NCHRP REPORT

Evolutions in the Geometric Design of Highways and Streets

Integrating Performance-Based Analysis

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Highway and street geometric design has evolved significantly in the past century, and the movement toward performance-based approaches is reaching practitioners. Transportation design has incorporated performance-based approaches for many years, primarily in relation to materials such as pavement or steel. Results from projects sponsored by the National Cooperative Highway Research Program (NCHRP) are bringing these approaches to highway and street geometric design.

Performance-based analysis allows professionals to consider and recommend solutions that are more effective and adaptable to the context of a project than those based on compliance with a nominal dimensional value from a design standard or specification. Geometric design solutions, for example, can be developed, assessed, and advanced based on their support of the desired outcomes for the project. This can lead to customized solutions and can help guide project decision making. Advances in performance-based methodologies support context-sensitive and practical solutions to meet project needs and to maximize investments.

Sources of Standards

Early roadway design focused on the quality of travel and on adapting to weather. Early in the history of automobiles, low traffic volumes and relatively low speeds made the quality of travel and year-round use the priorities. As traffic volume grew, and motorized vehicles became a dominant transportation mode between 1920 and 1940, vehicle designs advanced,

PHOTO: PIMPINELLUS, WIKIMEDIA COMMONS

The eastern span of the San Francisco–Oakland Bay Bridge was replaced in 2013 by a self-anchored suspension bridge that can withstand the largest earthquake expected in a 1,500-year period. Agencies are incorporating more performance-based approaches such as seismic design into highway infrastructure.

Photo: New York Public Library

The "modern highway" of the early 20th century adapted quickly to automobile use; most transportation policies focused on design uniformity across jurisdictions.

speeds increased, and highway and street design practices evolved to react and to adapt.

Transportation policies emphasized design uniformity and consistency on similar roadway types between the states. This allowed consistent construction practices, materials, and a uniform experience for roadway users. The design of facilities was uniform and consistent, regardless of jurisdictions, but the standards did not necessarily imply or consider a level of safety performance.

Standards evolved beyond consistency in dimensions and began to signify quality of performance in operation or safety. In the late 1960s and 1970s, groups such as the Highway Research Board—predecessor to the Transportation Research Board—moved beyond materials testing to assess user needs and human factors and to establish design values focused on operational outcomes and safety performance. Eventually, the Federal Highway Administration (FHWA) established 13 roadway design criteria to provide operational uniformity and design consistency, with the intent to attain desired safety performance.

Need for Flexibility

The evolution in roadway design has produced high-quality roadways serving a range of users and vehicle types. Applied research results have helped to quantify design criteria based on observed operations and safety performance. Nevertheless, despite advances in experience and software, the highway and street design process has remained centered on nominal design values or standards. Yet designers need to apply engineering judgment in their design activities, as well as the flexibility inherent in published design guidance.

Roadway agencies have limited financial resources and often develop projects within physical constraints—such as a limited right-of-way in an urban area or an area with specific environmental sensitivities. Constructing roadways categorically to meet design standards, therefore, is not always fiscally possible or reasonable.

Through initiatives such as context-sensitive solutions and performance-based practical design,

NCHRP Publishes Performance-Based Framework for Roadway Design

NCHRP Report 785, *Performance-Based Analysis of Geometric Design of Highways and Streets*, documents a process framework for conducting performance-based analyses of highway geometric design. The methodology is based on understanding intended project outcomes and then considering and selecting the geometric design elements or features that best meet a project's unique context.

The performance-based analysis framework in NCHRP Report 785 helps practitioners develop solutions that

- Facilitate walking, biking, and transit, in addition to serving passenger cars and goods movement;

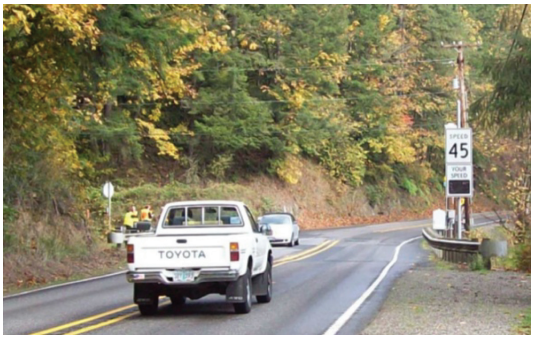
Clear delineation of curves is another low-cost safety improvement.

professionals are able to apply flexible design approaches to construct roadways adapted to the unique needs of each contextual environment. New approaches were needed to support contemporary planning and design decision making. A performance-based approach could support project documentation needs and inform and guide project decision making.

