Preliminary Investigation

Caltrans Division of Research, Innovation and System Information

Identifying Best Practices for Evaluation of Design Innovations

Requested by
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June 7, 2015

The Caltrans Division of Research, Innovation and System Information (DRISI) receives and evaluates numerous research problem statements for funding every year. DRISI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field. The contents of this document reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the California Department of Transportation, the State of California, or the Federal Highway Administration. This document does not constitute a standard, specification, or regulation. No part of this publication should be construed as an endorsement for a commercial product, manufacturer, contractor, or consultant. Any trade names or photos of commercial products appearing in this publication are for clarity only.

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Executive Summary

Background

Caltrans is interested in identifying effective methods and processes used by other states to evaluate the performance of design decisions. While Caltrans guidance provides flexibility in developing projects, it lacks a systematic process—or published guidance—for evaluating design decisions after implementation. By evaluating design decisions, Caltrans will be able to identify potential improvements to design standards and guidance. Performance measures for evaluating design decisions include safety performance, operational performance and long-term cost.

To assist Caltrans in identifying methods that other state departments of transportation (DOTs) use to evaluate design decisions, CTC & Associates:

- Interviewed seven state DOTs—Idaho, Minnesota, Missouri, New Jersey, Oregon, Utah and Virginia—by phone concerning the criteria they use to evaluate their design decisions when projects are complete (including before and after studies).
- Reviewed research and resources related to evaluating design decisions.

For interviews, CTC started by contacting members of the AASHTO Subcommittee on Geometric Design (http://design.transportation.org/Pages/GeometricDesign.aspx) and interviewed either these members or their referrals. CTC focused on obtaining interviews with Idaho, Missouri, New Jersey and Utah.

Summary of Findings

Consultation with State DOTs

Seven states responded to requests for interviews, including all target states. Three states use all the design criteria listed below, and the remaining states use most of the criteria:

- **Safety:** All states.
- **Operational performance:** All states.
- **Expediting project delivery (schedule):** All states except Minnesota and Missouri.
- **Lower costs of delivering projects (initial costs):** All states.
- **Life-cycle costs:** All states except Virginia.
- **Tort exposure:** Three states (Idaho, Oregon and Utah).
- **Political/external pressures:** Five states (Idaho, Minnesota, Missouri, Oregon and Utah).

All states use safety, operational performance and lower costs as design criteria; design decision factors for most states also include expediting project delivery, lowering life-cycle costs and political/external pressures. Only in the case of tort exposure do fewer than half of states actively take this into account (most interviewees felt like they were covered if they followed their guidelines or design exception processes). Most states provided links to roadway design manuals that detail the use of most of these criteria.

For remaining interview questions:

- **Funding:** Most states use the same design decision processes regardless of funding. Missouri DOT allows certain enhancements, usually aesthetic, for developer-funded projects.
- **Tort laws:** Even those states for which tort laws are a factor, decisions are governed principally by safety and operational performance. States feel that they are covered by following their design guidelines or design exception process.
- **Ranges:** All states use ranges and have a design exception process for decisions outside the range. See New Jersey DOT's Design Exception Manual for an example: http://www.state.nj.us/transportation/eng/documents/DEM/.
- **Post-mortem evaluations:** Most states (except New Jersey and Oregon) conduct post-mortem evaluations for some projects or routinely monitor the operational performance and safety of their system.
- **Post-evaluation candidates:** States do not seem to have a formal process for determining which projects to evaluate. Idaho evaluates those for which the largest changes have been made. In Minnesota, evaluations are usually associated with a design exception. Missouri evaluates innovative improvements such as J-turns.
- **Priorities:** States often have to deal with pressures from outside parties. Idaho has a formal system for prioritizing turn bays. Minnesota rectifies priorities on a project-by-project basis. Missouri allows certain enhancements on developer-funded projects. Oregon works with stakeholders when developing the project purpose and need. Virginia by law weighs such factors as congestion mitigation, economic development, accessibility, safety and environmental quality.

Related Resources

- CTC found several resources related to performance-based practical design, including numerous case studies (see **National Guidance** and **State Guidance**).
- Two ongoing studies, including NCHRP 15-47, are examining flexibility in geometric design, and another the use of risk-based criteria in analyzing geometric design (see **Research in Progress**).
- A recent synthesis by Washington State DOT includes numerous resources related to practical design (see **Related Research**).
- Numerous studies address the use of safety for evaluating design criteria; one examines tort liability in design flexibility and another risk-based reliability analysis for calibrating road design guides (see **Related Research**).

Gaps in Findings

- In most cases, interviewees were unable to provide documentation of the results of post-mortem evaluations.
- While all states rank safety and operational performance as top priorities, the details of how these priorities are balanced in practice against others (such as cost), are unclear. States do not seem to have a formal process for such decisions.

Next Steps

Moving forward, Caltrans could consider:

- Following up with agencies (including Minnesota DOT districts) to obtain documentation, where it exists, of the details of post-mortem evaluations.
- Following up on ongoing research projects, which have expected completion dates in 2015 and 2016 (see **Research in Progress**).

Detailed Findings

Consultation with State DOTs

To gather information about methods other state DOTs use to evaluate design decisions, CTC contacted members of the AASHTO Subcommittee on Geometric Design by email and phone with the following questionnaire:

1. What criteria does your agency use to evaluate design decisions (recognizing that many factors require trade-offs/balancing one for another)?
   a. Safety (nominal vs. substantive, risk, etc.).
   b. Operational performance.
   c. Expediting project delivery (schedule).
   d. Lower costs of delivering projects (initial costs).
   e. Life-cycle costs.
   f. Tort exposure.
   g. Political/external pressures.
2. Are your agency's design decisions the same for projects that are federally/state funded vs. locally/developer funded?
3. How do the tort laws (and liability caps) in your state factor into your design decisions? How does your agency manage risk exposure?
4. Does your agency have design standards involving ranges?
   a. If yes, how does your agency document your design decisions differently depending on whether a given design is within the range or outside the range?
   b. How do you evaluate standard designs in comparison to nonstandard designs?
5. Does your agency do post-mortem evaluations of design decisions (particularly those involving ranges or that are outside of standards) to measure substantive safety of those design elements/decisions or to revise/update your state's design standards/guidance?
6. How does your agency determine which projects are candidates for post-evaluation?
7. How does your department rectify different priorities when projects are proposed by outside agencies or local partners?

