CASE STUDY

# Maximizing Project Benefit Through Performance-Based Practical Design

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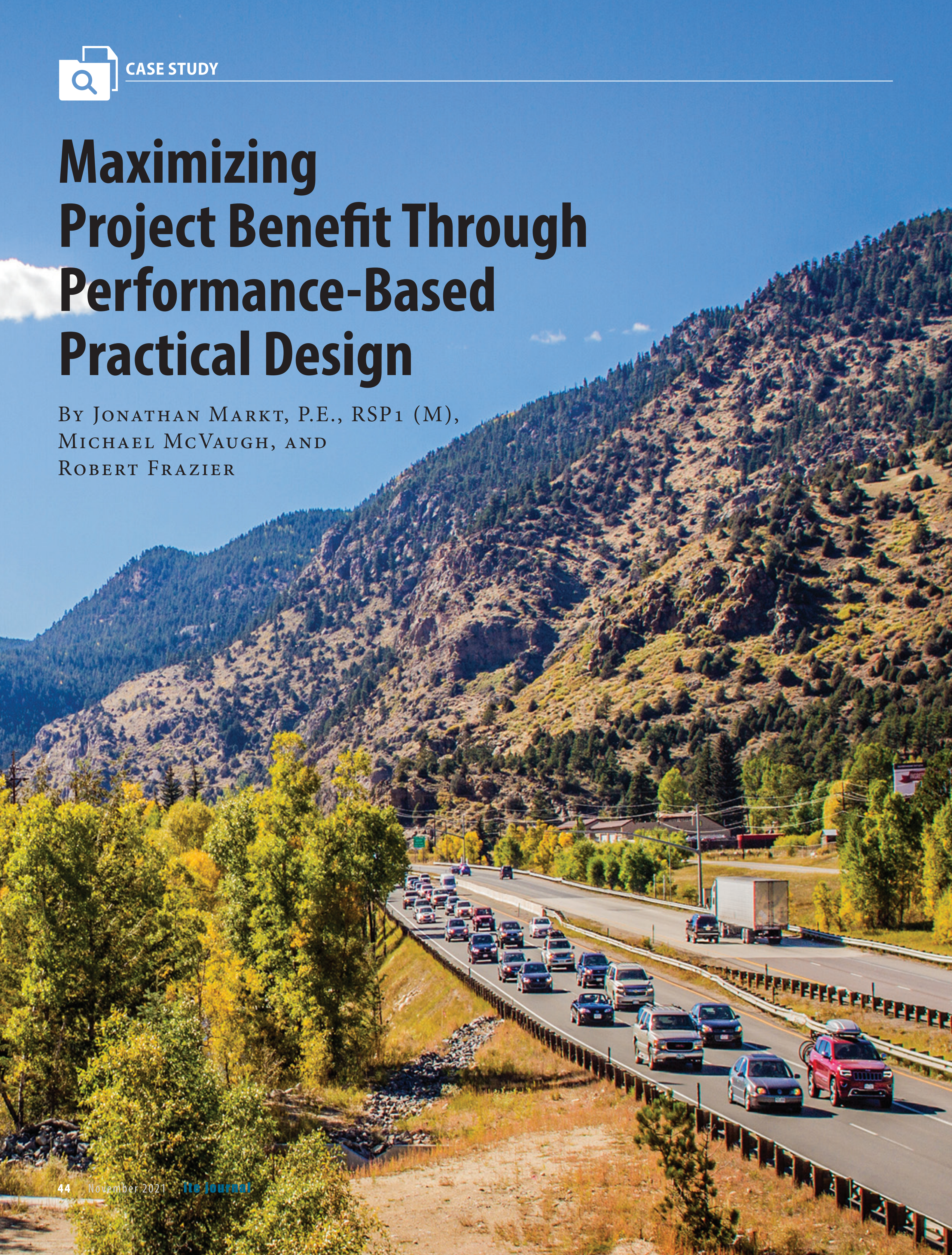

A 1.2-mile [1.9 kilometer (km)] stretch of the two-lane U.S. Route 550 was set to be widened in southwest Colorado, USA, providing safety and mobility improvements for the corridor used by tourists and for gas and oil transportation out of the San Juan Basin. This strategic project had been envisioned since the early 1990s to provide a four-lane highway with a grade separated interchange where US 550 and US 160 meet.

