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Geometric Design Strategic Research

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TRANSPORTATION RESEARCH CIRCULAR E-C110

Geometric Design Strategic Research

Transportation Research Board
Geometric Design Committee
Operational Effects of Geometrics Committee

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Transportation Research Board
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PART I

Background

The objective of this publication is to document the efforts leading up to and resulting from the Strategic Geometric Design Research Needs Workshop held in Williamsburg, Virginia, in July 2004. This workshop was a joint effort by three committees—the Transportation Research Board's (TRB's) Geometric Design Committee (AFB10) and Operational Effects of Geometrics Committee (AHB65), and the AASHTO Technical Committee on Geometric Design. This document also contains research problem statements organized in a prioritized and chronological order for possible use as a long-range geometric design research program by agencies such as AASHTO, FHWA, and other research sponsoring agencies.

From a broad perspective, the responsibilities of a TRB committee are to (*a*) peer review research findings, (*b*) facilitate presentation and publication of research results in circulars and records, and (*c*) identify what needs to be pursued in the area of committee specific research. To further facilitate the final charge, committees are encouraged to submit research problem statements to funding agencies for consideration at the beginning of each year. In the case of geometric design, the primary funding agencies have been AASHTO, which funds research through the NCHRP, the FHWA, and individual state departments of transportation (DOTs).

Both TRB committees have a subcommittee that is responsible for developing, collecting, and organizing research needs and problem statements from committee members, volunteers, other committees with similar scopes, outside peer groups (e.g., AASHTO, ITE, ASCE) and international stakeholders. Each subcommittee works to continually update and prioritize the submitted problem statements, communicate research priorities to the groups listed above, and to share the findings of research relevant to the each committee.

The TRB Geometric Design and Operational Effects of Geometrics Committees and the AASHTO Technical Committee on Geometric Design met jointly in the summer of 2002 in Santa Fe, New Mexico. At that meeting, the group participated in a joint 1-day brainstorming session on research issues and priority research topics organized under the chapter headings of AASHTO's *A Policy on Geometric Design of Highways and Streets* (Green Book). After the list of topics was generated, there was discussion regarding the need to develop the list into more than just topics, but into actual problem statements. A 100- to 120-person workshop (similar to the "Beyond the Green Book" workshop held in Texas in 1987) involving organizations and committees such as the ASCE, the National Association of County Engineers (NACE), AASHTO, the Geometric Design Committee, and the Operational Effects of Geometrics Committee was considered as one alternative to generate these problem statements. TRB and AASHTO formed a steering committee to investigate how such a workshop could best be conducted.

A draft plan of a workshop that would facilitate establishing a "framework for research that will improve the geometric design of highways and streets in the 21st century" was presented by the steering committee to the Geometric Design Committee and the Operational Effects of Geometrics Committee at the 82nd Annual Meeting of TRB in 2003. Representatives of the AASHTO Technical Committee serving on the steering committee were also present. The research topics developed at the 2002 midyear meeting, as well as a set of papers that would introduce the topics (combined under a specific heading) and identify research gaps and recommendations for future work, would serve as the starting point of the workshop. Members from the two TRB committees (Geometric Design Committee and Operational Effects of Geometrics Committee) and the AASHTO Technical Committee, along with FHWA and other professionals with expertise in geometric design would meet for 1.5 or 2 days to develop recommendations for a geometric design research program over the next 10 to 15 years. The entire effort would be documented in a final report to serve as the long-range Geometric Design Research Program. The three committees decided to hold the workshop in conjunction with their 2004 midyear meetings in Williamsburg, Virginia.

WORKSHOP PLANNING AND DEVELOPMENT OF AGENDA

The steering committee led the effort of workshop planning, preparation, and agenda development. The steering committee was made of representatives of all interested parties:

- John Mason, Steering Committee cochair;
- Joel Leisch, Steering Committee cochair;
- James Brewer, AASHTO Technical Committee on Geometric Design representative;
- James Bonneson, Operational Effects of Geometrics Committee member and volunteer;
- Ray Krammes, FHWA and Operational Effects of Geometrics Committee representative;
- Christopher Poe, Operational Effects of Geometrics Committee representative;
- Brian Ray, Geometric Design Committee representative;
- Seppo Sillan, FHWA representative; and
- Larry Sutherland, Geometric Design Committee representative.

The steering committee used input regarding general scheduling, possible conflicts, and logistics to determine that the workshop would be a 1-day meeting with the following general format:

- Morning session: White papers would be presented on major topics (to be determined by the steering committee) developed jointly by several authors representing the research, practitioner, and agency perspectives. Approximately 30 min per topic.
- Breakout groups: Discuss fundamental research needed on each topic, time needed, and approximate cost of research. Breakout leaders deliver a 10-min presentation of the findings of their group.
- Action plan: Entire group develops an action plan to achieve consensus on needed research, prioritize needs, and develop a chronology for accomplishing the research. Group also makes recommendations on the next steps to be pursued (such as the development of problem statements or the publication of an E-Circular).

The basis for the white paper topics was to list the priority topics developed at the Santa Fe brainstorming session. Subsequent to the Santa Fe meeting, the topics had been organized under two major headings: Design Controls and Elements and Facility Types. A survey for each major heading was sent to all possible workshop participants and other topical experts. These

TABLE 1 Research Topic Voting

No.	Problem Statement Title	AASHTO Votes	TRB Votes	Total Votes
1	Median Design and Barrier Issues in Urban and Rural Environments	13	15	28
2	Performance-Based Geometric Design Analysis	7	17	24
3	Multimodal Highway Design for "Complete Streets"	6	17	23
4	Investigation of Alternative Geometric Highway Design Processes	8	12	20
5	Horizontal Curve Design Philosophy	4	14	18
6	Right-Turn Interactions and Channelized Right-Turns	5	11	16
7	Ramp and Interchange Spacing	9	7	16
8	Transition Zone Design	5	9	14
9	Ramp Design as a System	3	11	14
10	Safety and Operational Tradeoffs of Freeway Lane and Shoulder Widths	4	9	13
11	Safety, Operations, and Usability Tradeoffs of Road User Groups	2	11	13
12	Safety and Operational Impacts of Four- and Six-Lane Cross-Sections with Raised Versus Two-Way Left-Turn Lanes	8	4	12
13	Superelevation Criteria for Steep Grades on Horizontal Curves	7	4	11
14	Geometric Design Guidelines for Major Intersection Alternatives to Accommodate Multimodal Users	4	7	11
15	Design, Safety, and Operational Considerations of Pedestrian Treatments at Intersections	3	7	10
16	One- and Two-Lane Loop Ramp Design	5	4	9
17	Effectiveness of Midblock Crossing Treatments	0	7	7
18	Intersection Design to Accommodate Pedestrian Crosswalk Cross-Slopes	4	2	6
19	Guidelines for Provision of Sidewalks	4	1	5
20	Safety Effects of Intersection Skew Angle	4	1	5
21	Accommodating Bicyclists on Rural Highways	3	0	3
22	Safety and Operational Effects of Angle Versus Parallel Parking	2	0	2

surveys were intended to further refine the Santa Fe list and determine the focus of the workshop white papers. The results of the surveys indicated that the technical white papers should be prepared on these topics:

- Combinations of design controls/elements;
- User and vehicle controls;
- Rethinking the design process;
- Rural highways;
- Freeways and interchanges;
- Intersections; and
- Urban streets.

The primary objectives of the white papers were to review previous research on the topic and indicate basic research gaps. These papers were presented during the morning session of the workshop and served as the basis for the breakout sessions and the development and prioritization of research needs.

At the conclusion of the breakout group session, strategic planning participants were asked to vote for short-term research needs. Short-term research needs were considered the "highest" priority with immediate pay-off. Detailed problem statements would be prepared at the conclusion of the strategic planning workshop and be included in the next submission of problem statements to the NCHRP. It should be noted that 56 workshop attendees participated in the voting. AASHTO members (22 present) votes were counted separately from the TRB committee members votes (34 present). Each participant was instructed to cast a total of five votes, one each for a topic that they considered a research priority. A list of all 22 problems statements are shown in Table 1 along with the number of votes cast for each research topic. The problem statements are provided in Part III of this document.

PART II

Research Implementation Plan

The Strategic Geometric Design Research Needs workshop in Williamsburg, Virginia, considered five research topics the "highest" priority. This meant that research problem statements would be prepared immediately after the workshop and these statements would be submitted to the NCHRP for consideration in the FY2006 research program. The remaining 17 topics would be considered in future funding cycles (and could also be considered by alternative funding sources such as the FHWA or others) as they represent "high" priority research needs. The five highest priority research topics were:

- Median design and barrier issues in urban and rural environments;
- Ramp and interchange spacing;
- Right-turn interactions and channelized right-turns;
- Superelevation criteria for steep grades on sharp horizontal curves; and
- Performance-based geometric design analysis.

As noted previously, the five highest priority problem statements were submitted to NCHRP for consideration in the FY2006 research program. The "Median Design and Barrier Issues in Urban and Rural Environments" and the "Performance-Based Geometric Design Analysis" projects were selected for funding by NCHRP and designated as projects 22-21 and 15-34, respectively. The "Ramp and Interchange Spacing" and "Superelevation Criteria for Steep Grades on Horizontal Curves" are included as contingency projects in the NCHRP FY2006 program but funds were not available to address these projects.

Table 2 provides a legend for the proposed implementation plan shown in Table 3. Table 4 is a proposed research sequence plan for the entire strategic geometric design research needs program.

