MIT scenario that employs both AC (asphalt concrete) and PCC (portland cement concrete) solutions while blue and orange indicate scenarios that use solely AC and PCC solutions, respectively.

11% better than the selection of asphalt alone and 8% better than concrete alone. Climate outcomes improved as well: the superior performance of the combined approach **would reduce road quality-induced emissions by 12%** compared to the asphalt-only strategy (See **Figure 4** on following page).

Building the Future

Confronting uncertainty is daunting. But by addressing it head-on, CSHub has found that it's possible to better prepare pavement networks for the future challenges they will inevitably face.

The ADAPT approach presented here considers uncertainty explicitly and provides three strategies that would each offer numerous performance and environmental benefits. But when combined, MIT found that they can provide an even greater return on every dollar spent, **reducing emissions by 21% and achieving the same performance with a 32% lower budget**.

Bold infrastructure investments, such as the U.S. Interstate System, have yielded enduring benefits. But amidst challenges like climate change, bold investment alone is no longer enough: Managing future risks will mean replacing past spending tools with state-of-the-art alternatives. And as the nation embarks on its next round of infrastructure investment, these new tools can help it attain similarly enduring benefits—and with far greater confidence, sustainability, and economy.

Collaborate with CSHub

CSHub welcomes collaboration. We are open to engaging in pilot programs with DOTs and municipalities to apply our models to numerous pavement networks. **To discuss potential projects, please contact us at cshub@mit.edu.**

Citation

Guo, F., Kirchain, R. (2021). "Improving America's Road Infrastructure by Considering Uncertainty." Topic Summary. Volume 2022, Issue 1.

References

1. American Society of Civil Engineers
2. Congressional Budget Office
3. *Transportation Research D*. Volume 99, October 2021, 103016.

This research was carried out by CSHub with sponsorship provided by the Portland Cement Association and the Ready Mixed Concrete Research & Education Foundation. CSHub is solely responsible for content.