Colorado Department of Transportation (CDOT) officials realized the connection to the interchange as proposed would entail moving 1.2 million cubic yards of embankment—an expensive prospect that had transportation officials recognizing taxpayer funds could be better spent to enhance other project features, rather than simply moving earth. As part of the design-build process, the project team took a fresh look at the proposed customer and agency benefits of the improvements through a performance-based lens to maximize the value gained while staying within the project's target budget.

The project's purpose and need was to improve safety, mobility, and access control. Following traditional American Association of State Highway and Transportation Officials (AASHTO) design standards meant widening the highway to the full extent, which resulted in substantial right-of-way impacts and earthwork. CDOT began looking at the 2018 seventh edition of *A Policy on Geometric Design of Highways and Streets* (The AASHTO "Green Book") more closely and chose to use a flexible, performance-based design approach to narrow the roadway template while still staying true to the purpose and need. Using a data-driven analysis process to

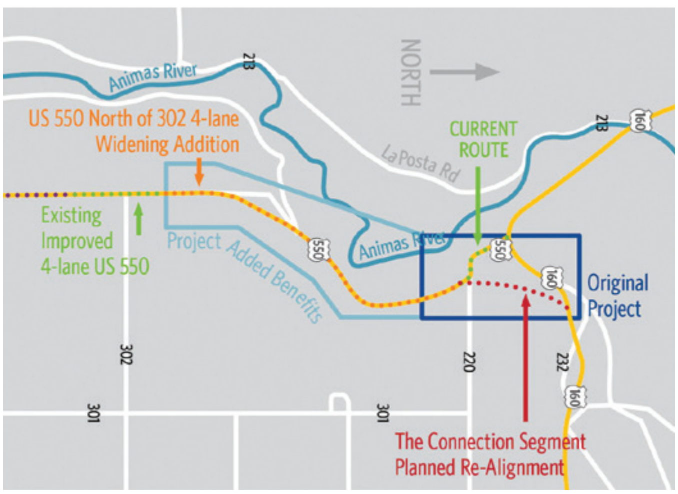


*Figure 1. Performance-based practical design thinking allowed CDOT to improve 4 miles (6.4 km) instead of the original 1.2 miles planned.*

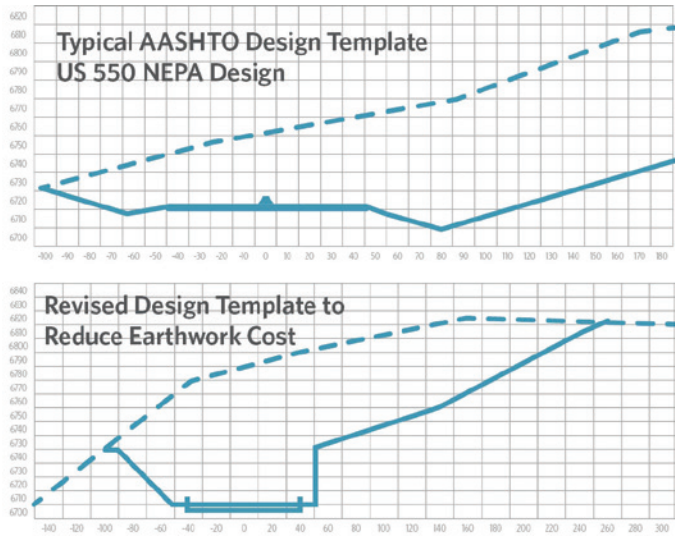


*Figure 2. Using the flexibility within AASHTO standards, CDOT reduced earthwork costs by 40 percent.*

## What Is Performance-Based Practical Design?

Performance-based practical design is a flexible approach that takes into account the most pressing needs of a project. The approach encourages targeted improvements that accomplish the project's purpose and need—say, decreasing crashes or delays—through a data-driven analysis of needs and performance, rather than simply conforming to a traditional full criteria design.