TABLE 2 Problem Statement Identifiers Legend for Implementation Plan (see Table 3)

Geometric Design Research Categories	Research Program Sequence
M = Methodology	A = Near Term Phase
C = Criteria	B = Second Phase
H = Highways	C = Third Phase
S = Streets	D = Fourth Phase
I = Intersections	
F = Freeways and Interchanges	

TABLE 3 Proposed Research Implementation Plan

Problem Statement Identifier	Research Topic(s)	Estimated Funding Level ($)	Estimated Project Duration (months)
M/A	Performance-Based Geometric Design Analysis	600,000	36
M/B/C/D	Investigation of Alternative Geometric Highway Design Processes (three projects)	~4,000,000	>36
	Project 1: Critical Review of Geometric Design Policy Formulation	250,000	18
	Project 2: AASHTO Design Model Research (seven parts)	~3,000,000	>36
	• Part 1: AASHTO Horizontal Curve Model	750,000	36
	• Part 2: Roadside Design Criteria in Urban Environments	500,000	36
	• Part 3: Urban Cross-Section Design Values	500,000	24
	• Part 4: Relationship of Level of Service to Substantive Safety	750,000	36
	• Part 5: Influence of Geometric Design Dimensions on Highway Maintenance	300,000	24
	• Part 6: Discretionary Decision Making, Tort Law, Risk Management—Synthesis of State Practice	200,000	18
	• Part 7: Sight Distance Criteria	300,000	24
	Project 3: Alternatives to Current Design Process	500,000	36
C/A	Superelevation Criteria for Steep Grades on Horizontal Curves	300,000	24
C/B	Horizontal Curve Design Philosophy	1,500,000	48
H/A	Median Design and Barrier Issues in Urban and Rural Environments	800,000	42
H/B	Transition Zone Design	500,000	30
H/C	Accommodating Bicyclists on Rural Highways	350,000	36
S/A	Safety and Operational Impacts of Four- and Six-Lane Cross-Sections with Raised Versus Two-Way Left-Turn Lanes	350,000	30
S/B	Effectiveness of Midblock Crossing Treatments	250,000	27
S/C	Guidelines for Provision of Sidewalks	500,000	24
S/D	Safety and Operational Effects of Angle Versus Parallel Parking	275,000	30
I/A	Multimodal Highway Design for "Complete Streets"	300,000	24
I/B	Right-Turn Interactions and Channelized Right-Turns	500,000	24
I/C	Safety, Operations, and Usability Tradeoffs of Road User Groups	500,000	30
I/C	Geometric Design Guidelines for Major Intersection Alternatives to Accommodate Multimodal Users	400,000	30
I/C	Design, Safety, and Operational Considerations of Pedestrian Treatments at Intersections	300,000	24
I/C	Intersection Design to Accommodate Pedestrian Crosswalk Cross-Slopes	500,000	24
I/D	Safety Effects of Intersection Skew Angle	400,000	36
F/A	Ramp and Interchange Spacing	500,000	30
F/B	Ramp Design as a System	500,000	36
F/C	One- and Two-Lane Loop Ramp Design	350,000	18
F/D	Safety and Operational Tradeoffs of Freeway Lane and Shoulder Widths	>$500,000	>36

TABLE 4 Proposed Research Program Sequence
(Corresponding Numbers for Problem Statements in Part III Shown in Parenthesis)

<table>
<tr><th rowspan="2">Research Categories</th><th colspan="4">Research Sequence</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td>Methodology</td><td>Performance-based Geometric Design Analysis (2)</td><td>Investigation of Alternative Geometric Highway Design Processes (4)</td><td>Continued</td><td>Continued</td></tr>
<tr><td>Criteria</td><td>Superelevation Criteria for Steep Grades on Horizontal Curves (13)</td><td>Horizontal Curve Design Philosophy (5)</td><td></td><td></td></tr>
<tr><td>Highways</td><td>Median Design and Barrier Considerations in Urban and Rural Environments (1)</td><td>Transition Zone Design (8)</td><td>Accommodating Bicyclists on Rural Highways (21)</td><td></td></tr>
<tr><td>Streets</td><td>Safety and Operational Impacts of Four- and Six-Lane Cross-Sections with Raised Versus Two-Way Left-Turn Lanes (12)</td><td>Effectiveness of Midblock Crossing Treatments (17)</td><td>Guidelines for Provision of Sidewalks (19)</td><td>Safety and Operational Effects of Angle Versus Parallel Versus Back-in Parking (22)</td></tr>
<tr><td rowspan="4">Intersections</td><td rowspan="4">Multimodal Highway Design for “Complete Streets” (3)</td><td rowspan="4">Right-turn Interactions and Channelized Right-turns (6)</td><td>Safety, Operations, and Usability Tradeoffs Between User Groups at Intersections (11)</td><td rowspan="4">Safety Effects of Intersection Skew Angle (20)</td></tr>
<tr><td>Geometric Design Guidelines for Major Intersection Alternatives to Accommodate Multimodal Users (14)</td></tr>
<tr><td>Design, Safety, and Operational Considerations of Pedestrian Treatments at Intersections (15)</td></tr>
<tr><td>Intersection Design to Accommodate Pedestrian Crosswalk Cross-slopes (18)</td></tr>
<tr><td>Freeways and Interchanges</td><td>Ramp and Interchange Spacing (7)</td><td>Ramp Design as a System (9)</td><td>One- and Two-Lane Loop Ramp Design (16)</td><td>Safety and Operational Tradeoffs of Freeway Lane and Shoulder Widths (10)</td></tr>
</table>

PART III

Research Problem Statements

MEDIAN DESIGN AND BARRIER CONSIDERATIONS FOR HIGH-SPEED DIVIDED HIGHWAYS IN RURAL AND URBAN AREAS

Research Problem Statement

AASHTO's *Roadside Design Guide* (RDG) contains median barrier warrant criteria. The existing criteria consider both median width and average daily traffic volumes as decision-making variables and have not changed since the 1970s. NCHRP Project 17-14: Improved Guidelines for Median Safety is using roadway cross-section and crash data to evaluate the appropriateness of these criteria. The RDG also contains guidelines regarding longitudinal barrier type and placement guidelines for median applications; however, additional guidance is needed to determine which median barrier systems are most cost-effective given a set of field parameters.

The AASHTO's Green Book also contains general median width and median side-slope design guidance that has remained unchanged for many years. Since the vehicle fleet, travel speeds, and traffic volumes have changed dramatically, there is a need to better understand the vehicle dynamics associated with median crossover crashes on high-speed highways in rural and urban areas. Design guidance is needed to supplement median barrier warrant criteria to include the influence of horizontal and vertical alignments; the presence, configuration, and traffic characteristics of interchange entrance ramps; and variations of median side slopes on median-related crashes. For instance, it is important to know if flattening median side slopes reduces the frequency and severity of single-vehicle median-related crashes at the expense of increasing the frequency and severity of multiple-vehicle median-related crashes (i.e., crossover crashes). NCHRP Project 17-14 conducted a before-after evaluation of slope flattening projects in one state; however, a larger sample of depressed median cross-section designs and profiles should be considered. The influence of median surface conditions (e.g., soil type, wet or snow-covered conditions, landscaping) and drainage in depressed medians has not been evaluated and should also be considered to enhance the design-decision process.

In addition to the design guidelines cited, there is a need to better understand median barrier type and placement decisions. Once all of the median design-safety parameters are well-understood, benefit-cost ratios of barrier type and placement guidelines would assist designers in making cost-effective decisions.

In summary, an application tool [Roadside Safety Analysis Program (RSAP)] is available for designers to assess roadside safety design decisions. A similar tool, however, is not available for assessing the cost-effectiveness of median design and barrier installation decisions. Median barrier warrant criteria have been developed to assist designers in determining the need for longitudinal barrier to prevent median crossover crashes. These criteria should be supplemented with additional guidelines that can be used by engineering professionals to determine the safety and cost-effectiveness of various design alternatives on high-speed divided highways.

Literature Search Summary

Research efforts that are either completed or are currently underway that relate to the problem statement include

- NCHRP Project 17-14: Improved Guidelines for Median Safety. This project is using median cross-section and crash data to assess the efficacy of the existing median barrier warrant criteria contained in the AASHTO RDG.
- NCHRP Project 17-11: Determination of Safe/Cost-Effective Roadside Slopes and Associated Clear Distances. While this effort is focused on the roadside area to the right of the travel lanes, its applicability to medians on divided highways should be considered. The objective of this research is to develop relationships between recovery-area distance and roadway and roadside features, vehicle factors, encroachment parameters, and traffic conditions for the full range of highway functional classes and design speeds.
- NCHRP Project 22-12: Guidelines for the Selection, Installation, and Maintenance of Highway Safety Features. The objective of this research is to develop improved guidance for the selection, installation, and maintenance of highway safety features based on the performance concept. Specifically, the research will address
  - Selecting the appropriate highway-safety feature given the characteristics of a site,
  - Installing highway safety features,
  - Maintaining highway safety features to ensure effectiveness over time, and
  - Upgrading existing highway safety features and justifying design deviations or field modifications. This effort was focused primarily on roadside features to the right of the travel lanes and not on the median of divided highways.
- *NCHRP Report 492: Roadside Safety Analysis Program—Engineers Manual*. This project developed a program to evaluate the cost-effectiveness of roadside safety features. It is intended for single-vehicle run-off-the-road crashes and is not suitable for determining cost-effective median design and barrier installation decisions.
- An FHWA Report (FHWA-RD-97-106), *Statistical Models of Accidents on Interchange Ramps and Speed Change Lanes*, suggests that ramp traffic volumes explain much of the variability in crashes at interchange locations. The area type, mainline traffic volume, ramp configuration, and ramp–speed change lane lengths were also considered in the analysis.
- Several state transportation agencies, including California, Florida, North Carolina, Pennsylvania, and Washington have conducted safety and cost-effectiveness evaluations of median crossover crashes. Although these efforts have focused primarily on median width and traffic volumes, they do contain median-involved crash statistics.