Idaho Transportation Department

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1. Criteria used:

a. Safety (nominal vs. substantive, risk, etc.).

b. Operational performance.

c. Expediting project delivery (schedule).

d. Lower costs of delivering projects (initial costs).
e. Life-cycle costs.
f. Tort exposure.
g. Political/external pressures.

The way Idaho makes these decisions is documented in a number of different manuals: http://itd.idaho.gov/manuals/manualsonline.htm. See especially its Roadway Design Manual: http://itd.idaho.gov/manuals/Manual%20Production/RoadwayDesign/Roadwaydesignprintable.htm

2. Federally/State Funded vs. Locally/Developer Funded
Decisions are made in the same way regardless of funding. Idaho relies on its manuals in all cases.

3. Tort Laws/Risk Exposure
Tort laws and risk factor into all of Idaho's decisions. But decisions are not ruled by these factors since the agency might be held liable no matter how well-documented its decisions. Idaho acknowledges that there's risk in everything it does. Sometimes the riskier decision is the right one. For example, on certain highway projects, the agency might make a design exception on shoulder width when it is extremely expensive to get the correct should width. Idaho looks at the safety of its entire system rather than at that of a particular product. If making a shoulder width narrower leaves funds for other parts of the system, then it may ultimately be the safer decision.

4. Ranges
Idaho's design standards involve ranges. If a decision exception is a long way from what the nominal design is, it requires more documentation than if outside the design range. For example, if the design criteria call for an 8-foot shoulder, it doesn't take as much documentation to justify a 7-foot shoulder as a 2-foot shoulder.

5. Post-Mortem Evaluations
For some projects, Idaho evaluates safety and operational performance. For example: http://www.us95thorncreek.com/wp-content/uploads/2012/12/Safety-TR-112012.pdf.

6. Post-Evaluation Candidates
For every project, Idaho evaluates how well the construction process went. It evaluates operational and safety performance on a project-by-project basis; there is no formal requirement to analyze every project. Idaho evaluates those projects for which there have been the largest changes. In one case, it converted a two-lane highway to a four-lane divided highway. It monitored this project very closely.

7. Rectifying Priorities
Idaho considers all comments about outside agencies and local partners; but this does not mean it will act on them. For example, Idaho gets many requests for left turn bays and right turn bays. It has a system in place for prioritizing which turn bays serve the public the most. When someone requests a turn bay, Idaho can tell them specifically how this location is ranked as a priority.

Minnesota Department of Transportation

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1. Criteria used:

a. Safety (nominal vs. substantive, risk, etc.).

b. Operational performance.

d. Lower costs of delivering projects (initial costs).

e. Life-cycle costs.

g. Political/external pressures.

Expediting project delivery is not officially factored into design decisions unless the design decision has a profound effect on the project schedule. Tort exposure is rarely a factor; Minnesota DOT has relatively liberal tort laws, and most designers are aware that they can get tort immunity by simply documenting decisions and articulating the source of their guidance. Political pressures often compel the addition of features to projects that are not economical, for example, requiring a four-lane highway where only a two-lane highway is necessary, or turning an intersection into an interchange because of pressure from a commissioner or governor. For documentation on how decisions are made, see Minnesota DOT's:

- Road Design Manual: http://roaddesign.dot.state.mn.us/.
- Highway Project Development Process: http://www.dot.state.mn.us/planning/hpdp/.

2. Federally/State Funded vs. Locally/Developer Funded

Minnesota DOT generally applies the same standards statewide, regardless of project funding. Local projects don't require federal approval on particular design decisions; on some federal projects, a very active federal area engineer could have a profound effect on the way the project is designed.

3. Tort Laws/Risk Exposure

Tort laws have a relatively small influence on design decisions, although they are always in the back of engineers' minds. Taking risk into account is a work in progress. Minnesota DOT is using Cost Risk Analysis & Value Engineering (CRAVE) (http://design.transportation.org/Documents/15-Milkert_Smith_Yoo.pdf), but it's unclear how well it's institutionalized.

4. Ranges

Minnesota DOT uses ranges. If a design decision is outside the range, it requires a design exception. The justification process for this is similar to other states and is documented in Chapter 2 of the Road Design Manual. Minnesota DOT has formal and informal design exceptions. The former involves one of the 13 controlling criteria and requires approval by a state design engineer; the latter involves more general design criteria and requires engineers to do their own documentation.

There is no formal difference between evaluations for design decisions depending on whether they are inside or outside the range.

5. Post-Mortem Evaluations
These are conducted informally and sporadically, not systematically, by district offices.

6. Post-Evaluation Candidates
Candidates are determined informally and are almost always associated with a design exception.

7. Rectifying Priorities
Priorities are rectified on a project-by-project basis, depending on the issues and the parties involved. It is an engineering and negotiating process that is very fluid and differs from situation to situation. It typically has something to do with access: local interests often want more access (such as interchanges typically to developments for the sake of spurring economic development and increasing land value) than it would like to give (because of operational and safety effects).

Missouri Department of Transportation

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1. Criteria used:

a. Safety (nominal vs. substantive, risk, etc.).

b. Operational performance.

d. Lower costs of delivering projects (initial costs).

e. Life-cycle costs.

g. Political/external pressures.

Missouri DOT is spearheading the practical design movement (see Missouri DOT's Engineering Policy Guide (http://epg.modot.org/index.php?title=Main_Page).

Safety is a key part of Missouri DOT's design decisions, but they also take into account cost. It uses life-cycle costs to bid asphalt against concrete pavements.

2. Federally/State Funded vs. Locally/Developer Funded
The vast majority of Missouri DOT projects are federally funded. Developer funded projects are evaluated in the same way, although they somehow allow enhancements that would otherwise be too costly (often aesthetic features such as landscaping and lighting).