Performance-Based Design

Other technical areas have adopted performance-based approaches since the 1970s. For example, fire safety design shifted from a code-compliance approach to a systems approach—the focus was not on how thick a wall must be but on how much protection the wall could provide and for how long before burning through.

Similar changes in the evolution of seismic design led to changes in engineering practice and research in structural engineering. Engineers recognized that code-based strength and ductility requirements for designing new buildings were not always suitable for evaluating and upgrading existing structures. Applying performance-based engineering methods in seismic structural design meant that a building must withstand a seismic event and minimize the loss of lives even if the structure becomes an economic loss. With this emphasis on making rational business- and safety-related decisions, seismic engineering moved toward predictive methods for assessing potential seismic performance.



Example low-cost safety treatments along a crash-prone stretch of roadway may include guardrails and speed feedback signs.

Varying from Standards

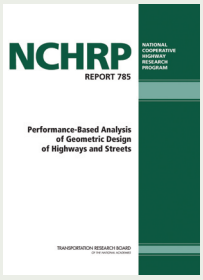
Designers often must consider geometric solutions with dimensions that differ from published values. Historically, engineers have considered design standards or other published nominal values as the measures for comparing and assessing design choices. With this approach, comparing design dimensions to nominally accepted values often becomes a surrogate for relative safety performance.

These decision-making approaches, however, cannot be used to document or support design choices that require variances or to evaluate design exceptions. In some cases, a variant design choice

- Reduce crash frequency and severity;
- Enhance a community's livability;
- Support economic development; and
- Support other context-sensitive and practical design considerations and approaches.

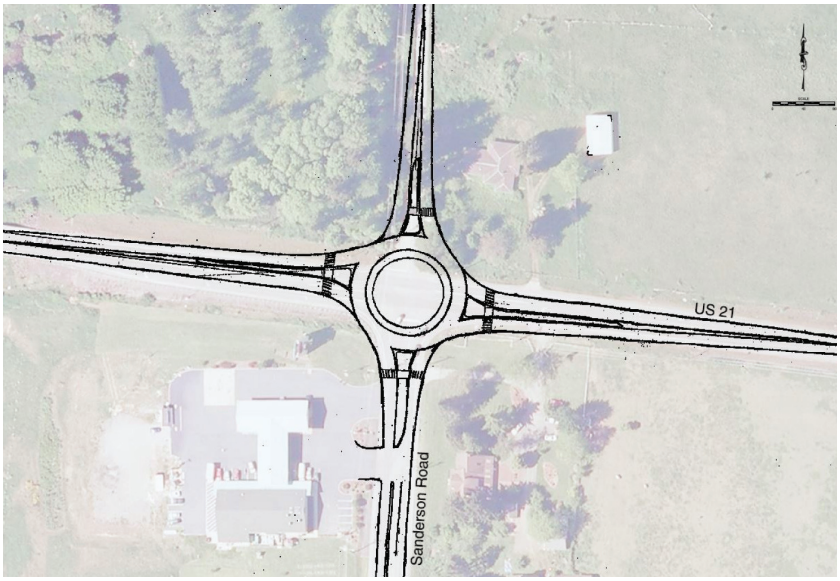
The performance-based approach supports project documentation needs and can inform and guide project decision making while supporting risk management. As NCHRP and AASHTO explore changes and approaches to improve the processes of highway geometric design, performance-based analysis will play a central role.

A performance-based process framework considers the performance factors for particular geometric design elements. Designers can consider and select design values or features based on the impact that the resulting geometric design performance has on the intended project outcomes. NCHRP Report 785 documents ways to consider and apply published design criteria for roadways and to assess a design's performance in terms of accessibility, mobility, quality of service, reliability, and safety.



NCHRP Report 785, *Performance-Based Analysis of Geometric Design of Highways and Streets*, is available from the TRB online bookstore, https://www.mytrb.org/Store/Product.aspx?ID=7394; to view the book online, go to http://www.trb.org/Main/ Blurbs/171431.aspx.

Transportation agencies have limited resources with many competing demands. Performance-based analysis provides designers with new methods and principles for customizing design recommendations from a range of solutions appropriate to any design context or environment. The NCHRP Report 785 framework supports a range of initiatives, including context-sensitive design and solutions, performance-based practical design, flexibility in design, complete streets, and multimodal design. This framework represents a fundamental, positive advance in the evolution of highway and street geometric design.