Research Objective

One objective of this research is to determine the influence that various median design variables have on safety. Horizontal and vertical alignment, interchange presence, median width, traffic volumes, and median side slopes must all be considered. Median soil conditions and landscaping should also be considered in the research. It is envisioned that statistical modeling, simulation, and other experimental methods should all be considered as viable research methodologies. Economic evaluations should be considered to verify that the analytical outcomes are feasible. Practitioners would then be able to assess the safety trade-offs of various design decisions.

A second objective is to determine the safety and cost-effectiveness of various median barrier type and placement guidelines. Future research should clearly outline the economic feasibility of various barrier installations given a set of field parameters. For instance, it is important that barriers be located such that when redirecting vehicles, a subsequent high-speed crash does not occur. Practitioners would also benefit from guidelines outlining how various barriers performed during impact given a set of field conditions (e.g., median cross-section design, weather conditions, landscaping, etc.). A systematic procedure for designers to make median barrier type and placement decisions is needed.

To accomplish the research objectives, the following tasks should be completed:

- **Task 1:** Literature review of previous research to identify design variables that influence median safety, statistical models of median-related crashes, roadside safety guidelines, and median barrier performance information.
- **Task 2:** Describe methods that could be used to better understand the dynamic associated with median-related crashes as they relate to median design variables, traffic characteristic and/or driver performance. Include methods for crossover crashes and single-vehicle crashes with median barriers, rollovers, and other crash types. A procedure to identify the frequency of median excursions that do not result in a reportable crash should also be considered.
- **Task 3:** Describe methods that could be used to improve guidance related to median barrier type and placement guidelines. Possible methods include an in-service performance evaluation or cost-effectiveness analysis using safety and roadway inventory data, among others. All of the approved barrier in the AASHTO RDG should be considered as should other barrier systems that are gaining nationwide appeal (e.g., Brifen Wire Rope Safety Fence).
- **Task 4:** Prepare a work plan, with estimated costs, that outlines the various methods being considered. This includes, but is not limited to, vehicle simulation, field data collection and analysis, finite element modeling, and cost-effectiveness evaluation. The intent of this task is to provide the panel with information that can be used to determine which evaluation methods are most feasible for the project.
- **Task 5:** Submit an interim report to the panel containing all of the elements described in Tasks 1–4. Meet with the panel to review the report and discuss the second project phase.
- **Task 6:** Execute the work plan that is agreed to by the panel.
- **Task 7:** Prepare and submit a draft final report outlining the findings of the research. This document should contain a decision-making methodology that practitioners can use to evaluate various median designs, including barrier type and placement guidelines. Case studies describing the performance of various median barrier systems should also be included, especially for those barrier systems that are not yet included in the AASHTO policy.
- **Task 8:** Meet with the panel to discuss the draft final report and findings from the research.
- **Task 9:** Submit the final report.

Estimate of Problem Funding and Research Period

Recommended Funding

It is anticipated that the research outlined in Task 5 above would cost approximately $800,000. This includes $500,000 to accomplish the first objective and $300,000 to accomplish the second objective.

Research Period

It is anticipated that the research described would take approximately 42 months to complete.

Urgency, Payoff Potential, and Implementation

The urgency and potential payoff of this research is very high. Various state transportation agencies are being pressed to consider revised median designs or installation of median barriers on divided highways to prevent severe, high-speed median-related crashes. Although NCHRP Project 17-14 is intended to update the existing AASHTO RDG median barrier warrant criteria, there is additional research needed to supplement the revised warrants. The economic benefit of preventing median-related fatalities could be very high if a systematic procedure is developed to assist designers in determining where longitudinal a barrier should be located once the decision is made to install it.

It is recommended that this research develop a protocol that designers can use to evaluate median design and median barrier placement decisions. This procedure should be included in the AASHTO RDG and could also be included in future versions of the RSAP.

Problem Statement Development

- Eric T. Donnell, Pennsylvania State University;
- Kathleen A. King, Ohio DOT;
- Paul A. Dorothy, Burgess & Niple; and
- Don Arkle, Alabama DOT.

PERFORMANCE-BASED GEOMETRIC DESIGN ANALYSIS

Research Problem Statement

AASHTO's Green Book includes a geometric design process to guide designers toward a range of dimensional values for various features (e.g., curvature, grades, and traveled way widths). The recommended range is usually specified through a single limiting value (i.e., maximum, minimum), such as for bridge width, lane width, and radius. For some variables, upper and lower values are suggested, as with normal cross-slope. The current geometric process is intended to provide operational efficiency, safety, and comfort for the motorist.

For any given geometric design situation, many potential alternative solutions exist. In evaluating the adequacy of a facility's geometric features, designers and analysts often compare actual (existing) and proposed values to those recommended by the Green Book. Such comparisons are often misinterpreted and misrepresented as indications of acceptable or optimal design. In fact, these comparisons are usually too simple to allow any meaningful insights as to how a facility will serve various user groups. In an era of context sensitive design/context sensitive solution (CSD/CSS) and proactive public involvement, stakeholders and decision-makers desire reasonable insights as to the results of selecting among different design choices. The current design process does not quantitatively characterize future facility performance. A set of tools is needed to more explicitly characterize the effects of geometric design factors on future facility performance.

Literature Search Summary

The term or practice of "performance-based geometric design analysis" has not been the subject of previous research. However, the term lies at the convergence of both public policy and engineering trends that have been studied extensively. Within publicly funded functions, there is an increasing demand for results (i.e., performance) rather than process. Hence, the principles of performance-based systems (e.g., measurement) are amply reported in the literature. Performance-based design systems are used for transportation structures and, as revealed by a search of TRIS, numerous research studies have been published. The findings are not directly related to the proposed research. There are a number of completed and ongoing geometric analysis research projects that are relevant to the proposed research. The most notable of these include development of Interactive Highway Safety Design Model (IHSDM) and the Highway Safety Manual (HSM), funded by FHWA and NCHRP. This problem statement was developed with full awareness of the IHSDM and HSM efforts and calls for coordination of the performance-based geometric design analysis research with those activities.

Research Objective

The research project should produce: (1) a user's guide for conducting geometric performance analysis using available technology, and (2) a detailed plan for developing performance analysis techniques and tools not currently available. Both products will address application to the project development and geometric design processes. The analysis tools will be used by project design teams (i.e., agencies, consultants) in conjunction with, or as part of, design policies (i.e., Green Book, DOT design manuals).

Accomplishment of the project objective will require the following tasks:

- **Task 1:** Review and summarize literature and research related to development of performance-based processes in other disciplines, transportation related and otherwise.
- **Task 2:** Identify performance characteristics of interest to transportation project stakeholders and decision makers. Performance should be viewed broadly to include consideration of pedestrians, motorized and nonmotorized vehicles, transit, special populations (e.g., disabled, elderly), safety, mobility, design consistency, speed, land access, enforcement, and life-cycle costs.
- **Task 3:** Review completed research and summarize known relationships between facility geometric elements and design values to performance. Indicate the quantitative and nonquantitative methods of characterizing these relationships. Identify, assess and summarize the capabilities and limitations of existing and developing analytic techniques and technologies to

relate geometric design decisions to performance [e.g., IHSDM, *Highway Capacity Manual* (HCM), HSM]. The assessment should cover the range of common facility types and elements (e.g., multilane rural highways, intersections). Evaluate the usefulness of prediction tools for actual design and analysis applications, with an emphasis on accuracy. Other characteristics to assess include data requirements and user factors (e.g., technology, interface, expertise, license fees).

- **Task 4:** Evaluate current use of performance-based analysis in the project development and design process (i.e., planning, programming, scoping, functional design, and final design). Develop an outline for a guidance document on how performance-based geometric analysis using currently available techniques and technologies can improve common state DOT processes (e.g., design exceptions, alternative evaluation).
- **Task 5:** Conduct a requirements analysis for a comprehensive performance-based geometric design analysis system. Develop optional architectures to meet the identified functionality requirements. The term "architecture" refers to the framework for constructing the performance-based geometric design analysis system and how information is exchanged. Also, assess how the comprehensive performance-based geometric design analysis system would be applied to the project development process. Evaluate the feasibility of developing the capabilities and identify critical issues that would need to be addressed or overcome to enable routine application (e.g., data requirements, tort liability). Rank the various options in terms of technical and technological feasibility, usefulness across the diverse range of DOT users and development cost.
- **Task 6:** Prepare a draft interim report summarizing the results of Tasks 1 through 5. The draft interim report will identify significant issues and detailed recommendations for executing Tasks 8 through 10.
- **Task 7:** Meet with the panel to review the interim report. Following the meeting, the panel will provide comments on the draft interim report and Task 9 direction. Prepare a final interim report based on panel comments.
- **Task 8:** Expand on the Task 4 effort to produce a handbook-like publication for practitioners. The publication should include presentation of performance-based analysis techniques and also reference other applicable, commonly available techniques. Include examples. Identify general characteristics and specific passages of the Green Book that should be revised or augmented so that application of the Green Book and performance-based geometric design analysis are complementary.
- **Task 9:** Develop a detailed plan for the development of one or two optional comprehensive, integrated geometric-performance analysis architectures as designated by the panel. Other aligned current and anticipated research should be recognized. At a minimum, the analysis of architecture(s) should address
  - Applicable facility types and elements,
  - Performance characteristics and corresponding metrics,
  - Maturity and accuracy of analysis techniques,
  - Data requirements and sources, and
  - Development cost.