3. Tort Laws/Risk Exposure
Tort laws don't factor into Missouri DOT design decisions – it focuses on safety and the best engineering for the job. Lawsuits are inevitable.

Missouri has a tort limit of $385,000 in such cases, and is the only state agency required by state law to go to binding arbitration. They often fare well in court, and binding arbitration means no further appeals.

4. Ranges
Missouri DOT uses ranges, and requires a design exception when outside the range. Decision decisions are evaluated similarly whether inside or outside the range.

5. Post-Mortem Evaluations
Missouri DOT uses the *Highway Safety Manual* to analyze impacts on safety, and these sometimes lead to modifications of standards. It also assesses operational performance.

6. Post-Evaluation Candidates
Candidates are usually innovative safety improvements, such as J-turns and diverging diamonds, where Missouri DOT wants to validate their performance.

7. Rectifying Priorities
On projects funded by others, Missouri DOT allows increased discretion when it comes to non-operational enhancements, for example a 10-foot pedestrian way instead of standard sidewalk; or aesthetic enhancements. It might allow an additional lane where one is enough.

New Jersey Department of Transportation

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1. Criteria used:

a. Safety (nominal vs. substantive, risk, etc.).
b. Operational performance.
c. Expediting project delivery (schedule).
d. Lower costs of delivering projects (initial costs).
e. Life-cycle costs.

New Jersey DOT has a very limited budget and there is little new construction. It focuses more on maintenance and safety or congestion improvements. Improvements cannot be expedited in any way; these require an involved environmental approval process. It can bypass the design exception or environmental processes in some cases where maintenance rather than reconstruction is involved. It uses value engineering on every project over $3 million. While cost is always an issue, it is not a driving priority in the way that congestion and safety are.

See New Jersey DOT's Roadway Design Manual:
http://www.state.nj.us/transportation/eng/documents/RDM/.

2. Federally/State Funded vs. Locally/Developer Funded
Decisions are the same regardless of funding.

3. Tort Laws/Risk Exposure
Tort exposure is not a factor. The focus is safety.

4. Ranges
New Jersey DOT uses ranges. When outside a range, a design exception process is required, and the decision needs to be justified. See New Jersey DOT's Design Exception Manual: http://www.state.nj.us/transportation/eng/documents/DEM/.

5. Post-Mortem Evaluations
New Jersey DOT doesn't do post-evaluations.

6. Post-Evaluation Candidates
N/A.

7. Rectifying Priorities
This is not a factor.

Oregon Department of Transportation

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1. Criteria used:

a. Safety (nominal vs. substantive, risk, etc.).
b. Operational performance.
c. Expediting project delivery (schedule).
d. Lower costs of delivering projects (initial costs).
e. Life-cycle costs.
f. Tort exposure.
g. Political/external pressures.

For practical design, what may be more important than any of these criteria is staying within project purpose and need statements. See Oregon DOT's Highway Design Manual: http://www.oregon.gov/odot/hwy/engservices/pages/hwy_manuals.aspx.

2. Federally/State Funded vs. Locally/Developer Funded
Typically decisions are the same regardless of funding. If the project is a state jurisdiction facility or federally funded, Oregon DOT generally uses the same design procedures (stewardship agreement with Federal Highway Administration (FHWA)).

3. Tort Laws/Risk Exposure
Oregon DOT believes that if it follows its policies and procedures, it generally does not have any issues with tort liability. With recent changes to the tort liability caps, this may become a bigger issue.

4. Ranges
Oregon DOT uses ranges. When outside a range, a design exception process is required, which is similar to federal guidance (type of project, environmental impact, cost/benefit, crash history, historical nature, adjacent section of locations, etc.).

5. Post-Mortem Evaluations
Oregon DOT doesn't normally do post-evaluations.

6. Post-Evaluation Candidates
N/A

7. Rectifying Priorities
The project development process takes into account working with stakeholders (city/county/public) in developing project purpose and need. This will also depend on the jurisdiction of the facility.

Utah Department of Transportation

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1. Criteria used:

a. Safety (nominal vs. substantive, risk, etc.).
b. Operational performance.
c. Expediting project delivery (schedule).
d. Lower costs of delivering projects (initial costs).
e. Life-cycle costs.
f. Tort exposure.
g. Political/external pressures.

Expediting project delivery is less of a factor than the others, and political/external pressures are rarely a factor. Tort exposure is only a factor if a design exception is required.

2. Federally/State Funded vs. Locally/Developer Funded
There are no developer-funded projects. All projects are federal aid projects.

3. Tort Laws/Risk Exposure
Generally Utah DOT feels that if it is following its guidelines, then it doesn't have any tort exposure. For nonstandard installations, a design exception process is required. The documentation involved in this process, including the consideration of alternatives, is generally enough to eliminate tort exposure.

4. Ranges
Utah DOT uses ranges. If the decision is made within the range, it is not documented at all. Outside of the range, a design exception process is required (see http://www.udot.utah.gov/main/f?p=100:pg::::1:T,V:653).

Evaluations do not differ depending on whether decisions are within or outside of the range.

5. Post-Mortem Evaluations
Utah routinely measures traffic volume, speed, delay and safety. These could play a role in updating standards in guidance. For example, Utah DOT installed a continuous flow intersection, monitored it for three years and developed its guidance for these intersections based on the results.

6. Post-Evaluation Candidates
Utah DOT is constantly monitoring its system. It also does project-specific follow-ups. If there is a safety issue at a location, it might make a change and then track the safety of that location for three to five years to make sure the project had the desired effect.

7. Rectifying Priorities
This is not a factor.

Virginia Department of Transportation

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1. Criteria used:

a. Safety (nominal vs. substantive, risk, etc.).

b. Operational performance.

c. Expediting project delivery (schedule).

d. Lower costs of delivering projects (initial costs).