This can be applied to a variety of assets to maximize user benefits of the roadway. Using a targeted approach to improve performance without unnecessary construction costs can save substantial portions of a project's budget—and that's money that could fund additional safety upgrades or other needed improvements.

inform their decisions, CDOT officials realized they could meet the project goals while reducing the earthwork quantity by 40 percent. The cost savings would in turn allow them to extend the widening project an additional 2.8 miles (4.5 km) within the existing budget constraints. Those extra miles extended the project to where the highway already had four lanes. The overall benefit of this design flexibility was being able to improve more roadway, which provided greater safety and mobility benefits to the user without increasing agency and taxpayer cost.

### Maximizing Project Value

CDOT's example embodies the principles of performance-based practical design, an approach that empowers agencies and the public to get the most value for their transportation dollars, regardless of funding levels.

"Through those engineering decisions, and with the input from the project team, we were able to dramatically increase the scope of the design-build project while still meeting the project goals," said Kevin Curry, CDOT's Region 5 Program Engineer. While remaining within the target budget, the new project design more than doubles the length of the wider, safer highway, resulting in projections to reduce crashes by 50 percent.

This performance-based practical design approach gives agencies and engineers proven methods to target the most effective and cost-efficient upgrades, rather than simply applying a standard template approach to roadway design.

"We're always looking to maximize project value to our customers out of every project," said Curry. "At the same time, we certainly always have safety in the forefront of every design."

### New Data and Tools, Same Consistent Design Framework

The industry shift toward performance-based practical design is enabled, in part, by tools and data collection capabilities that have come into common use in the past decade.

Agencies seek to make defensible decisions and use design manuals and project development processes to foster consistency in design. As performance-based practical design emerges, a common process or framework for data and tools is being used to establish consistency in process. A recommended framework designers and owners can follow uses these five steps:

1. Data and design impacts
2. Performance models
3. Outputs/metrics
4. Benefit/cost analysis
5. Data-informed decisions

Using traditional AASHTO design standards, a designer may select a design parameter from a table and move straight into detailed design. This approach skips the performance modeling through benefit/cost steps, which quantify the benefits and drawbacks of that design decision. The performance-based practical design framework instead assists the designer in consistently applying all five steps for more nuanced decision-making based on project-specific outputs.

Industry advancements enable a comprehensive examination of the predicted outcomes for a range of possible design options. The engineering profession now has safety performance functions to predict crashes and cost beneficial mitigation strategies for many types of roadways and intersections thanks to the AASHTO *Highway Safety Manual* (HSM) and the Crash Modification Factors (CMF) Clearinghouse. Designers have more effective operational models that can predict how transportation professionals will impact the system both at a system level and a local level. And designers have new ways of quantitatively predicting travel time reliability developed in the last decade, such as the Second Strategic Highway Research Program (SHRP 2) Reliability Data and Analysis Tools that are now being more broadly applied.[1] These new methods and data sources allow designers to better predict the actual impacts of their decisions on the number of crashes, travel time reliability, asset life cycle, emissions, and other important metrics.

## Where to Start

***If your agency does not yet use PBPD,*** these are some of the types of projects your agency might want to start with.

- Shoulder and lane width improvements are a common place to start using performance-based practical design as described in examples in this article.
- Pavement asset management for resurfacing projects show that it is often more cost-effective to maintain pavement than to wait to reconstruct the pavement, and data can help prioritize areas to maximize the longevity of the pavement.
- Safety projects can use crash data, information, and analysis to allow a laser focus on the biggest problem spots and the most cost-effective solutions.
- Intersection design is a good place to optimize mobility and reliability—the simple addition of a turn lane or conversion to a roundabout can reduce the number and duration of vehicle stops and improving safety, thereby maximizing user benefit.