  Describe how incremental progress and final attainment of the performance-based geometric design analysis capability is likely to affect the project development and geometric design processes. Identify impacts that will be positive, negative, and unknown.
- **Task 10:** Prepare a draft final report describing how the project was conducted and include two appendices: (1) a guide on how to conduct geometric-performance analysis using

available technology, and (2) a plan for development of comprehensive performance-based geometric design analysis system, to include one or two architectures and their respective strengths and weaknesses. The second appendix will include an evaluation of how comprehensive performance-based geometric design analysis capabilities should be incorporated into the project development and geometric design processes.

- **Task 11:** Meet with panel to review the interim report.
- **Task 12:** Prepare a final report based on panel comments.

Estimate of Problem Funding and Research Period

Recommended Funding

$600,000.

Research Period

36 months.

Urgency, Payoff Potential, and Implementation

The research products are needed to reflect the current technical and policy realities of facility design. The current geometric design process was developed for highways on new alignment and with primary consideration of motorists. Current emphasis areas are CSD/CSS, consideration of diverse groups and system preservation. The tools developed under the proposed project will provide useful information from agency decision makers and stakeholders on the likely consequences of various geometric design alternatives.

Problem Statement Development

- Kevin Mahoney, Pennsylvania State University;
- James O. Brewer, Kansas DOT;
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MULTIMODAL DESIGN TO CREATE "COMPLETE STREETS"

Research Problem Statement

There is increasing recognition that successful highway designs, and particularly successful designs for urban streets, must effectively serve all transportation modes and provide an appropriate balance among those modes. An effective street design must accommodate vehicles and users of all types: passenger vehicles, trucks, pedestrians, bicycles, and transit. Facilities for each transportation mode must be provided with the modes safely separated. Additionally, space must be provided for roadside hardware and underground and above-ground utilities. Further, the design must fit within the context of adjacent development. Any street design that successfully meets all of these needs can be referred to as a “complete street.”

The need for “complete streets” has been recognized, and much has been written about the importance of multimodal considerations. However, there is little practical guidance on how to effectively serve all transportation modes along the same facility or corridor. Most available design guidance deals with design for a particular mode but not with how to serve the competing needs of multiple modes.

Part of the challenge of creating multimodal design is to recognize that the mix of transportation modes, and the priority that should be given to each, differs by functional class. Thus, there is a need to determine the primary and secondary users of each highway functional class and assess how best to serve the mix of users found on each class. Another challenge is how to fit a complete street design into an existing environment with right-of-way and other design challenges.

Literature Search Summary

A literature search has found extensive work on multimodal planning, especially on an area-wide basis, but very little on multimodal design at the level of an individual facility.

Research Objective

The objective of the research is to identify the mix of users, including primary and secondary users, that need to be served on various highway functional classes; to identify the types and designs of facilities needed to serve each of those types of users; to develop examples showing how those types of facilities have been or could be designed effectively as part of the same corridor; and to present the results in the form of multimodal design guidelines for specific highway functional classes. The first objective—identifying mixes of user on specific functional classes—should address the full range of highway functional classes. The latter objectives could also address a range of functional classes or could focus on selected functional classes of interest.

For specific functional classes, the research should develop examples of projects that have effectively implemented multimodal designs and should highlight the features of those designs that allow multiple transportation modes to be served both safely and effectively. The research should also suggest new concepts that could be considered in future projects.

The design guidance developed should be both integrated and multimodal. The guidelines should not discuss each transportation mode in separate chapters. An adequate amount of separate material on each mode is available in other sources. Instead, the guidelines should focus on fitting the individual modes together into an integrated facility that meets the needs of each in a balance appropriate for the functional class of the facility. The guidelines should indicate the expected operational and safety performance of alternative approaches to facility design.

Estimate of Problem Funding and Research Period

Recommended Funding

$300,000.

Research Period

2 years.

Urgency, Payoff Potential, and Implementation

This research topic was selected by the AASHTO Technical Committee on Geometric Design and TRB's Geometric Design Committee and Operational Effects of Geometrics Committee at their combined meeting in June 2004 as a priority issue from among a broader set of problems considered. The research is needed to address an unresolved issue in highway geometric design. The research results should be presented in a stand-alone document that can be used to supplement existing design policies and manuals.

Problem Statement Development

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INVESTIGATION OF ALTERNATIVE GEOMETRIC DESIGN HIGHWAY DESIGN PROCESSES: STRATEGIC RESEARCH

Research Problem Statement

Accomplishing the design of a highway—its three-dimensional features (alignment and cross-section) and appurtenances to provide for drainage, traffic control and safety, requires a well-defined process. AASHTO and its predecessor, AASHO, developed a highway design process that has been essentially unchanged since it was formalized in the 1940s. The current process can be briefly outlined as follows.

- It is dimensionally based, with design values for physical dimensions directly derived from tables and charts.
- It requires establishment of fundamental design controls including location, terrain, and functional classification that represent the context in which the highway exists.
- It requires designers to make choices for other design controls from within established ranges. These primarily include design speed and design traffic, which includes not only volume but also type of vehicle.
- It is based on selection of a design speed, and in some cases design traffic, other physical dimensions are directly derived or obtained for minimum dimensions (e.g., lane width, curve radius) and/or maximum dimensions (e.g., grade) as appropriate for the design controls and assumptions.

- Direct performance measures are in terms of mobility such as speed and level of service. In many cases, costs versus benefits are also an integral part of the design process. Safety is presumed through proper application of the process and technical guidance, but is nonetheless an indirect outcome of the process.
- It relies on relatively simple mathematical design models as the basis for derivation of dimensional values.

A Critique of the AASHTO Design Process and Models

There is an underlying philosophy and understanding about the design process and AASHTO policies that should be understood. The design process and roles of highway design professionals have long been viewed as being focused on providing the highest levels of mobility possible or feasible. Within this framework, speed is viewed as a surrogate for quality. The implication is that a well-designed highway is one that enables drivers to drive as fast as possible and hence to minimize their travel times. Cost-effectiveness, and in particular, minimizing construction costs is also central to execution of the process. Within this framework designers generally "design to the minimum," with the underlying assumption being the minimum is good enough, and anything greater is inherently more expensive and hence not cost effective.

Design Models

During the past 60 years much has changed in the vehicle fleet, knowledge about driver characteristics, and safety and operations. AASHTO has committed to continually update its policies. Yet, for the most part, such updates have not altered the fundamental process or even, in most cases, the basic design models. For example, the definition of design speed has changed, yet its role relative to the fundamental execution of the process remains essentially unchanged from the 1940s. Design models for horizontal and vertical alignment [e.g., the AASHTO horizontal curve and stopping sight distance (SSD) models] have undergone dimensional revisions over the years, yet the fundamental model forms and assumptions (many of them simplifying) have not changed. Mathematical simplifications driven by lack of information and/or ease of computing may no longer be appropriate, and may result in suboptimal outcomes in the aggregate.

Construction Versus Reconstruction

In the 1930s and 1940s, continuing into the 1960s, most of the work performed by highway engineers involved construction of highways on new alignment. While such work continues, for the most part most highway agencies' programs are heavily weighted to reconstruction or rehabilitation, and not construction on new alignment.

Current design policy and processes treat new construction the same as complete reconstruction. As is readily apparent, the two are inherently different in terms of the context in which the designer is operating. Reconstruction along an existing alignment by definition means retention of the basic alignment within existing right-of-way, with its possible expansion or minor revision. In the former case, the constraints and controls that influence the design are fixed. Also, there is (or should be) a known traffic operational and substantive safety record that may be considered as part of the design decision-making process. For new alignments, there is no history of operational performance; therefore, assumptions and reference to similar facilities or conditions in the area drive decision-making. However, designers are selecting a right-of-way from a wide range of corridor choices. Under current policy, both new construction and reconstruction are considered equivalent and treated identically according to AASHTO. It might appear that the substantial differences between the two types of problems warrant their separation within the design process.

Interdisciplinary Design Decision Making

The highway design process is now recognized as being intertwined with environmental and public stakeholder input processes. Decisions involve investigation of options or choices, interaction with other technical disciplines, and a collaborative approach to decision making. Design decisions are increasingly seen as being interdisciplinary in nature, and not restricted to highway engineering or civil engineering discipline.

Research Objective

There are many questions about the current design process. Two major questions exist:

- Within the current design process, what changes or updates are necessary to incorporate the latest traffic operations and safety knowledge?
- Is the current design process moving forward? Or is there evidence that fundamental changes related to public policy or other factors are needed?

The following program outlines research to address the two major questions by focusing on design decision support (decision making):

- Does the structure of the current AASHTO policy formulation meet the needs of all stakeholders?
- What gaps exist in the current Policies and how should those gaps be filled?
- Are there other model processes that may be more applicable and appropriate? If so, what are the organizational, institutional, legal, and cultural issues associated with replacing the current AASHTO formulation and how should these issues be addressed?