Virginia DOT makes design decisions based on the following factors:

- Safety: Virginia DOT uses the Highway Safety Manual and several studies for STARS and HSIP projects that indicate substandard features of a roadway: http://www.virginiadot.org/business/ted_app_pro.asp.
- Operational performance: Virginia DOT uses Level of Service from the Highway Capacity Manual to determine operational performance. It also uses myriad software (VISSIM, CORSIM, etc.) to determine operational characteristics.
- Expediting project delivery: Virginia DOT uses design-build procurements to expedite project delivery when needed. Virginia DOT also looks at minimizing right of way impacts, which possibly limit property negotiation time frames.
- Lower costs of delivering projects: Virginia DOT uses a system called Value Engineering to investigate where on a project it can save money, whether through time or direct material costs based on the flexibility shown in the AASHTO Green Book and its Road Design Manual: http://www.virginiadot.org/projects/VE-default.asp.

2. Federally/State Funded vs. Locally/Developer Funded
Design decisions for projects that are state and federally funded follow the Virginia DOT design manuals and AASHTO guidelines. All Local Public Agency (LPA) administered projects to be maintained by Virginia DOT, regardless of funding source, must be designed in accordance with Virginia DOT's Road Design Manual or seek a design waiver. All LPA-administered projects to be maintained by the LPA must be designed in accordance with AASHTO's Policy on Geometric Design of Highway and Streets (the Green Book) or seek a design exception.

Developer projects must follow the guidelines above depending on the responsibility for maintaining the project after construction. Virginia DOT adopts roadways into its system through an application process by the developers and therefore the design would follow Virginia DOT standards, which do not go below AASHTO.

3. Tort Laws/Risk Exposure
Virginia DOT follows the standards, policies and procedures set forth in AASHTO and in Virginia DOT design manuals. For limits on claims, see https://leg1.state.va.us/cgi-bin/legp504.exe?000+cod+8.01-195.3.

4. Ranges
Virginia DOT uses ranges. If a project design is within the range, then the justification could be set at the scoping or documented in a note to the project file in which the criterion was decided upon to base the design. If outside the range, then either a design waiver (less than Virginia DOT, but greater than AASHTO) or a design exception (less than AASHTO) is required.

5. Post-Mortem Evaluations
Standard designs as compared to nonstandard designs based on the feasibility of the design using a common sense approach to determining the design criteria and weighing the risks involved.

The Construction Division has a post-construction manual that outlines procedures for closing out a project: http://www.virginiadot.org/business/resources/const/pc_manual.pdf.

6. Post-Evaluation Candidates
See answer to question 5.

7. Rectifying Priorities
The Commonwealth of Virginia General Assembly enacted into law House Bill 2 on April 6, 2014, which provides five decision factors to prioritize a project. The law requires that "prioritization shall weight factors such as congestion mitigation, economic development, accessibility, safety and environmental quality and be applied within each highway construction district." Currently, Virginia DOT is working through the procedural process for this prioritization evaluation.

Related Research and Resources

National Guidance

Performance-Based Practical Design, Federal Highway Administration, October 9, 2014.
http://www.fhwa.dot.gov/design/pbpd/
FHWA's web site on performance-based practical design includes:

- A brief overview: http://www.fhwa.dot.gov/design/pbpd/documents/pbpd_brief.cfm. Performance-based practical design involves an emphasis on "scoping projects to stay within the core purpose and need" to "eliminate nonessential project design elements resulting in lower cost and improved value," allowing states "to deliver a greater number of projects than otherwise possible under their previous project development approaches."
- A webinar: https://connectdot.connectsolutions.com/p9aazbkknpx/?launcher=false&fcsContent=true&pbMode=normal.
- Case studies: http://www.fhwa.dot.gov/design/pbpd/case_studies.cfm (see **Case Studies**, below).

NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets, Brian Ray, Erin Ferguson and Julia Knudsen, 2014.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_785.pdf
This report details an approach for selecting performance measures for evaluating the impact of alternative geometric design decisions and a method for incorporating performance-based analysis into the project development process. The report includes six project examples illustrating how this framework can be applied to actual projects.

NCHRP Report 783: Evaluation of the 13 Controlling Criteria for Geometric Design, Douglas Harwood, Jessica Hutton, Chris Fees, Karin Bauer, Alan Glen and Heidi Ouren, 2014.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_783.pdf
From the abstract: This report describes the impact of the controlling roadway design criteria on safety and operations for urban and rural roads. In 1985, the FHWA designated 13 specific design elements as controlling criteria for roadway design. The 13 controlling criteria are (1) design speed, (2) lane width, (3) shoulder width, (4) bridge width, (5) structural capacity, (6) horizontal alignment, (7) vertical alignment, (8) grade, (9) stopping sight distance, (10) cross slope, (11) superelevation, (12) vertical clearance, and (13) horizontal clearance. Federally assisted highway construction and reconstruction projects must meet the established design criteria for these elements, or a formal design exception must be prepared and approved. Different procedures apply to rehabilitation projects, but these design elements are still key considerations in design. Since their designation, the 13 controlling criteria and their application have not been reconsidered as new knowledge has been gained about the relationships between geometric design elements and safety and operations. In this research project, the research team investigated what is known about the safety and operational effects of the 13 controlling and other important geometric design criteria. Several small studies were done to augment the information found in the literature. This information was used to assess the sensitivity of safety and operations to design decisions for these criteria for different types of roads. The research also addressed how to reduce confusion related to the definitions of the controlling criteria. The use of the controlling criteria in design exception processes was also explored, including through interviews with state department of transportation (DOT) personnel. This report will be useful to geometric designers and those responsible for reviewing designs, particularly in agencies that are transitioning away from “standards-based design.”

NCHRP Synthesis 443: Practical Highway Design Solutions, Hugh McGee, 2013.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_443.pdf
This report describes the various cost-saving approaches states have adopted for roadway project development.

NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design, Paul Dorothy and Stephen Thieken, 2011.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_422.pdf
From the abstract: This synthesis describes the processes that transportation agencies currently use to evaluate geometric design trade-offs between competing interests. It also highlights existing key publications on conventional approaches, context-sensitive solutions/context-sensitive design, and performance-based approaches, as well as gaps in information or analysis processes available to support design decisions. The audience for this report includes practitioners in transportation project development and delivery. Information used in this study was acquired through a review of the literature and surveys.

NCHRP Report 480: A Guide to Best Practices for Achieving Context Sensitive Solutions, Timothy Neuman, Marcy Schwartz, Leofin Clark and James Bednar, 2002.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_480a.pdf
This guide describes how state DOTs and other transportation agencies can implement context sensitive solutions in developing transportation projects, particularly when highway projects are perceived as having clear and measurable adverse impacts on the communities through which they pass.

State Guidance

A selection of state guidance related to performance-based practical design (via http://www.wsdot.wa.gov/Projects/PracticalDesign/nationwide.htm):

- **Idaho:** Practical Solutions for Highway, undated. Design, http://www.itd.idaho.gov/manuals/Manual%20Production/DesignSolutions/files/DesignSolutionsPrintable.pdf.
- **Missouri:** Practical Design Implementation Manual, revised February 24, 2006.
  http://www.modot.org/business/PracticalDesign.htm.
- **New Jersey:** Smart Transportation Guidebook, March 2008. http://www.state.nj.us/transportation/community/mobility/pdf/smarttransportationguidebook2008.pdf.
- **Oregon:** Practical Design, undated.
  http://www.oregon.gov/ODOT/HWY/TECHSERV/pages/practical_design.aspx.
- **Utah:** Practical Design, revised February 3, 2011.
  http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:3195.

Case Studies

From the FHWA Performance-Based Practical Design web site (http://www.fhwa.dot.gov/design/pbpd/):

Kansas: Design to Budget

- **Case Study:** K-177 Modernization Project
  Agency: Kansas Department of Transportation
  Location: Morris and Geary counties, Kansas
  Region: Central
  Setting: Rural

Safety Performance Analysis

Documented Applications of IHSDM

- Arizona DOT: "Application of HSM Predictive Method and IHSDM to Design Decision-Making – An Arizona Case Study".
- California DOT: "Quantitative Road Safety Analysis in Value Engineering: A Case Study".
- Idaho DOT: "Using HSM Predictive Methods for a Corridor Study in Idaho".

- Kansas DOT: "Designing to a Budget and More: Use of the Highway Safety Manual at the Kansas Department of Transportation".
- Nevada DOT: "HSM Pilot Project: SR 147 - Safety Performance Evaluation".
- South Dakota State University and North Dakota State University (for the North Dakota DOT and FHWA): "Evaluating Local and Tribal Rural Road Design with the IHSDM".

Highway Safety Manual Case Studies

- Using Predictive Methods for a Corridor Study in Idaho.
- Using Predictive Methods for Alternative Selection in Florida.

Operational Performance Analysis

- Operational/Design Case Study – Traffic Impact Study.
- HCM/Analytical Model – Queuing Analysis.

Low-Cost Operational Solutions to Traffic Bottlenecks

- Arkansas (Metroplan MPO, Little Rock region): Public survey of localized congestion problems.
- Austin, Texas: Restriping of two lanes to "reclaim" a third lane.
- Arvada, Colorado: A grade-separation project to eliminate recurring problems caused by a railroad crossing.
- Danbury, Connecticut: Restriping an interchange instead of rebuilding.
- Madison, Wisconsin: Ramp meters as a countermeasure to delays and crashes.
- Manchester, New Hampshire: Expedited improvement of a congested exit ramp as part of long-term phased construction.
- Minneapolis-St. Paul, Minnesota: A study to determine effectiveness of ramp meters.
- Pittsburgh, Pennsylvania: Conversion of a freeway shoulder into an acceleration lane at former chokepoint at top of ramp entrance.
- Renton, Washington: Use of a freeway shoulder to maintain lane congruency and eliminate a lane drop chokepoint.
- Saginaw County, Michigan: Replacement of tight diamond ramp intersections with roundabouts as countermeasure to insufficient signalized intersections.
- Washington DOT: Description of Washington State's 3-tiered "Moving Washington" congestion relief plan.

Research in Progress

Developing a Context-Sensitive Functional Classification System for More Flexibility in Geometric Design, NCHRP 15-52, ongoing, completion date: May 14, 2016.
Abstract at: http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3656
From the abstract: Since 1984, the American Association of State Highway and Transportation Officials (AASHTO) "Green Book" (A Policy on the Geometric Design of Highways and Streets) and other roadway design criteria have been based on a functional classification system of a hierarchical roadway network composed of arterials, collector roads, and local roads. This classification is further broken out by an urban or rural designation. This system is described in Highway Functional Classification Concepts, Criteria and Procedures (FHWA-PL-13-026). This system of highway classification has been under increasing scrutiny and discussion due to some incompatibilities with context-sensitive design, practical design, and other innovative approaches. The following are some concerns: (1) Designation as urban or rural is insufficient to adequately account for the range of contexts for a roadway. (2) The current system is focused on the needs of vehicle drivers and does not help in serving the needs of other types of users (e.g., transit riders, pedestrians, bicyclists). In particular, it does not help with design decisions that must balance benefits for one mode against disbenefits for another (e.g., narrower lanes that benefit pedestrians but make it harder for trucks to use the road). (3) Classification leads to recommended or limited design choices that may not be optimal for the particular roadway. These restrictions promote "designing to standards" rather than a careful consideration of the safety, operational, and other impacts of design decisions. (4) The public often questions the use of these classifications as the basis for design decisions. The current functional classification system has implications on many aspects of transportation agency functions (e.g., http://goo.gl/ah3fER). Research is needed that is not constrained by the traditional functional classification system and explores potential consequences to uses other than geometric design. The objective of this research is to identify potential improvements to the traditional functional classification system to better incorporate the context, user needs, and functions of the roadway facility. The potential improvements should lead to a flexible framework that can be used by planners and designers in the development of optimal geometric design solutions.