***If you are a practitioner,*** you should think through the metrics that are critical for your project and how you can apply the PBPD framework to evaluate them and make effective decisions. A practitioner should start by learning what the underlying conditions are that the roadway is experiencing. Is it a failing asset, or does it have safety deficiencies, operational deficiencies, or a combination of problems? Once this is understood, then using the data, analysis, and mitigation tools, the practitioner should begin identifying the most cost beneficial solutions to use to maximize user and agency benefit.

## Iowa DOT's Shoulder Design Analysis

Another example of applying a performance-based practical design approach was on a roadway project in Iowa, USA. The project design included full depth pavement reconstruction and increased shoulder width with flattened sideslopes. The increased shoulder width and sideslopes were selected from a standard design parameter table. Without performance models, the design process would not have considered that the existing gravel shoulder and sideslopes had a history of limited crashes. Thus, a performance-based practical design process using AASHTO HSM methods was conducted. Using HSM Part C methods, the existing 6-foot (ft.) gravel shoulders and 3:1 slopes were found to have CMFs of 1.01 and 1.0 for shoulder width and type and roadside design, respectively (see inset). The build condition of 6-ft. paved shoulders and 6:1 slopes yields CMFs of 1.0 and 0.87. While a reduction in crashes of 14 percent ((0.87-1.01)/1.01) was calculated, further evaluation showed the predicted safety performance function (HSM Equation 10.6) yields a predicted crash frequency of 2.5 crashes per year over the project length due to low average daily traffic.

The analysis identified that the project benefits were not consistent with the project costs. The user safety benefits for the shoulder and side slope enhancements was $700,000 USD based on a benefit monetization process. In the benefit/cost analysis, the safety benefits for shoulders and side slopes were far less than the project costs to construct these enhancements. This Iowa DOT "post-construction" quantitative analysis confirmed the assumption of the agency that the user benefits of the improvements were out of sync with the project costs. This resulted in a reexamination of the scoping process to best suit the project's overall purpose and need and maximize value to the users. This successful application provided the basis for the use of a performance-based practical design approach on future rural projects.

## Focusing on Safety Performance

Existing Shoulder CMF

| | | |
|---|---|---|
| | Shoulder | 1.01 |
| | Roadside 3:1 slopes | 1.0 |

Build Condition CMF

| | | |
|---|---|---|
| | Shoulder | 1.01 |
| | Roadside 6:1 slopes | 0.87 |

Calculated crash reduction 14 percent ((0.87-1.01)/1.01).

With ADT = 1,200 vehicles/day, predicted crash frequency of proposed shoulder and side slope improvement is minimal (2.5 crashes per year).

## Nebraska DOT's Experience

The examples of design beyond the defined purpose and need are plentiful; this fact was made clear through an experience with the recent design policy study for Nebraska DOT. The project team looked at six projects comparing a traditional design that employed the standard state design parameter table to a performance-based practical design evaluation. The projects reviewed were largely driven by the need to maintain the pavement asset. All were two-lane highways where our analysis focused on how shoulders and roadside earthwork were designed. The primary approach at the design stage was to avoid additional earthwork from a pavement grade-raise by introducing a slight shoulder reduction to tie grading into the existing foreslope. Reduction in shoulder width can be offset by increasing the paved portion of the shoulder and/or adding rumble strips.