Project 1: Development of a Research Program to Refine Geometric Design Models and Process

Objective: Perform a critical review of the format, structure and basic assumptions included in the AASHTO Policies governing geometric design of highways and streets. There is a need to review and critique the structure of current AASHTO policy formulation to assure it meets the needs of all stakeholders. The project should identify the current applicability of the source data that was used a basis for the past research that formulated the AASHTO policies. Such policies primarily include Green Book (*1*) and *Roadside Design Guide* (*2*), as well as the *Guide for Achieving Flexibility in Highway Design* (*3*). The issues to be addressed through this research include:

- **Task 1:** New construction versus reconstruction. As currently written, the AASHTO Green Book (*1*) considers new construction and reconstruction to be similar in nature, and to be treated as new construction from the perspective of applicable design policy. Reconstruction of existing highways is in many respects fundamentally different from highways on new alignment. There is a need to revisit this policy assumption and make recommendations regarding retention, development of separate policies for reconstruction, or revision to the formulation of design criteria reflecting unique reconstruction issues.

- **Task 2:** AASHTO design models. There is both research and anecdotal evidence that many of the AASHTO design models and assumptions within the design models are outdated, overly simplistic or understood not to reflect actual traffic operations. Design models of interest include the horizontal curve model, SSD model, passing sight distance (PSD) model, maximum/minimum grade and length of grade models, minimum vertical curve length model, cross sectional guidance, and roadside encroachment models. AASHTO presents basic geometric guidance information inconsistently. In some cases (as with rural highway cross section and roadside design guidance) traffic volume is a direct, core input to design policy. In others (as with SSD and horizontal curvature) the criteria are volume insensitive. Similarly, functional classification and area type plays a varying role in the formulation of design inputs within certain models. A critique of all models is needed as to their adequacy and applicability across the range of location, traffic conditions, and functional classification. This research effort should directly involve the AASHTO Geometric Design Task Force and Subcommittee on Design. Recommendations as to needed refinements in the design models would lead to follow-up research.
- **Task 3:** Related research. NCHRP Project 15-25: Alternatives to Design Speed for Selection of Roadway Design Criteria (*4*) should provide background and focus for some of the effort. However, the issue goes beyond design speed alone.

Funding and Period of Performance Funding: $250,000; schedule: 18 months

Project 2: AASHTO Design Criteria and Design Model Research

Based on the findings from the first project, a series of research studies to fill the gaps in design policy formulation would occur. The following issues (which would need confirmation) are believed to represent core needs:

- **Task 1:** AASHTO Horizontal Curve Design Model
  - Objectives: (1) Develop a new model to define design criteria, and (2) develop relationship between curve design criteria deficiency and substantive safety.

  Research has demonstrated the inadequacy of the AASHTO horizontal curve model in describing actual vehicle operations. The model itself is based on providing comfort. The model does not include a volume component, does not vary by functional classification, assumes passenger car operation, and does not consider or account for grade effects. The model is an operational model, and not directly related to substantive safety research or a risk assessment. The model also focuses solely on curve radius, omitting any reference to curve length or central angle. Knowledge on driver operating behavior in response to upstream conditions has been established through research, but such knowledge is not incorporated in the AASHTO model. A review of the model, including its background, design inputs, and applicability to the full range of conditions is needed. Reference to design practice by other countries should be included. Results of this research would produce revised criteria and/or design models for horizontal curves across the full range of highway types and conditions.

− Funding and Period of Performance: Funding: $750,000; Schedule: 3 years

- **Task 2:** Roadside Design Criteria for the Urban Environment

− Objective: Develop relationship between roadside design criteria deficiency and substantive safety.

Roadside design is among the most challenging tasks for designers in the urban environment. Through research, AASHTO has produced a *Roadside Design Guide* (*2*), which provides technical background and guidance on design of clear zones, slopes and ditches, and barriers. Unfortunately, the research and much of the definitive guidance in the *Roadside Design Guide* (*2*) do not reflect urban conditions. Of particular concern is the lack of definitive information concerning vehicle encroachment behavior on roadways with curbs (both slope and vertical faced). Also, in the urban environment there are competing uses for the space considered part of the clear zone. Such uses include bicycles and pedestrian paths, and space for utilities and other objects.

[Note: This project may be addressed substantially by ongoing research under NCHRP 16-04 (5). It is listed here to acknowledge the need and make sure that this issue is recognized as being of fundamental importance.]

− Funding and Period of Performance: Funding: $500,000; Schedule: 3 years

- **Task 3:** Cross-Section Design Criteria for the Urban Environment

− Objective: Develop relationship between cross section design criteria deficiency and substantive safety.

Recently completed research [NCHRP Project 20-7, Task 171) (6)] highlights inconsistencies and questions regarding AASHTO policy guidance for urban facilities. Other recent research has established the importance of medians, differences in median types, and value of access control in urban street operational quality. Urban streets by their nature are generally constrained (i.e., available dimensions are frequently less than those considered desirable) and multiple uses of the limited space are typical. There is a need for AASHTO to revisit cross sectional guidance in the Green Book (*1*) and RDG (*2*), looking at the urban cross section in its totality, including lanes and medians of all types (and their widths), and border areas (including clear zones and space for pedestrians). Definitive guidance for total cross section design is needed for the full range of functional classes, design speeds, design vehicle, design user and traffic volumes.

− Funding and Period of Performance: Funding: $500,000; Schedule: 2 years

- **Task 4:** Relationship of level of service (LOS) to substantive safety.

− Objective: Establish relationship between substantive safety and LOS for the range of highway types and contexts.

Selection of a design LOS is a fundamental decision made at the beginning of the design process. Such choices generally influence sizing of a highway (number of lanes, intersection channelization, etc.). Design policies and resultant design dimensions, though, are typically independent of such choices. The AASHTO policy provides guidance for appropriate LOS, but these are based on mobility as the primary input value and have not been revisited for over 30 years. AASHTO recently endorsed the notion of choice in selecting an appropriate LOS to reflect the unique design context. And, quite clearly, in many cases an ideal LOS can not be achieved for practical, context specific reasons, leading designers to select a LOS lower than that suggested by AASHTO. This issue is prevalent in urban areas on facilities of all types, but also in certain suburban and rural contexts.

Much is known about the operational effects of varying design dimensions; but there is little knowledge that directly relates congestion measures to safety. Such knowledge would better inform decisions by designers. There is some research by Lord and others (*7*) as well as much anecdotal evidence of a relationship between substantive safety and LOS. There is a need to establish any such relationship for the range of highway types and contexts, to enable more informed decision-making as part of the design process.

− Funding and Period of Performance: Finding: $750,000*; Schedule: 3 years*

*Funding and schedule could be adjusted based on priorities to address this issue for the full range of highway functional classes. Budget and schedule estimate assumes focus on arterials, major intersections, and controlled access facilities.

- **Task 5:** Influence of geometric design dimensions on highway maintenance.

− Objective: Develop relationship between design dimensions and maintenance costs/considerations.

The AASHTO policy contains much technical guidance on design dimensions. Not all such guidance is based on explicit safety considerations. Indeed, many recommended practices are based on enabling or facilitating highway maintenance, or in reducing the cost of such maintenance. Unfortunately, such considerations are not well understood by users of the Policies.

There is a need to conduct a thorough review of the key geometric elements in the AASHTO policy with respect to their influence on highway maintenance activities and costs. Moreover, there is a need to publish any known cost or other value relationships, to both refine the policies and enable more informed decision making. Issues such as the benefits of paved shoulders (remove edge drop-offs), paved versus unpaved roads, and superelevation practices are generally understood, but more knowledge would be useful, particularly given our need to understand the full value of any dimension held out as a minimum threshold.

Key design elements that should be considered include lane width, shoulder width, bridge width, horizontal curvature, vertical curvature, grade, SSD, cross-slope, superelevation, and vertical clearance.

− Funding and Period of Performance: Funding: $300,000; Schedule: 24 months.

- **Task 6:** Discretionary decision making, tort law, and risk management—state practices.

− Objective: Prepare a synthesis of state practices related to discretionary decision making, tort law, and risk management.

The design exceptions process is a central piece of design decision making. A recent *NCHRP Synthesis of Highway Practice* report (*8*) outlined practices within DOTs in the area of design exceptions. While the general principles of tort law and legal risk are common, actual state laws and court precedents vary widely. Many designers do not fully understand the actual risk associated with design decision making in their state. Many designers firmly believe that going outside published standard represents an unacceptable tort risk. Conversely, there is a misunderstanding that adherence to a minimal standard constitutes 100% protection from a suit. Indeed, there is a level of concern among many in the design community that the engineering profession has lost control over design decisions, that we have become overly defensive in both our practices and our outcomes. It would be useful to assemble and synthesize the current status of tort laws and court precedents relative specifically to discretionary decision making. Also of interest would be a review of exemplary risk management practices by state DOTs, including design review, documentation and document management practices to support decision making and legal protection.

- Funding and Period of Performance: Funding: $200,000; Schedule: 18 months.

- **Task 7:** AASHTO sight distance design models.
  - Objectives:
    1. Evaluate and, if needed, develop a new model to define SSD criteria,
    2. Develop relationship between SSD criteria deficiency and substantive safety,
    3. Evaluate and, if needed, develop a new model to define intersection sight distance (ISD) criteria,
    4. Develop relationship between ISD criteria deficiency and substantive safety,
    5. Evaluate and, if needed, develop a new model to define PSD criteria, and
    6. Develop relationship between PSD criteria deficiency and substantive safety.