Risk- and Reliability-Based Approaches to Analyzing Road Geometric Design Criteria, Mountain Plains Consortium, ongoing, completion date: January 31, 2016.
http://www.mountain-plains.org/research/projects/downloads/2012_mpc_406.pdf
From the abstract: Federal and state transportation agencies set goals related to surface transportation system performance. The American Association of State Highway and Transportation Officials' (AASHTO's) Strategic Plan, for example, includes goals to cut fatalities in half by 2030, create a congestion free surface transportation system, and improve system performance (AASHTO, 2009). Policies and procedures that explicitly consider performance goals at all organizational levels in transportation agencies will maximize the likelihood they are achieved. Performance measures are being used to increase accountability for how highway funds are being spent (FHWA, 2012). Moving Ahead for Progress in the 21st Century Act (MAP-21) establishes a performance-based Federal highway program, where investment decisions are made through performance-based planning and programming. States are expected to invest resources in projects that achieve performance targets and collectively contribute to achieving national performance goals. Once funds are allocated, road design activities and decisions should be consistent with performance goals set during planning and programming. A performance-based design approach would be a significant contribution to achieving performance objectives and making well-informed design decisions. FHWA has recently formed a task force to explore the transition from a criteria-based road design to performance-based

road design. The Transportation Research Board's (TRB's) Operational Effects of Geometric Committee (AHB65) created a Subcommittee on Performance-Based Analysis to investigate processes and procedures to incorporate safety and operational performance prediction into the project development process. Current highway geometric design processes require establishment of fundamental design controls (e.g. area type, terrain, functional classification, design vehicle, traffic volume) and selection of design speed. The process then becomes dimensionally-based, with minimums, maximums and ranges in design values directly derived from tables, charts and equations. Acceptable performance in terms of mobility and safety is presumed to result from proper application of design criteria. The variability in factors influencing design criteria (e.g., driver performance, road conditions, and vehicle performance) is often large and is addressed implicitly by using "conservative" values. This can lead to performance outcomes that are different than intended (Porter et al., 2012). The relative likelihoods (or probabilities) that design alternatives will meet transportation performance goals throughout their life cycles are not explicitly or quantitatively evaluated. A risk and reliability-based highway geometric design approach is a possible solution to address these gaps. This idea has received national interest, evident from an invited TRB podium session at the 2012 annual meeting, "Risk and Reliability Analysis in Geometric Design of Highways and Streets." Design approaches based on levels of risk (the probability of an event occurring and the impact that the event will have on the achievement of design, project or agency objectives) and reliability (the ability of a system to consistently do what it was expected or designed to do) are currently used in several engineering/technical disciplines (e.g., structural design, hydrology and hydraulics, systems engineering and management). This project will provide a strategic step towards development of road design processes that: 1) explicitly consider and quantify the variability and uncertainty in factors that influence design criteria and design decisions; and 2) explicitly incorporate expected performance outcomes and the uncertainty of performance predictions into design decisions.

Developing an Improved Highway Geometric Design Process, NCHRP 15-47, ongoing, completion date: December 14, 2015.
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3415
From the abstract: The objectives of this research are to (1) develop a comprehensive, flexible design process to meet the needs of geometric designers in the future and (2) update American Association of State Highway and Transportation Officials' (AASHTO's) Guidelines for Geometric Design of Very Low-Volume Roads. The design process (Objective 1) must consider: (1) Specification of the project purpose and need, including the modes that will be using the facility. (2) Context setting of the facility. (3) Desired performance outcomes for the facility for the various modes; including safety, mobility, and access management. (4) Methods for evaluating tradeoffs associated with different design alternatives. (5) Optimization of the design given the project's financial and other constraints. (6) Flexibility to address issues that arise from stakeholder involvement or environmental reviews. (7) Documentation of decisions to address tort liability concerns.

Related Research

Practical Design/Flexible Design

Best Practice in Practical Design: Synthesis, Washington State Department of Transportation, August 2013.
http://www.wsdot.wa.gov/NR/rdonlyres/340BBA6E-ABD9-4FD8-87C3-B3767987BA16/0/PracticalDesignSynthesisNBoyd.pdf
This recent synthesis includes a number of resources relevant to practical design.

INVEST, Federal Highway Administration, 2013.
https://www.sustainablehighways.org/
INVEST is an online tool for states and local agencies to use in integrating sustainability best practices into transportation projects and programs, including practical design principles as community involvement.

Practical Transportation: Better Solutions for Better Transportation Systems, Florida Department of Transportation, June 2012.
http://www.dot.state.fl.us/structures/designExpo2012/Presentations/PracticalDesignExpo.pdf
This presentation describes the five state programs (Missouri, Kentucky, Idaho, Oregon and Utah) that currently have practical design guidelines.

"Practical Design," *Public Roads*, Vol. 73, No. 4, Jan/Feb 2010.
http://www.fhwa.dot.gov/publications/publicroads/10janfeb/06.cfm
This article reviews the Missouri Department of Transportation's practical design-related efforts, which have yielded 13 percent in savings and 24 percent reduction in fatal crashes between 2005 and 2008.

"Risking Success Through Flexible Design," *Public Roads*, Vol. 73, No. 4, Jan/Feb 2010.
http://www.fhwa.dot.gov/publications/publicroads/10janfeb/05.cfm
This article discusses practical design and context-sensitive solutions.