A roundabout alternative for an intersection project, designed to prevent turning and angle crashes.

may have been accepted depending on its closeness to a published standard or value, assuming acceptable safety risk.

Performance-based analysis is a natural step forward from historical, nominal dimension-based approaches to highway and street geometric design and project development. Practitioners can make informed decisions about the performance trade-offs often encountered in fiscally and physically constrained environments.

The approach is applicable when upgrading or refurbishing a facility and can inform decision making when evaluating and implementing new facilities. NCHRP Report 785, *Performance-Based Analysis of Geometric Design of Highways and Streets* (see sidebar, page 28), advances the principles and methods of roadway design, allowing users to augment standards as the measure of an appropriate design.

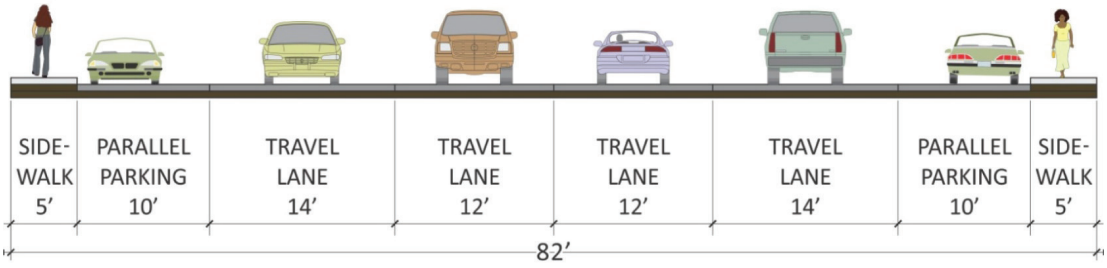
Performance-Based Analysis

Geometric design always has considered a project's context in establishing three-dimensional values for roadway segments and intersections. Engineering judgment and experience, combined with geometric policies—such those established by the American Association of State Highway and Transportation Officials (AASHTO)—have provided a sound basis for effective designs.

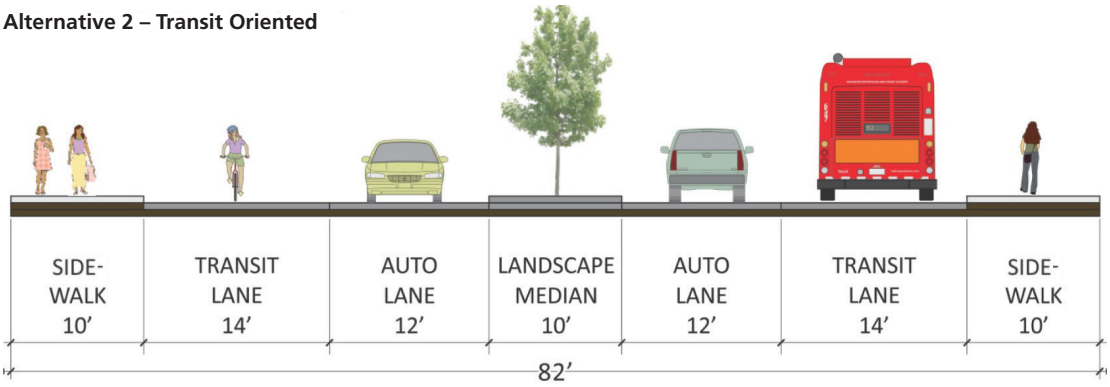
Adapting geometrics to specific conditions has remained a concern, because of the perceived risk of deviating from published values. But attaining full standards can increase project costs and generate other issues; FHWA therefore has emphasized flexibility in highway design. AASHTO has supported design flexibility and a context-sensitive approach but recognizes that more substantial methods for quantitatively assessing alternative options for geometric design were needed.

Practical design focuses on applying design

Alternative 1 – Existing Conditions



Alternative 2 – Transit Oriented



Alternative designs for a roadway alignment (*top*) include a transit-oriented design (*bottom*).

(*continued*)

elements to meet identified project needs in the best way at the greatest value. This differs from a focus on how far a design varies from a published nominal value. Many agencies struggling to manage and operate roadway facilities with limited funding have embraced the concept of flexible geometric design solutions to meet documented project needs—often identified through public and stakeholder outreach—and intended project outcomes.