Much recent research has addressed design criteria for sight distance. *NCHRP Report 400* (*9*) resulted in a revised model for SSD as well as revised design values for SSD and for vertical and horizontal alignment. *NCHRP Report 383* (*10*) presented new design models and values for ISD. Both research reports resulted in changes to AASHTO design policy. NCHRP Project 15-26: Passing Sight Distance Criteria (*11*) is currently underway. It will presumably accomplish a similar mission—revisiting and updating as needed the passing model and resultant design values.

All current and presumably future models are based on the fundamental AASHTO design speed model. The SSD model values were revised, but the basic operational model was not fundamentally changed. The models are not sensitive to either functional classification or traffic volume. Widespread advances in in-vehicle technology, incorporating advanced warning and even in-vehicle control may influence design policy. Depending on the results of the above research, there may be a need to revisit design approaches or criteria for one or more sight distance parameters.

- Funding and Period of Performance: Funding: $3,000,000; Schedule: 36 to 60 months.

Project 3: Alternatives to the AASHTO Design Process

Objective Develop a recommended design process that reflects the explicit consideration of performance (LOS, safety) and promotes efficient, if not optimal, combination of design elements to yield designs that are cost-effective when considering life-cycle benefits and costs.

Project 1 would address the building of our knowledge base on the fundamental technical inputs to current geometric design features. Implicit in Project 1 is the assumption that our current process will continue to be used. However, there are other model processes that may be more applicable or appropriate. There is a need for the highway design community to step back and ask whether other design decision models are better suited.

This project includes these tasks:

- **Task 1:** Research design decision models or approaches used elsewhere either by transportation or highway agencies, or in other technical disciplines;

- **Task 2:** Seek out additional models, characterize their advantages and disadvantages; and
- **Task 3:** Address the organizational, institutional, legal, and cultural issues associated with replacing the current AASHTO approach.

The following discussion highlights some, but not necessarily all, of the potential alternative design model approaches:

Performance-Based Design Mahoney (*12*) has written about the need for and value of performance based design. Design values would be produced based on an explicit determination of their performance (rather than the indirect manner as is currently the case). Such an approach more closely mirrors other engineering and technical disciplines. Some research efforts (most notably, those dealing with development of AASHTO design criteria for very low volume local roads) have acknowledged a performance basis for determination of criteria where risk is low. So, the notion of relating basic design dimensions to some measure of performance or risk is not new.

Design Domain Robinson (*13*) has written of the concept of design domain, which is now part of Canadian geometric design practice. The concept of design domain, introduced in the new (Canadian) guide (*14*), is intended to ask the designer to select design criteria from ranges of values considering the costs and benefits of the selected criteria.

This concept recognizes that

> "A well-designed facility necessarily provides a balance between a number of design objectives such as level of service, cost, environmental impact, and its level of safety. Because such a balance must reflect local values and policies, it will not necessarily be uniform across all jurisdictions or road agencies. Nor will it be constant with time…."

The design domain can be thought of as a range of values that a design parameter might take, as illustrated in Figure 1.

Designers must choose a solution reflecting consideration of explicit value-based trade-offs. According to Robinson (*13*) "In the lower regions of the domain for a single design parameter, resulting designs are generally considered to be less efficient or less safe – although also perhaps less costly to construct. In the upper regions of the domain, resulting designs are generally considered to be safer and more efficient in operation, but may cost more."

The notion behind design domain is that it requires designers to make explicit choices, reflecting specific conditions and referencing relevant, site-specific data and information. Proponents of the design domain assert that

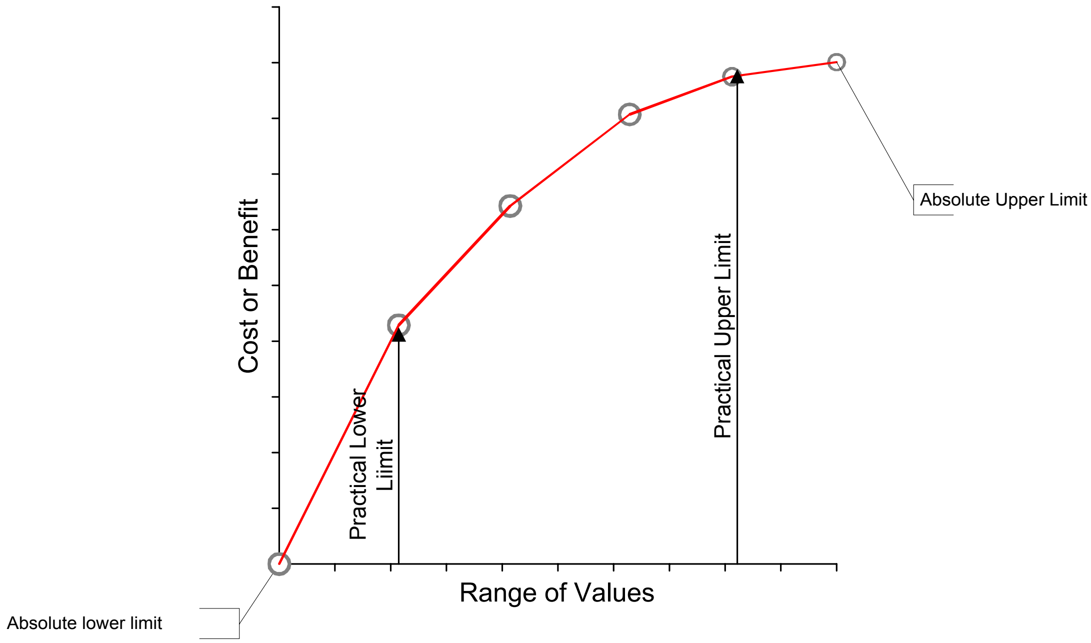

FIGURE 1 The design domain concept. (Notes: The value limits for a particular criterion define the absolute range of values that may be assigned to it. The design domain for a particular criterion is the range of values, within these limits, that may be assigned practically to that criterion. Source: *1999 Canadian Geometric Design Guide: Road Safety Initiatives*, J. B. L. Robinson, Delphi Systems Inc., Canada, Gerald Smith, UMA Engineering, Ltd., Canada.)

- "It is more directly related to the true nature of the roadway design function and process, since it places a greater emphasis on developing appropriate and cost-effective designs rather than those which simply meet standards;
- It directly reflects the continuous nature of the relationship between service, cost and safety, and changes in the values of design dimensions. It reinforces the need to consider the impacts of trade-offs throughout the domain, and not just when a "standard" threshold is crossed;
- It provides an implied link to the concept of Factor of Safety, which is commonly used in other civil engineering design processes where risk and safety are important."

Design Through Optimization There are analytical processes (e.g., multi-attribute utility analysis) that incorporate weighing of widely disparate values directly into an optimization of any given decision. Such processes are ideally suited to the complex context-sensitive world. They produce a highest value solution reflective of technical assessment of many individual criteria of interest. For example, deriving an optimal solution for a specific project may involve an approach that includes value functions for optimizing traffic throughput, minimizing crashes, minimizing footprint encroachments on specific land uses, minimizing noise, optimizing pedestrian access, and minimizing costs.

Central to such an approach is the ability to vary the relative importance or weights of the individual criteria to reflect unique conditions. This process thus directly incorporates ‘external’ factors within the design process itself (rather than in a reactive or external manner as is the case today). Such a process would inevitably produce roadway designs and footprints that would differ from one location to the next, such difference reflecting differences in local context, project objectives and relative values.

Current Related Research This research is fundamentally unique. AASHTO has commissioned NCHRP Project 15-25: Alternatives to Design Speed for Selection of Roadway Design Criteria (*4*) which is to look at alternative approaches to the use of design speed as the fundamental input. However, Project 15-25 does not appear to address the far-reaching implications of a design approach that fundamentally differs from the AASHTO approach.

Funding and Period of Performance

Funding

$500,000.

Schedule

36 months.

Problem Statement Development

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- David McDonald, Hanson Professional Services, Inc.

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HORIZONTAL CURVE DESIGN PHILOSOPHY

Research Problem Statement

While recent research and synthesis efforts have examined/reported on individual design elements of horizontal curves, neither a generalized safety relationship between radius of curvature and design speed nor a comprehensive study of the "minimum radius" model has been conducted since its initial adoption by AASHTO's. Research is needed to more fully address the safety and operational issues related to the geometric design procedures for horizontal curves. The principal knowledge gaps include

- Definitive data on a relationship between the distribution of available side friction factors (pavement type/conditions) and net accelerations (longitudinal, lateral and vertical) by different vehicle classes [large vehicle (SUVs, trucks, buses) overturning/rollover thresholds], tire properties, and curvature classes.
- Appropriateness of the minimum radius equation to capture the relationships/interactions of vehicle characteristics (over simplification of the "point-mass" model), driver's human factors tolerances (e.g., acceleration limits, rollover potentials, reaction times), operating conditions on various functional classes of roadways, roadway elements (turning roadways, interchange ramps, at-grade intersection turning radii), effects of vertical alignments, and respective vehicle operating speeds approaching and through the actual accommodated horizontal curves.
- Sight distance consideration on alignments where combined horizontal, vertical and cross sectional elements are present.
- Safety performance measurements and collision prediction models for curved roadway segments.

