MPC-406

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Project Title:
Risk- and Reliability-Based Approaches to Analyzing Road Geometric Design Criteria

University:
University of Utah

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Research Needs:
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.

Research Objectives:

The objective of this project is to define and critically assess alternative approaches for incorporating risk and reliability analysis into the process of establishing road geometric design criteria and making road design decisions. One or more of FHWA's 13 controlling design criteria or key decisions regarding facility type (i.e., freeway or surface facility) and number of lanes will be used to evaluate selected alternative risk- and reliability-based approaches that are identified.

Research Methods:

The project will begin with a comprehensive review and critical synthesis of risk and reliability analysis approaches applied to engineering systems, with a focus on civil engineering disciplines. Possible applications of their general frameworks to highway design decisions will be identified. This initial step is consistent with research needs identified in *Transportation Research Circular E-C110: Geometric Design Strategic Research*. A detailed work plan based on the findings of the critical synthesis will then be developed. A combination of several methods will likely be used to accomplish the research objective. The principal investigator's initial thoughts on possible approaches are provided below. Flexibility is built into the approach. The research methods ultimately implemented will depend on the findings of the review and critical synthesis.

The first possible approach will analyze existing design models (e.g., point-mass horizontal curve model, stopping sight distance), treating key parameters as random as opposed to fixed. The distributions of design supply (e.g., available friction, available sight distance) and design demand (e.g., required friction, required sight distance) will be developed. The result will be estimates of margins of safety built into design criteria under different operating conditions. Different alternatives will be explored for creating the distributions of key design parameters, including existing literature, accessible field databases, and driving simulator studies. This first general research approach builds on pioneering work in this area by Ismail & Sayed (2009, 2010).

The second possible approach will investigate the use of performance predictions to support design decisions, while explicitly considering the uncertainty in both the model predictions and in the model input values. Relationships between design decisions and performance distributions will be quantified. The focus will be on safety and operational performance. Existing and highly utilized performance prediction tools and frameworks, such as those in the *Highway Safety Manual*, *Highway Capacity Manual*, and microscopic traffic simulation packages, will be employed. The performance-prediction approach will then be extended to incorporate comparisons to project-, corridor-, and network-and agency-level performance goals. The probability and consequences of an undesirable outcome (e.g., not meeting one or more project performance goals) will be quantified as the risk associated with a decision. This second general approach will build on concurrent work conducted as part of NCHRP 15-34A, *Performance-Based Analysis of Geometric Design of Highways and Streets*.

The final stage of the research will describe the utility of the research results to road design practice by preparing an implementation plan. The context of geometric design decisions will be explored as either risk-based approaches, where decisions are based primarily on the assessment of risk, or risk-informed approaches, where decisions are based on assessment of risk in addition to other relevant factors not specifically included in the risk assessment. Ibrahim et al. (2012) described one possible approach to implementation. The role of incorporating subjective assessments of risk, based on a road designer's context-specific experience, professional opinion, and judgment, into risk-based approaches will also be explored.

Expected Outcomes:

This project will provide a strategic step towards development of 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. The expected project outcomes support the trend towards more performance-based design decisions and are nationally recognized strategic research needs (see 'Research Needs' discussion). The implementation plan will frame possible applications of the research results in the context of road design practice. Initial applications are likely to focus on design exceptions given the research focus on FHWA's 13 controlling criteria and the unique needs of design exception analysis [see Mason & Mahoney (2003) for discussion of design exceptions]. This project is likely to have an impact on the specific directions of future research related to the 'Alternative Highway Geometric Design Processes Strategic Research Program,' defined by the TRB Geometric Design and Operational Effects of Geometrics Committees (http://sites.kittelson.com/TRB-AFB10/Downloads/514). Several peer-reviewed journal articles and conference presentations are expected to result from the work in addition to a final report and implementation plan,.

Relevance to Strategic Goals:

The project is most relevant to the USDOT strategic goals of 'Safety' and 'State of Good Repair.'

Safety: The expected outcomes will support explicit consideration of safety-related principles and expected safety performance when establishing design criteria and making design decisions. This is consistent with quantitative, data-driven approaches to safety.

State of Good Repair: The expected outcomes will support improvements to critical aspects of highway system performance by explicitly incorporating expected performance outcomes and the uncertainty of performance predictions into design decisions. This will increase the likelihood that agency performance goals are met. The project is also intended to result in improvements to highway design procedures by providing methods to make more informed design decisions.