Safety and Performance

"A Combined Crash Frequency – Crash Severity Evaluation of Geometric Design Decisions: Entrance-Exit Ramp Spacing and Auxiliary Lane Presence," Transportation Research Board 94th Annual Meeting, 2015.
http://docs.trb.org/prp/15-5881.pdf
From the abstract: This paper quantifies the effects of freeway ramp spacing and auxiliary lane presence on crash frequency and crash severity. Crash frequencies are predicted using a safety performance function and crash severities are estimated using a "severity distribution function." The paper then demonstrates how to combine quantitative knowledge related to the effects of ramp spacing and auxiliary lane presence on both crash frequency and severity into a framework for assessing the overall crash cost for different ramp configurations. Geometric features, traffic characteristics, and crash data were collected for 404 freeway segments in California and Washington State. Negative binomial regression models and multinomial logit regression models are used to estimate the effects of ramp spacing and auxiliary lane presence on expected crash frequencies and crash severities, respectively. Results show that expected multi-vehicle crash frequency increases when ramp spacing decreases. Meanwhile, there is a decrease in the proportion of severe crashes (fatal, incapacitating injury) with a decrease in ramp spacing, even though the overall frequency of these severe crashes remains relatively unchanged. Providing an auxiliary lane is expected to decrease crash frequency, although this reduction appears to be primarily in less severe crashes (possible injury and property damage only). The findings appear to effectively capture the complex relationships between geometric design designs and operations and the high sensitivity between speed and crash severity. The paper provides quantitative tools for making informed freeway and interchange design decisions where ramp spacing is a consideration.

"Examining the Safety Threshold for Roadway Design," Transportation Research Board 94th Annual Meeting, 2015.
Abstract at: http://trid.trb.org/view/1338626
From the abstract: This paper discusses the inherent tension between economically and feasibly designing a roadway and establishing a level of safety that society expects, in light of the movement to modify or replace standards-based design with alternative approaches. For a concrete example, the recent evolution of stopping sight distance design practice and the influence of alternative perspectives are described, along with the related attempts to propose a threshold to distinguish acceptable from unsafe design practice. Then, for perspective, the paper presents examples from private enterprise that illustrate society's current mandates for acceptable levels of safety. By considering the costs and penalties society imposes when the level of safety provided is not high enough to avoid unacceptably harmful consequences, one can clarify what safety threshold to strive for and what amount of effort and expenditure is mandated to minimize potential harm. The paper ends with an assertion that significant improvements in crash databases are required before it is feasible to reliably assess the performance of some types of roadway design elements, along with mentioning possible changes that could improve the safety database and facilitate the introduction of alternative design frameworks. While shortcomings with crash databases is not a new issue, the move toward performance-based and other design paradigms, combined with the recent technological developments that finally make the database improvements feasible, add new urgency to rectifying the long-standing crash database problem so that safety thresholds of design decisions may be adequately evaluated.

"Lessons Learned from Adopting the Highway Safety Manual to Assess the Safety Performance of Alternative Urban Complete Streets Designs," Transportation 2014: Past, Present, Future—2014 Conference and Exhibition of the Transportation Association of Canada, 2014.
http://conf.tac-atc.ca/english/annualconference/tac2014/s-16/barua.pdf
From the abstract: A safety assessment of street designs is an essential stage in the planning process of future transportation systems. Such an assessment guides decision-makers in selecting the safest and most sustainable design options. In this study, the Highway Safety Manual (HSM) predictive methods were used to assess the associated safety risks of alternative Complete Streets designs drafted by the City of Edmonton. The City proposed a total of 63 (42 collector, 12 local, and nine arterial road) design drafts. For each of the design proposals, the safety indices were computed and alternative options were compared. The objective of this paper is twofold: i) assess the safety performance of those alternative design drafts; and ii) highlight the lessons learned as well as the issues and challenges faced while using the HSM predictive methods to conduct the assessment. The results obtained from the safety assessment reveal that road cross sections with a large lane width, a large offset of a roadside fixed object, the presence of a median, no on-street parking, and no on-street bike lane have less safety risks compared to road cross sections that do not possess these features. As for the second objective, several issues and challenges were faced: i) unavailability of baseline models for certain site types (e.g., six-lane divided arterial) and roadway categories; ii) difficulties in finding appropriate crash modification factors (CMFs) for some geometric road features; iii) debatable credibility of some of the CMFs as a result of regional factors (e.g., weather, terrain, etc.); iv) the fact that some CMFs were only developed for certain roadway categories or collision severities, while others do not specify the roadway category; thus, using these CMFs is based on assumption; and v) the number of CMFs used to adjust each base model exceeded three, which affects the accuracy of the predicted number of collisions. These issues and challenges may provide a future research direction to enhance the scope of the HSM. Furthermore, the assessment process illustrated herein can be proactively used during roadway

planning and design to compute the associated safety risk of different Complete Streets cross sections.

Developing Safety Performance Measures for Roundabout Applications in the State of Oregon, Oregon Department of Transportation, April 2013.
http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/2013/SPR733_Roundabout.pdf
From the abstract: This report documents the research effort to quantify the safety performance of roundabouts in the State of Oregon. The primary goal of this research is to provide the Oregon Department of Transportation (ODOT) with safety performance functions (SPFs) that can be used to evaluate the safety performance of single-lane, four-leg roundabouts. These safety metrics generally conform to the statistical models and methodologies similar to those outlined in the Highway Safety Manual (HSM) published in 2010 by the American Association of State Highway and Transportation Officials (AASHTO).

"A Proposed Performance-based Highway Design Process: Incorporating Safety Considerations," 17th International Conference on Urban Transport and the Environment, pages 517-528, May 2011.
Abstract at: http://trid.trb.org/view/1118627
From the abstract: This paper describes how current highway design practice in the United States allows for flexibility in the application of geometric design principals. However, current design practices lack a formal methodology, which results in varying degrees of application by region, agency and individual. While the consequences of design flexibility (i.e., construction cost, capacity, highway safety, etc.) are recognized, an improved method of quantifying and comparing the consequences of design decisions is needed in order to allow for more informed decision making. This paper proposes a performance-based design process that can be implemented using the tools, research, and published design documentation that already exists within the highway engineering community. This process capitalizes on existing workflow for increased acceptance among professionals. Implementation will lead to an improved understanding of the impacts to safety and other outcomes caused by relaxing design standards to accommodate existing right of way (ROW), environmental constraints, and other items traditionally viewed as constraints. This paper presents a proposed performance-based highway design process that is demonstrated using highway safety as the measurable outcome. The proposed process can be extended to include other highway engineering performance outcomes such as vehicle capacity, but this paper focuses solely on the safety performance of highway alternatives.