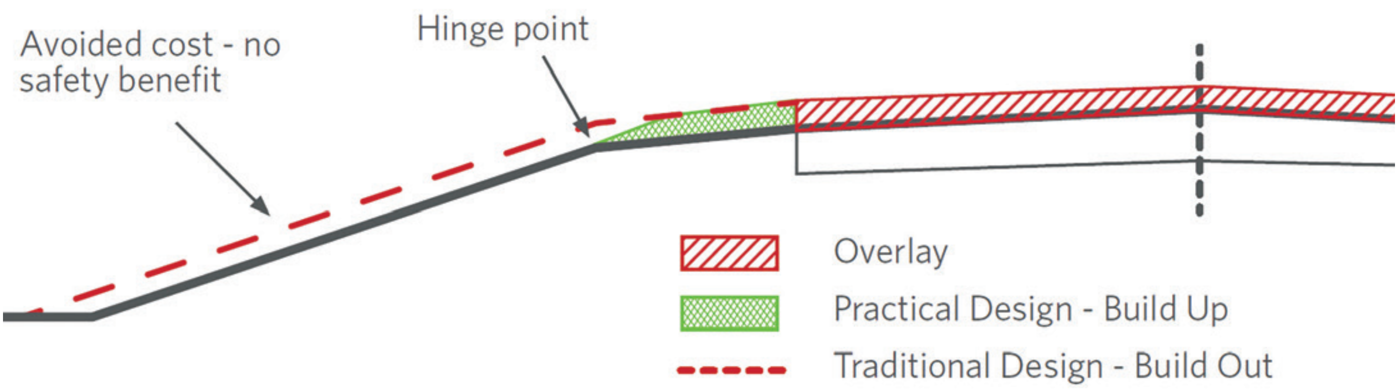


*Figure 3. Careful analysis of safety benefits supported practical design decisions.*

The review team used the existing HSM tools like the NCHRP 17-38 Smart Spreadsheets to complete crash prediction analysis of geometric improvements including shoulder type, shoulder width, and roadside slope and to consider the effect of recent crash history.[3] Across these projects, the enhancements under consideration were predicted to prevent less than 0.1 crashes per year regardless of the design. The safety analysis justified a less aggressive design that was slightly different from the applicable design standards. This was because the more costly improvements were found to provide a limited, measurable safety benefit over the alternate performance-based practical design.

At the corridor level, the user benefits and agency costs were combined to establish a net present value (NPV) for the proposed projects assuming one alternative as a traditional design and the other as a practical design. To answer the policy question "Is practical design a better investment for this corridor than a traditional, standards-based design?" the team combined the present value (PV) calculations as follows:

$$\textit{Incremental NPV} = (\textit{User Benefits}_{PV,\ Practical} - \textit{Construction Safety Costs}_{PV,\ Practical}) - (\textit{User Benefits}_{PV,\ Traditional} - \textit{Construction Safety Costs}_{PV,\ Traditional})$$

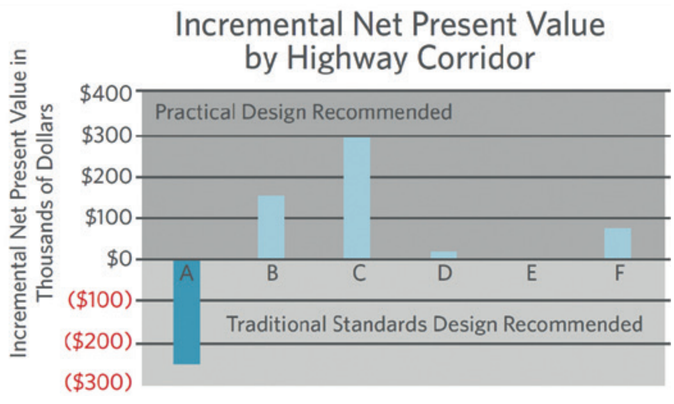


*Figure 4. In five of six corridors, the process recommendation identified the performance-based practical design as the preferred option by benefit-cost analysis.*

The results of the quantitative corridor level analysis (shown in Figure 4) indicated decreased corridor construction costs ranging from $40,000 to $300,000 in five of the six corridors by using the performance-based practical design approach. Based on the performance-based practical design efforts to date, Nebraska DOT is implementing a revised design policy and has developed a performance-based practical design spreadsheet tool for roadway designer use.

## Industry-Wide Shift

The U.S. Federal Highway Administration (FHWA) embraced performance-based practical design concepts in its *Flexibility in Highway Design* document, and AASHTO reflects this in the HSM.[3] In late 2020 when announcing rulemaking on *Design Standards for Highways*, FHWA said, "These proposed design standards provide a range of acceptable values for highway features, allowing for flexibility that best suits the desires of the community while satisfying the purpose for the project and needs of its users."

