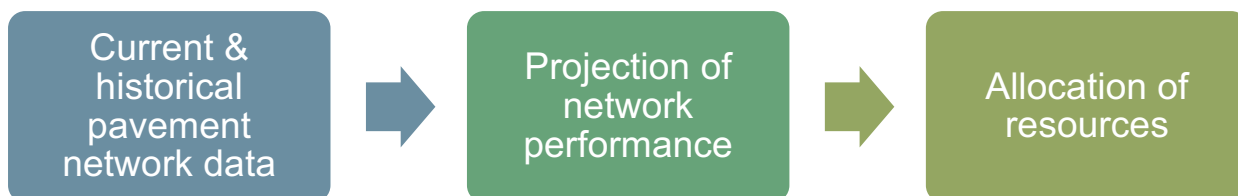


Performance-Based Planning: Pathways to Economic and Environmental Sustainability of Pavement Management Systems

Roadway infrastructure across the United States is in desperate need of repair. But with funding shortages, departments of transportation (DOT) must continually do more with less. These funding concerns, coupled with requirements set forth by the Moving Ahead for Progress in the 21st Century Act (Map-21), have pushed transportation agencies to adopt quantitative tools to plan their infrastructure projects. **Pavement management systems (PMS)** are a vital tool for DOTs to collect, analyze, maintain, and report data on the condition of pavements in a network. **Performance-based planning (PBP)** for pavements involves the use of data from a PMS to project the performance of the network and implement strategies to meet performance and spending targets. It is a strategic approach to allocate limited resources where they can have the greatest impact.

While most DOTs already employ at a minimum a basic PMS, these systems can be enhanced to more efficiently allocate funding and lessen environmental impacts through the use of PBP. The key elements of this process are outlined in the illustration below. Current and historical data exist in the PMS, but the projection of network performance and allocation of resources in PBP is a complex process that is fraught with uncertainty and rarely considers environmental impacts. CSHub researchers are developing new approaches to improve the methods used in pavement PBP by considering uncertainty and explicitly incorporating greenhouse gas (GHG) emissions from vehicles and the construction and maintenance of pavements. The researchers have gained valuable insights by applying these methods to data from DOTs.



CASE STUDY: NORTH CAROLINA

In a study conducted in collaboration with the North Carolina Department of Transportation (NCDOT), CSHub researchers analyzed the NC interstate system using data from the NCDOT and PBP models. They identified the impact of key parameters in PBP on projected NC interstate system performance using a range of different preservation (thin asphalt overlays and concrete diamond grinding), rehabilitation (thick asphalt and concrete overlays), and reconstruction techniques. The study highlights significant opportunities to enhance the performance of the network using pavement condition, economic, and environmental metrics. Specifically, the analyses showed the benefits of leveraging four main strategies.

A mix of pavement types achieves the same performance at a lower cost

- Figure 1 shows how a diverse set of paving strategies that incorporate a mix of both asphalt and concrete solutions improves network performance compared to constrained decision trees. This result is a direct outcome of accounting for future uncertainty in paving prices and deterioration.
- The benefits of diversification in pavement networks resemble the benefits of diversification in a financial portfolio where a mixture of stocks and bonds can mitigate the impacts of volatility. Similarly, DOTs can alter investment strategies at moments of spiraling costs for some MRR actions and suppressed price levels for others.
- To maintain current network conditions with a mix of pavement types would require an annual budget of \$130 million. To maintain this same level while using exclusively concrete or asphalt would require budgets of \$180 million. (See Figure 1)

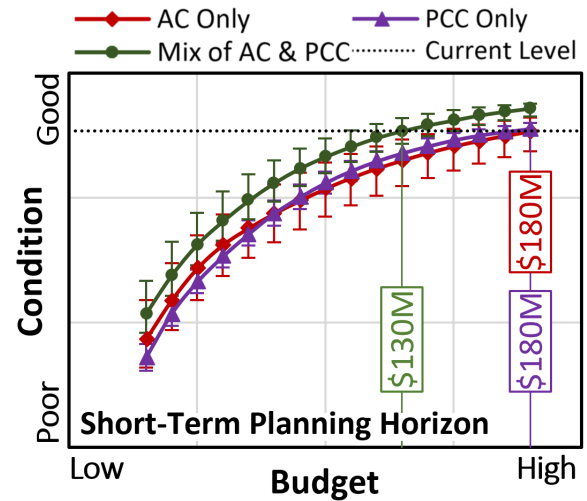


Figure 1 — Network conditions after 50 years versus annual agency budget, with PMS allocation policy to only use asphalt concrete (AC), portland cement concrete (PCC), or a mix of the two solutions to maintain the pavement network with short-term planning horizon.