Literature Search Summary

Research efforts that are either recently completed or are currently underway that relate to the problem statement include:

- *NCHRP Report 439: Superelevation Distribution Methods and Transition Curves* recommended changes to the distribution of lateral acceleration via Superelevation transitions on roadway sections between tangent alignments and a horizontal curve.
- *NCHRP Synthesis of Highway Practice 299: Recent Geometric Design Research for Improved Safety and Operations* cites various studies addressing horizontal curve designs for safety and operational issues associated with passenger cars and trucks.
- *NCHRP Report 500: A Guide for Reducing Collisions on Horizontal Curves—Volume 7* provides general guidance on improving or restoring superelevation and modifications to horizontal curvature.
- Ongoing research via NCHRP Project 15-25: Alternatives to Design Speed for Selection of Roadway Design Criteria is envisioned to provide guidance on the selection of "design" speed for various geometric design elements.

Research Objective

The principal research objectives include

- **Task 1:** Validation and appropriateness of current limiting values used in horizontal curve designs.
- **Task 2:** Identification and implications of the pertinent safety relationships associated with the respective limiting values.
- **Task 3:** Development of alternative horizontal design formulae, models or criteria based upon the resulting validation and safety findings.
- **Task 4:** Testing and calibration of the recommended horizontal curve design criteria, policies or procedures.

This research should assess the limiting values used in current AASHTO policy for superelevation rates and side friction demands. The study would consider the broad range of vehicles, various functional classes of roads and streets and commensurate operating speeds. Research activities would represent observed in-field conditions, closed track data, model simulation/calibrations and laboratory testing/validation. Collected data would represent the continuum of driver/vehicle/roadway characteristics and would represent horizontal curve designs across the range of high speed and low speed alignments. Research is particularly needed for operating speeds below 60 mph (100 km/h) due to increased attention to context sensitive design situations. Statistical modeling, simulation, and other experimental methods should all be considered as viable research methodologies. The research data would be analyzed to determine if the basic, "minimum radius equation" formula and respective parameter assumptions are appropriate for current and anticipated vehicle fleet and operating conditions.

Regardless of the resulting findings, i.e., that all current horizontal curve design conditions are found to be valid, or new alternative design methods are recommended, it is envisioned that both safety and economic evaluations be established to assess the application/implementation of the findings and potential recommendations. The safety and economic analyses will assist practitioners in assessing trade-offs of various horizontal curve design decisions.

Estimate of Problem Funding and Research Period

Recommended Funding

$1 to $1.5 million to address the full range of horizontal curve applications e.g., road/street segments, ramps, turning roadways and turning radii for at-grade intersections. The funding could be segmented/prioritized by roadway functions and/or design elements.

Research Period

48 months for full range of applications. Likewise, if funding is partitioned, then research periods could be adjusted accordingly.

Urgency, Payoff Potential, and Implementation

This research topic was ranked among the highest priorities at the joint meeting (June 2004, Williamsburg, VA) of the AASHTO Technical Committee on Geometric Design, the TRB Committee on Geometric Design and the TRB Committee on Operational Effects of Geometrics. The implications are broad ranging and will directly assist designers in addressing new, reconstructed, and context sensitive design situations across various functional classes of roads and streets. The findings will also provide the necessary guidance to accommodate various vehicle classes while considering safety and economic issues associated with horizontal curve designs. Urgency is high and the potential payoff of this research is substantial. The implementation would be via the AASHTO Geometric Design Policy, the Interactive Highway Design Safety Model, the AASHTO guide for Achieving Flexibility in Highway Design, the developing Highway Safety Manual, and other state and local geometric design standards.

Problem Statement Development

- John M. Mason, Jr., Pennsylvania State University;
- Basil Psarianos, Faculty of Rural and Surveying Engineering; and
- David R. McDonald, Jr., Hanson Professional Services, Inc.

RIGHT-TURN INTERACTIONS AND CHANNELIZED RIGHT-TURNS

Research Problem Statement

The Americans with Disabilities Act (ADA) requires that public rights-of way, including sidewalks and crosswalks, be accessible to pedestrians with disabilities. The U.S. Access Board’s ADA accessibility guidelines specify the minimum level of accessibility in new construction and alteration projects and serve as the basis for enforceable standards maintained by other agencies. On June 17, 2002, the U.S. Access Board published draft rights-of-way guidelines (Docket No. 02-

1) proposing to require pedestrian signals at channelized turn lanes that would create and identify gaps in the vehicle stream adequate for pedestrians who are crossing without vision cues. Many transportation agencies are looking for guidance on working with these proposed provisions.

Better information is needed about the effects of channelized right-turn lanes on urban streets on motorist (cars, trucks and busses), pedestrian, and bicyclist safety. Many agencies use channelized right-turn lanes to improve vehicular operations at urban intersections, particularly on urban arterials. Previous research found no reliable evidence to verify the assumption that channelized right-turn lanes provide safety benefits to both motorists and pedestrians. Since concerns about the accessibility of these turn lanes to pedestrians with vision impairments have arisen, research is needed to determine whether channelized right-turn lanes do or do not enhance safety for motorists, pedestrians and bicyclists. In addition, where a channelized right-turn lane is provided, there are differences of opinion about where the striped crosswalk, if provided, should be located. Some advocate putting it near the entry of the channelized right-turn lane so pedestrians are more in the field of vision for approaching drivers. Others advocate putting the crosswalk near the end of the channelized right-turn lane because visually impaired pedestrians will tend to cross the right-turn lane close to the parallel flow of traffic.

Research in NCHRP Project 3-78 will be investigating crossing solutions for pedestrians with vision impairments at channelized right-turn roadways. The focus of this research is to evaluate and substantiate the safety benefits or disbenefits of various applications of right-turn channelization for the motorist, bicyclist, and pedestrian.

Literature Search Summary

- In NCHRP Project 3-72, “Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas”, design guidance and criteria are being developed for addressing the safety and operational tradeoffs for motorists, pedestrians, and bicycles for two specific topics: selecting lane widths and using right-turn deceleration lanes at driveways and unsignalized intersections. Sufficient funds were not available to address the subject of right-turn interactions and channelized right-turns in that project.
- Research in NCHRP Project 3-78 will be investigating crossing solutions for pedestrians with vision impairments at channelized turn lanes and roundabouts. However, that project will not look at the more fundamental question of whether the provision of channelized right-turn lanes actually improves safety as has been historically assumed.
- A search of TRIS online and the Research in Progress database identified a paper presented at the 1999 Urban Street Symposium and published in e-Circular E-C019. The paper by Dixon, Hibbard, and Nyman entitled “Right-Turn Treatment for Signalized Intersections” makes some comparison of vehicular safety for various right-turn designs but it does not address the safety of other users with respect to the design of right-turn lanes.

Research Objective

The objective of this research is to recommend whether design policy related to right-turn design should be modified, based on the safety impacts of various designs upon different user groups. Exploration of the proper balance among the needs of passenger cars, trucks, busses, pedestrians (including pedestrians with vision impairments), and bicycles is central to achieving the objectives of the research. Accomplishment of the project objective will include at least the following tasks.

- **Task 1:** Review the existing geometric design, traffic control, and other relevant literature (both domestic and international) to (a) document the current state of practice with respect to pedestrian, bicycle and vehicular control at channelized right-turn lanes, (b) document the safety of various designs on the various modes, and (c) determine engineering policies and practices that may need to be revised as a result of the anticipated recommendations from this research effort.
- **Task 2:** Select an appropriate number of sites with and without channelized right-turn lanes and conduct field studies. Sites should be those utilized by as many different modes as possible and the interactions between the modes should be documented.
- **Task 3:** Analyze accident/crash reports for the above sites and document the number and type of accidents and the modes involved at each location.
- **Task 4:** Simulate the impact on various modes for different designs of channelized right-turn lanes and develop recommendations for design policy.
- **Task 5:** Submit a final report that documents the entire research effort, recommends design criteria for right-turn lanes on various classes of roadways, and includes the products of Tasks 1 through 4. Where appropriate, the report should include appendices with recommended language for the AASHTO Policy on Geometric Design of Highways and Streets; the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities; the AASHTO Guide for the Development of Bicycle Facilities; and other documents as appropriate.

Estimate of Problem Funding and Research Period

Recommended Funding

$500,000.

Research Period

24 months.

Urgency, Payoff Potential, and Implementation

State and local transportation agencies would use the information obtained from the research project to develop guidelines for the design of right-turn lanes considering all modes of travel and several types of vehicles. This would result in a transportation system that better considers all modes and provides the safest design for all users, based on site-specific conditions. Documents that would potentially be affected are the AASHTO Policy on Geometric Design of Highways and Streets; the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities; and the AASHTO Guide for the Development of Bicycle Facilities.

Problem Statement Development

- Elizabeth Hilton, Texas Department of Transportation;
- Ingrid Potts, Midwest Research Institute;
- John LaPlante, TY Lin International; and
- Karen Dixon, Oregon State University.

RAMP AND INTERCHANGE SPACING

Research Problem Statement

The American Association of State Highway Transportation Officials' (AASHTO) Policy on Geometric Design of Highways and Streets contains guidelines on the distance between successive ramp terminals. On urban freeways and other facilities that carry large traffic volumes, two or more ramp terminals are often located in close succession. To ensure that there is adequate space for signing and that sufficient weaving lengths are provided, minimum ramp terminal spacing dimensions for various ramp pair combinations are provided. Spacing between successive ramp terminals is dependant on the classification of the interchanges involved (system vs. service), the function of the ramp pair (entrance vs. exit), and the potential for weaving. The recommendations provided in the AASHTO Policy are acknowledged to be based on operational experience and should be evaluated based on Highway Capacity Manual procedures to ensure acceptable traffic operations.