Practical design and solutions became the means of meeting project needs in a cost-effective and value-oriented way. FHWA is exploring performance-based practical design approaches to quantify and support project design decisions.

Diverse Users and Contexts

Whether an approach is practical design, flexible design, or "3R"—resurfacing, restoration, and rehabilitation—the intent is the same. New initiatives recognize that design choices must consider various users and must balance needs and performance for each unique context.

Complete streets legislation at the state level recognizes the importance of serving each type of road user. Whether a facility serves freight, transit, or pedestrian and bicycle needs, designers must allocate three-dimensional design values to meet a variety of user needs.

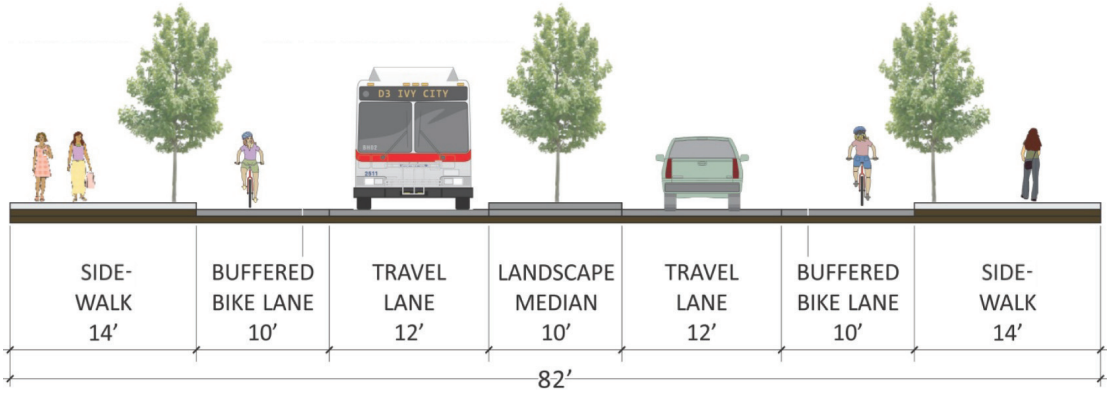
PHOTO: SEATTLE DOT

Bicycle lanes, refuge islands, and on-street parking accommodate all users of this Seattle, Washington, street.

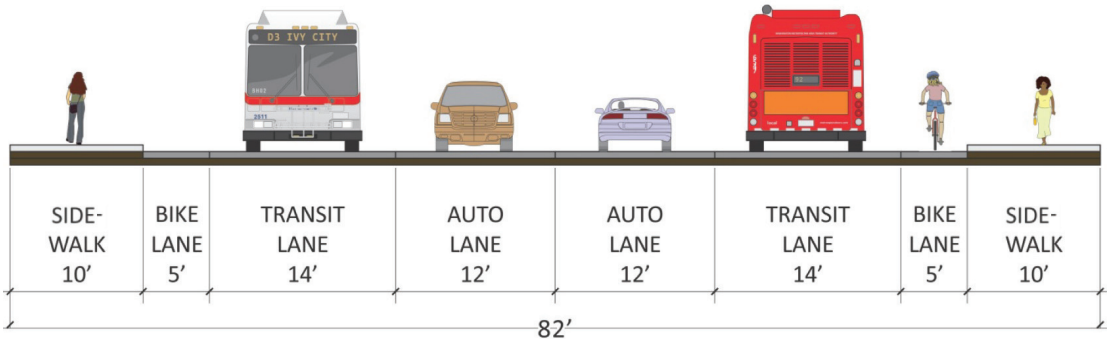
Increasingly, nominal-based, published dimensions have proved inadequate for assessing and recommending design elements and values. Performance-based analysis is a more comprehensive means of supporting geometric design decisions.

Street and highway geometric design is an evolving practice. The emerging methods, philosophies, and approaches integrating performance-based analysis to guide and inform project decisions will lead to community supported, practical, and cost-effective geometric design solutions. Performance-based approaches, integrated into many areas of engineering practice, are becoming available to designers for highway and street design and construction.

Alternative 3 – Bicycle and Pedestrian Oriented



Alternative 4 – Hybrid of Transit, Pedestrian, and Bicycle



Alternative designs for a roadway alignment (*continued*): a bicycle- and pedestrian-oriented design (*top*), and a hybrid design (*bottom*).