

Sustainable Pavements



According to the Environmental Protection Agency, U.S. road transportation accounts for 83% of greenhouse gas (GHG) emissions from the transportation sector and 27% of all GHG emissions in the U.S. The road system, which requires 350 million tons of materials annually for maintenance, gets a grade of D from the American Society of Civil Engineers (ASCE). The ASCE also reports that congested highways cost roughly \$101 billion in wasted time and fuel annually.

For the foreseeable future, U.S. infrastructure funding will remain significantly below what is required to improve conditions and performance. Because of the

environmental impact of pavements and the economic challenge of building and maintaining them, there is a growing need to better quantify performance and cost over pavements' entire life cycle.

To meet that need, the MIT Concrete Sustainability Hub (CSHub) is developing tools and data for decision makers to evaluate pavement designs and make choices that are both cost-effective and environmentally responsible. CSHub research results are peer-reviewed.

TOOLS FOR SMARTER PAVEMENT DESIGN, CONSTRUCTION, & MAINTENANCE

CSHub researchers are examining the cost and environmental impacts for the full life of pavements and are creating integrated life-cycle assessment (LCA) and life-cycle cost analysis (LCCA) tools that account for the use and maintenance phase of pavements—not just the costs or GHG emissions that occur during initial construction.

- Researchers developed a comprehensive methodology outlining the best-practice concepts for any pavement LCA or LCCA, including accounting for uncertainty in the data used in the analyses. When properly designed, the inputs to both LCA and LCCA models can be taken directly from Pavement-ME—the current standard of pavement design software.
- Analyses of a range of scenarios showed that the contribution of the use phase to the life-cycle GHG emissions of a pavement ranges from 25% to nearly 60%. Higher traffic volumes generally lead to higher use-phase impacts. More specifically, the degree to which PVI contributes to the use phase depends upon both traffic volume and climate.
- The LCCA accounts for uncertainty in initial costs, future price projections, and the timing of maintenance activities. Analyses of a range of scenarios indicate that a life-cycle perspective is important when making pavement design decisions and that the uncertainty in initial cost is the largest driver of uncertainty in overall LCCA results. Better understanding of the variation in initial cost could significantly improve pavement decision-making.
- Scenario analyses also showed that the cost of maintenance and rehabilitation (even when discounted into today's value) represented as much as 45% of the life-cycle cost of a pavement. Ignoring life-cycle costs such as M&R can lead to unwise long-term spending.

The ultimate goal is to create tools that will be embedded in the pavement design process.

PAVEMENT-VEHICLE INTERACTION (PVI)

The CSHub has quantified excess fuel consumption due to PVI—primarily associated with road stiffness and roughness—and has demonstrated significant environmental impacts for pavements over time.

Numerous experimental studies have demonstrated that PVI causes additional fuel consumption, and analyses have shown that the impact of PVI on GHG emissions worsens as roads age.

- A CSHub experimental method uses a novel small-scale approach to look solely at the interaction of the wheel and the pavement and confirms behavior predicted in CSHub models.
- The University of California Pavement Research Center is leading a collaborative effort to review and test existing models of PVI related to pavement stiffness, including CSHub models.
- The CSHub is collaborating with several departments of transportation in the U.S. to evaluate environmental impacts due to PVI at the pavement network level.

Understanding PVI is essential to the analysis of the lifetime environmental impacts of pavements.

ASSET MANAGEMENT

CSHub-developed modeling tools allow engineers to quantify the impact of PVI on vehicle fuel consumption and pavement network greenhouse gas and smog-forming emissions across a network.

- Models show stiffer pavements could reduce fuel consumption up to 3% for the U.S. road network—a savings that could add up to 273 million barrels of crude oil per year and result in an accompanying annual decrease in GHG emissions of 46.5 million metric tons.
- A sample CSHub case study showed a significant impact on fuel consumption due to roughness—an increase of 30,000 gallons of fuel per mile over a 14-year test period.
- Both deflection- and roughness-induced PVI contribute to fuel consumption within a network, but the impact differs by vehicle type. Impact from deflection-induced PVI is higher for trucks, whereas roughness-induced PVI has a higher impact on passenger vehicles. Stiffer pavements in roads with high truck traffic and smoother pavements in roads with high car traffic lead to the highest reduction in fuel consumption.
- Flexible pavement designs must be 25% to 60% thicker to achieve the fuel consumption savings associated with the stiffness of rigid pavements.
- CSHub-developed data-driven models allow researchers to identify the specific lane miles where rehabilitation would result in significant improvements across the network.

CSHub researchers have also developed a network-level pavement management model that can be used to support asset management allocation decisions. The tool accounts for present and future cost uncertainty and also a wide range of pavement maintenance and rehabilitation alternatives. The risk-based allocation model shows the significant cost and performance benefits of considering uncertainty and diversification in pavement maintenance and rehabilitation strategies.

Finally, CSHub researchers are studying the impact of intra-industry competition within a state's paving industry. Initial analyses suggest that paving prices in states with robust spending on multiple paving materials are partially driven by the presence of that competition in that state.

Asset management decision support is crucial to efficient allocation of tax-payer resources.

IMPROVING CONCRETE PAVEMENTS

CSHub researchers developed a cost-effective analysis to determine whether or not a given environmental reduction strategy made economic sense for concrete pavements. Among the strategies evaluated, two significantly reduced embodied energy: increased fly ash and optimized design. They were found to decrease GHG emissions by approximately 10% and 17%, respectively, while also lowering initial construction costs.