AASHTO's Green Book is increasingly referring to performance-based design, allowing state DOTs flexibility to adapt and apply the spirit and intent of industry standards in a more context-sensitive approach rather than simply the rigid letter of the standard. States frequently confer with their counterparts in other states who are moving forward with adopting these approaches and can share how modeled outcomes compare to real outcomes. In 2020, a synthesis of published state practices in performance-based practical design was compiled for Kansas DOT, including 16 states in gray on the map below (Figure 5).

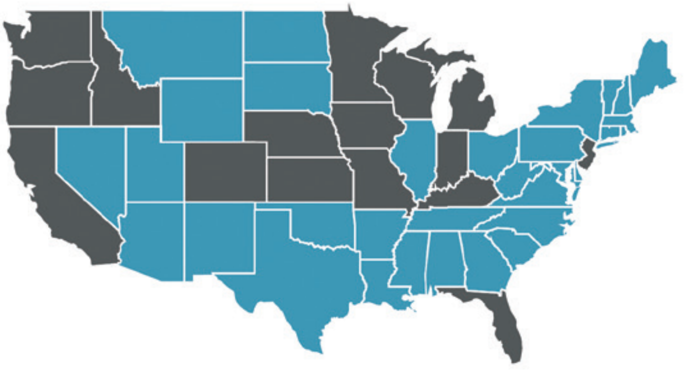

*Figure 5. Sixteen U.S. states were surveyed to assess their use of performance-based practical design techniques.*

The synthesis found that to be successful, it helps to have a champion at the agency level. And it's imperative to create data-driven tools that are useful to the design workforce to help guide the engineering judgement and consistent data-driven and research-based application of performance-based practical design that is needed. For example, a tool that allows designers to input information they already have, such as lane width, and then calculate cost/benefit, can expedite the analysis for the engineer while standardizing the process and making it accessible across the agency (see Figure 6). This approach improves benefits across the system, targeting funding only to necessary improvements and using the remainder for additional projects that also need those dollars.

**Step 7 - Design Mode: Refine Design Alternatives**

*Define design alternatives and project costs. it is recommended left shoulder width be set equal to right shoulder width for design. The output results are shown in the table in "Macro Output" tab.*

| Design Geometry | Alternative 1 ☑ | Alternative 2 ☑ | Alternative 3 ☑ | Alternative 4 ☑ |
|---|---|---|---|---|
| Lane Width (ft) | 11.0 | 11.0 | 11.0 | 12.0 |
| Right Shoulder Width (ft) | 3 | 3 | 3 | 6 |
| Right Shoulder Type | Turf | Paved | Turf | Composite |
| Left Shoulder Width (ft) | 3 | 3 | 3 | 6 |
| Left Shoulder Type | Turf | Paved | Turf | Composite |
| Sideslope | 1V:3H | 1V:3H | 1V:4H | 1V:3H |
| Construction Cost ($) | $5,193,037.39 | $5,894,080.94 | $5,278,201.20 | $6,243,228.12 |
| Total Project Length (mi) | 13.017 | 13.017 | 13.017 | 13.017 |

*Figure 6. Calculator tools such as this streamline designers' work by estimating costs based on design parameters.*

## Benefits

Our industry is in the midst of a strategic shift to make better use of data and analytics, allowing progress toward performance-based practical design. Agencies around the country are seeing benefits—cost-effective projects resulting in focused improvements that prevent severe crashes and increase reliability systemwide. As Colorado's US Route 550 project shows, funding can beneficially impact much more of the system when the design is targeted to solve the major challenges. The results are strong evidence of this tool; reducing the earthwork saved more than $7.5 million USD, which allowed CDOT to more than double their roadway improvements, creating greater benefits that will benefit users systemwide.

That's sound engineering economics. **itej**

## References


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