A mix of short-term and long-term fixes improves performance and lowers cost

- To optimize future spending, sustain long-term pavement network conditions, and minimize GHG emissions, agencies must purposefully employ a range of short-term, medium and long-term treatment actions, also known as a “mix of fixes.” (See Figure 2)
- By allowing cost-benefit analysis and network optimization to determine a set of diverse treatments, system performance improved in comparison to conventional decision trees that do not change with fluctuating cost and performance over the lifecycle.
- Using a “mix of fixes” could maintain the current level of network conditions with an annual budget of \$50 million. By comparison, using exclusively short-term preservation or long-term rehabilitation and reconstruction would require budgets of >\$180 million and \$70 million respectively to achieve the same network conditions. (See Figure 2)

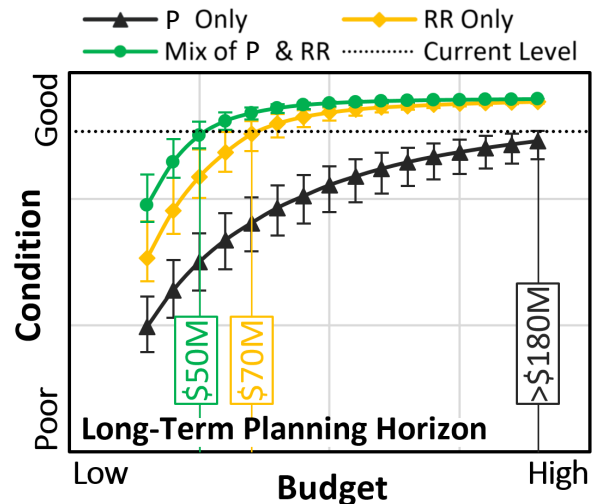


Figure 2 — Network conditions after 50 years versus annual agency budget, with PMS allocation policy to use preservation (P), rehabilitation and reconstruction (RR), or mix of all solutions with a long-term planning horizon.

Sufficient budgets and planning horizon can decrease GHG emissions while improving performance

- It was found that a long planning horizon (PH) of over 10 years is key to reducing long-term spending and GHG emissions. Long-term planning horizons result in long-term rehabilitation and reconstruction activities, improved network performance and reduced risk over the network life, as seen in Figure 3.
- With a 20-year PH, current network conditions and GHG emission levels could be achieved with an annual budget of \$50 million. To achieve similar levels, a 5-year PH and a 1-year PH would require budgets of \$90 million and \$130 million respectively. (See Figure 3)

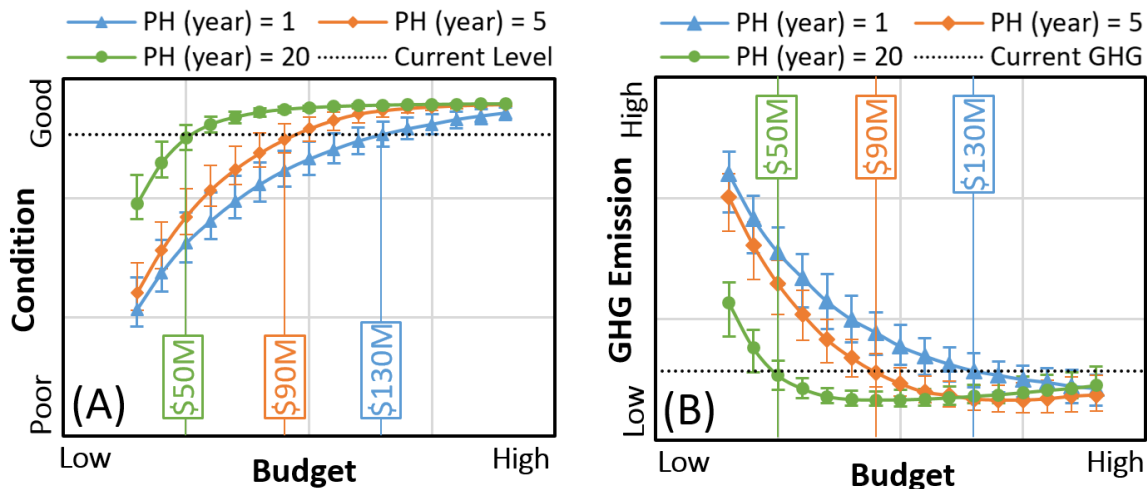


Figure 3 — Impact of budget and planning horizon (PH) on (A) network condition and (B) GHG, when all PRR activities are used for allocation. Markers represent the 50th percentile, with the error bars representing the 5th and 95th percentiles.

A critical budget defines the level of funding required to maintain the condition of the pavement network

- There exists a critical budget that defines the agency’s ability to improve system performance and reduce GHG emissions. This budget-performance relationship is not linear, resulting in significant performance loss with below-critical funding while showing only moderate performance gains in overly funded systems, as shown in Figures 1-3.
- Though initial investment may prove high when implementing a long planning horizon and a mix of fixes, the desired performance level is ultimately achieved at a lower long-term cost.

SUPPORTING PUBLICATIONS

Akbarian M., Gregory J., Kirchain R., Ulm F.-J., Economic and Environmental Analysis of Pavement Management System Parameters for Performance Based Planning Opportunities: A Case Study of North Carolina’s Interstate System, Transportation Research Record, Conference Proceeding, 2019.

Swei O., Gregory J., Kirchain R., "[Does Pavement Degradation Follow a Random Walk with Drift? Evidence from Variance Ratio Tests for Pavement Roughness](#)", Journal of Infrastructure Systems, Vol. 24, No. 4, 2018.

F. Guo, O. Swei, J. Gregory, R. Kirchain, "[Sensitivity Analysis of Performance Metrics to Different Parameters in Pavement Management Systems](#)", the Transportation Research Board 97th Annual Meeting Compendium of Papers, Washington, DC, January 7-11, 2018. (PDF)

Swei O., Gregory J., Kirchain R., "[Pavement Management Systems: Opportunities to Improve the Current Frameworks](#)", Transportation Research Board 95th Annual Meeting, No. 16-2940. 2016.

A complete set of publications may be found at: <https://cshub.mit.edu/pavements>