Educational Benefits:
Two graduate students will be heavily involved in the research. They will lead the preparation of journal publications resulting from the work and, in most cases, deliver conference presentations. The project will serve as a basis for their dissertation and thesis work. The principal investigator will also look for opportunities to involve one or more undergraduate students in specific data collection activities. The University of Utah currently has a graduate course on "Quantitative Methods in Transportation." This project will lead to new material on risk- and reliability-based methods that expand the current scope and audience of the course beyond transportation operations to include quantitative methods for transportation infrastructure design, including geometric design, pavement design, and bridge design.

Work Plan:
The work plan consists of seven research tasks to be accomplished over a 15-month period as described below:

<u>Task 1</u>. Execute a comprehensive review and critical synthesis of risk- and reliability-based analysis approaches that have been applied to engineering systems, with a focus on civil engineering disciplines.

<u>Task 2</u>. Identify and describe possible applications of the risk- and reliability-based analysis frameworks identified in Task 1 to highway design decisions, with a focus on FHWA's 13 controlling design criteria or key decisions regarding facility type (i.e., freeway or surface facility) and number of lanes.

<u>Task 3</u>. Prepare a work plan to test one or more of the possible applications identified in Task 2 that can be executed within the project budget and schedule. The work plan may include one or more approaches related to analyzing existing design models with random input parameters and/or investigating the use of performance predictions to support design decisions. A combination of analytical models, simulator studies, pre-collected field data, and performance-prediction tools will be considered.

<u>Task 4</u>. Execute the work plan prepared in Task 3.

<u>Task 5</u>. Create a framework for making geometric design decisions as either risk-based approaches or risk-informed approaches. The framework may include the role of subjective

assessments of risk, based on a road designer's context-specific experience, professional opinion, and judgment.

Task 6. Prepare a draft final report describing all previous tasks of the research. A draft implementation plan based primarily on the results of Task 5 will be included as an appendix to the report. Circulate the draft report for peer review.

Task 7. Submit a final report and implementation plan that addresses comments received during the peer review.

A schedule of activities is provided on the following page.

Technology Transfer Plan

The potential audiences for this research are individuals involved in the design of highways, including design and pre-construction staff at FHWA and at individual state DOTs. It also includes FHWA and state DOT policy makers responsible for creating and adopting design policy, processes, and procedures. The following agencies, offices, and committees are those most likely to take a leadership role in implementing the research results:

- FHWA Office of Safety
- FHWA Office of Infrastructure
- AASHTO Subcommittee on Design
- TRB Geometric Design Committee
- TRB Operational Effects of Geometrics Committee
- TRB Safety Performance Committee

The proposed principal investigator routinely interacts with FHWA, members of the AASHTO Subcommittee on Design, and the listed TRB Committees. The 2013 Joint Midyear Meeting of the AASHTO Subcommittee on Design, TRB Geometric Design Committee, TRB Operational Effects of Geometrics Committee, and TRB Safety Performance Committee will be an opportunity to share early results and future directions of the research project. Staff members from the FHWA Offices identified above generally attend this midyear meeting. The proposed principal investigator will work with the committee chairs to possibly get a presentation on the project added to the agenda. The proposed principal investigator and his graduate students routinely attend TRB's annual meeting as well. At least one TRB paper on this work will be submitted for presentation and publication.

Schedule of Research Activities

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Month 14	Month 15
Task 1 Review and critically synthesize analysis approaches	■	■	■	■	■										
Task 2 Identify possible applications to highway design			■	■	■										
Task 3 Prepare work plan					■										
Task 4 Execute work plan						■	■	■	■	■	■	■			
Task 5 Create framework for making geometric design decisions										■	■	■	■		
Task 6 Prepare draft final report and implementation plan													■	▨	
Task 7 Submit final report and implementation plan															■

■ Research Task
▨ Peer Review

Project Cost:
Total Project Costs: $209,761
MPC Funds Requested: $104,820
Matching Funds: $104,941
Source of Matching Funds: NCHRP 15-34A ($76,744) and faculty start-up funds ($28,197)

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TRB Keywords: Design; Geometric design; Highway design; Performance evaluations; Reliability; Risk analysis; Road design

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