Evaluating the Performance and Safety Effectiveness of Roundabouts, Michigan Department of Transportation, December 2011.
http://www.michigan.gov/documents/mdot/MDOT_Research_Report_RC1566_379286_7.pdf
From the abstract: This report documents the evaluation of the performance and safety effectiveness of roundabouts within the State of Michigan. The study began with the identification of roundabouts within Michigan. This was followed by collecting data on the geometric features of the roundabouts and crash history for each roundabout site from January 1, 2001 to December 31, 2010. The analysis of the roundabouts within Michigan included a literature review, a best practices review of other municipalities, an evaluation of the crash data (both a simple before and after and an Empirical Bayes (EB) analysis, and a site visit to a select group of roundabouts that was determined by the study team. The site visits included a speed study at several of the locations, a conflict analysis at several of the locations, and an assessment of overall operations of the roundabout, including noting any potential issues that may be observed from the operations of the roundabouts. Another finding of the analysis was an average cost savings that the various types of roundabouts are expected to have based on

savings from the reduction in delay and crash reduction. Additional findings from the site visits resulted in a rating of issues based on Collision Risk Assessment Method. Based upon the results of the EB analysis, Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs) were established to reflect the roundabouts in Michigan. These are the first SPFs and CMFs that were developed to reflect the behaviors of Michigan roundabouts.

"Evaluating the Effects of Freeway Design Elements on Safety," *Transportation Research Record: Journal of the Transportation Research Board*, Issue 2195, 2010.
Abstract at: http://trid.trb.org/view/910828
From the abstract: Increased emphasis has been placed on improving the explicit role of highway safety in making decisions on highway planning, design, and operations. This end can be achieved by quantifying the safety effects of geometric design elements for various highway facilities. The objective of this study was to investigate the safety effects of two important design elements for freeways: ramp density and horizontal curve. Data available for use in the evaluation included 324.2 centerline mi of freeways collected in Texas. Five years (1997–2001) of freeway crashes were examined. Negative binomial regression models were used to estimate the effects of independent variables on crashes. The final model for evaluation revealed that crashes on freeway segments were associated with average daily traffic, on-ramp density, degree of curvature, median width with inside shoulder, the number of lanes (for urban freeways), and whether the freeway is in an urban or rural area. Off-ramp density was not statistically significant in the model. Furthermore, the effect of on-ramp density on freeway crashes was significant for horizontal curves but not for tangent sections and indicates that freeway designers should eliminate or minimize the number of on-ramps within the horizontal curves. The statistical modeling results were geared into the development of accident modification factors for on-ramp density and horizontal curves that can be used for safety prediction of freeways.

Development of Tools for Evaluating the Safety Implications of Highway Design Decisions, Texas Transportation Institute, Texas Department of Transportation and Federal Highway Administration, February 2007.
http://tti.tamu.edu/documents/0-4703-4.pdf
From the abstract: Highway safety is an ongoing concern to the Texas Department of Transportation (TxDOT). As part of its proactive commitment to improving highway safety, TxDOT is moving toward including quantitative safety analyses earlier in the project development process. The objectives of this research project are: (1) the development of safety design guidelines and evaluation tools to be used by TxDOT designers, and (2) the production of a plan for the incorporation of these guidelines and tools in the planning and design stages of the project development process. This document summarizes the research conducted and the findings for the initial three years of the project. This research included a review of the TxDOT design and safety evaluation process, identification of the safety information sources and needs, identification of the data needed to use selected safety evaluation tools, assessment of the applicability of accident modification factors for design evaluation, and calibration of selected safety evaluation tools for Texas application.

Tort Liability

"Tort Liability Defense Practices for Design Flexibility," *NCHRP Legal Research Digest 57*, March 2012.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_lrd_57.pdf
From the abstract: In response to community and developmental demand, many state transportation agencies have modified their design policies to specifically require staff to consider historical, environmental, and other context-related elements during the design

process rather than merely focusing on following "generally accepted" standards. However, the threat of tort claims continues in a number of states and that is having a damping effect on designers' willingness to tailor designs to suit projects' unique contexts rather than designing projects that follow standard templates. This research, which focuses on tort liability defense practices and cases involving the exercise of discretion in design, will hopefully provide a framework for determining successful strategies employed when defending design decisions made following the principles of Context Sensitive Solutions (CSS). This digest explores the concept of discretion as a defense to government tort liability, and defending these actions based on the designers' and policy-makers' discretion may be described by terms such as governmental immunity, official immunity, design immunity, or policy immunity. The existing law is relevant to analysis of tort legal defenses available to protect the decisions inherent in CSS. Many departments of transportation have adopted CSS principles or related concepts such as Practical Design to encourage flexibility in design decision-making. The digest's processes for documenting design decisions, articulating clearly the various factors considered in making a decision with a focus on decisions that involve design exceptions, should be of great help to attorneys, administrators, information officers, document retention officials, risk managers, planners, designers, and others responsible for such decisions.

Risk/Reliability

"Calibrating Road Design Guides Using Risk-Based Reliability Analysis," Transportation Research Board 92nd Annual Meeting, 2013.
Abstract at: http://trid.trb.org/view/1240709
From the abstract: Existing geometric design guides provide deterministic design standards for highway elements which ignores the uncertainty associated with many design parameters. Reliability analysis has been advocated as an approach to account for this uncertainty and to evaluate the risk associated with a particular design feature. This paper discusses one important application of reliability analysis: the calibration of geometric design models to yield consistent safety (risk) levels. The paper provides calibrated design charts for the middle ordinate (M), defined as the lateral distance between edge of median barriers and centerline of the adjacent traffic lane, at different probability of non-compliance levels. The results show that the calibrated values of middle ordinate (M) are generally lower than those derived from the AASHTO design guide. The calibrated design charts can offer designers dealing with highways with constricted right-of-way an option to use lower middle ordinate values and enable them to estimate the safety consequences of their decisions. Overall, the calibrated charts can aid the decision maker in determining the safety implications of deviating from geometric design standards and quantifying the safety level built in design values that are deemed acceptable.

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