Although the location and spacing of interchanges (and ramps) on freeways has a major effect on the ability of a freeway to carry traffic effectively, this is a topic for which there has been little research or literature published. To a certain extent the guidelines in AASHTO are arbitrary, as they are not based on operational conditions experienced on a freeway network. Recent research indicates that a majority of freeway accidents occur at interchanges and in weaving sections between closely spaced entrance and exit ramps. The spacing of interchanges on an urban road network often results in tradeoffs between providing adequate service and access with both safety and operations. The issue of interchange spacing is a complex issue and consequently a candidate for basic research.

Literature Search Summary

As noted earlier, there is limited research in this subject area. Several studies dating to the 1960's dealt with recommended interchange spacing dimensions based on operational models in use at the time. These are no longer applicable. Associated research efforts that have been completed or are currently underway that relate to the problem statement include:

- *Accidents and Safety Associated with Interchanges* (Twomey, et.al). This study indicates increased accident rates as interchange spacing decreases.
- NCHRP Project 3-75: Analysis of Freeway Weaving Sections. The objectives of this research are to develop improved methods for capacity and level of service analysis of freeway weaving sections. Current methodologies are based on studies from the 1970's and 80's and have been shown to be limited in their ability to predict operation of a facility.
- Caltrans has conducted several studies dealing with merging and diverging areas of freeway weaving sections. However, these efforts have not focused on interchange or ramp spacing issues.

Research Objective

The objective of this research is develop ramp and interchange spacing criteria based on quantitative information obtained from actual field observation, theoretic considerations, simulations, or a combination of the three approaches. Research should highlight the safety, operational, and other trade-offs associated with varying ramp and interchange spacing dimensions for the full range of interchange types (system and service) and facility types (freeway, expressway, collector-distributor roads).

The research should include a literature review of previous research and current practice in regard to ramp and interchange spacing, development of a work plan to achieve the research objectives, collection of applicable field data and other information, evaluation of the safety and operational effects of various combinations of ramp and interchange spacing, and preparation of a final report. The final report should include proposed changes to AASHTO Policy, if results support a change.

Estimate of Problem Funding and Research Period

Recommended Funding

$500,000.

Research Period

30 months.

Urgency, Payoff Potential, and Implementation

This research topic was selected by the AASHTO Technical Committee on Geometric Design, the TRB Committee on Geometric Design, and the TRB Committee on Operational Effects of Geometrics at their combined meeting in June 2004 as one of the five highest priorities for research. The research is needed to fill performance gaps in current interchange and freeway system design. It will be of use in the design of highways nationwide.

Problem Statement Development

- Nicholas D. Antonucci, CH2M Hill, and
- Joel P. Leisch, Consultant.

TRANSITION ZONES: DESIGN FROM HIGH-SPEED TO LOW-SPEED RURAL SECTIONS

Research Problem Statement

According to the National Highway Traffic Safety Administration, speeding is one of the most prevalent factors contributing to traffic crashes. In 2002, speeding was a contributing factor in 31% of all fatal crashes, and 13,713 lives were lost in speeding-related crashes. Communicating changes in speed environment and drivers’ need to adjust their speed is difficult.

Transitioning high-speed rural highways through small rural towns and into the suburban/urban environment is a design challenge. Increasing transition safety is an important goal.

AASHTO's Green Book contains general guidelines related to taper design when transitioning from two-lane operation to four-lane operation. Transition taper design is a function of speed and the amount of cross-section width being added to or removed from a roadway section. The *Manual of Uniform Traffic Control Devices* (MUTCD) provides additional information about taper design for passing sections on two-lane highways. We need to figure out better ways of doing it. There is a need to evaluate and to quantify how combinations of horizontal and vertical alignment, together with cross-section elements can be used in conjunction with human factors to influence and successfully manage operating speeds.

Literature Search Summary

There has been limited research in this subject area. NCHRP Project 15-22 "Safety Consequences of Flexibility in Highway Design," developed guidance to help project planners and designers estimate the safety consequences of varying designs when flexibility is applied for roads that transition from rural to built-up areas or pass through a built-up area on a predominately rural section of roadway. The study used a case study approach and found, for almost all case studies examined, that the operating speed was higher than the design speed and posted speed through the transition. One general observation from the NCHRP 15-22 case study projects was that most transitions between rural and urban areas took place over relatively short distances (in most cases, only a couple hundred feet, or less). These were inadequate in achieving any real operational speed changes. The study recommends further research to develop better methods and processes for designing transition zones.

- The traffic-calming literature (e.g., Publication No. FHWA-RD-99-113 "Traffic Calming: State of the Practice" and Publication No. FHWA-RD-98-154 "Synthesis of Safety Research Related to Speed and Speed Management"), while it focuses on urban and suburban applications, includes treatments that might be applied in rural settings. There is considerable experience in Europe with the use of gateways and other treatments to reduce speeds on main rural roads entering built-up areas. Publication No. FHWA-PL-01-026 "Geometric Design Practices for European Roads," summarizes the findings of a joint AASHTO-FHWA scan tour that included several related issues including transition zones.
- There is a considerable body of research literature on design speed, operating speed, posted speed, and their interrelationships. Most of the previous research addresses two-lane rural highways, with much more limited literature on the urban environment. No U.S. literature specifically addresses transition zones. NCHRP Report 504 addresses this topic. NCHRP Project 15-25 "Alternatives to Design Speed for Selection of Roadway Design Criteria" is pending.

Research Objective

The objective of this research is to develop improved treatments and procedures for designing transitions from high-speed rural highways to lower-speed rural built-up areas and suburban/urban environments. The research should compile existing treatments and methods in the U.S. and other countries, review previous research on their applicability and effectiveness, develop a work plan for the additional research needed to achieve the research objectives, collect applicable field data and other information, analyze the data, and prepare a final report. Issues to be addressed by the research should include alignment design features, cross-section elements, traffic control devices, roadway delineation, rumble strips, and channelization.

The final report should include proposed changes to AASHTO Policy, if results support a change.

Estimate of Problem Funding and Research Period

Recommended Funding

$500,000.

Research Period

30 months.

Urgency, Payoff Potential, and Implementation

This research topic was selected by the AASHTO Technical Committee on Geometric Design, the TRB Committee on Geometric Design, and the TRB Committee on Operational Effects of Geometrics during their joint meeting on Strategic Geometric Design Research Needs in June 2004. The research is needed to fill performance gaps in current design policy and practice. It will be of use in the design of highways nationwide. It will yield design treatments and procedures that will impact speed-related crashes, which account for 31% of all fatal crashes nationwide.

Problem Statement Development

- TRB Geometric Design Committee and
- TRB Operational Effects of Geometrics Committee.

RAMP DESIGN AS A SYSTEM

Research Problem Statement

The American Association of State Highway and Transportation Officials' (AASHTO) Policy on Geometric Design of Highways and Streets contains general guidelines for the relationship of ramp design speed to the mainline highway design speed, as well as general guidelines for the design speed of ramp terminals, which includes freeway entrance and exit terminals and highway intersections. However, the design of ramps has not traditionally been viewed as a composite system consisting of the three integral parts which form the ramp: the ramp proper and the appropriate terminals, whether freeway or highway, on each side of the ramp proper.

A large number of accidents occur on freeway ramps annually. Although ramp design has a major effect on the ability of a freeway and the interchanging roadway to carry traffic safely and efficiently, little research or literature has been published on the composite ramp system.

Typically, ramp terminals and the ramp proper are designed independent of each other and simply put together in designing a ramp. Ramp design practices should consider driver expectations and behaviors over a full range of geometric and traffic conditions which would include the interchange form, ramp type, the area environment (rural vs. urban) and the functional classification of the two interchanging roadways. The issue of a ramp design as a composite system is a complex issue in need of basic research.

Literature Search Summary

As noted above, there is limited research on the subject of ramp design as a composite system. Most of the existing research on ramp design addresses singular issues related to one of the three integral parts of the ramp (freeway-ramp relationships or ramp terminal design).

- Much of the recent limited literature on ramp design is summarized in NCHRP Synthesis 299. NCHRP 15-31, *Design Guidelines for Acceleration and Deceleration Lanes for Freeways*, begun in 2005, may yield some pertinent data relevant to this research.

Research Objective

The objective of this research is to develop composite ramp design criteria based on quantitative information from actual field observations, theoretical considerations, simulations, or a combination of the three approaches. Research should highlight the safety and operational aspects of composite ramp design for the full range of interchange forms, ramp types, system vs. service interchange ramps, and area environments (rural vs. urban). The final report should include proposed changes to AASHTO policy, if results support a change.

The proposed research tasks include the following:

- **Task 1:** Conduct literature search and state-of-the-art review. Conduct a survey of U.S. and state DOT experience. Identify study/research sites and data collection methodology. Identify potential operational/design software which can be calibrated. Prepare an interim report
- **Task 2:** Collect data at identified sites. Collected develop new or calibrate existing operational/design software to use in simulating operation on various ramp design combinations.
- **Task 3:** Prepare a final report summarizing all aspects of the research. Develop draft material for replacement of relevant sections of AASHTO's, *A Policy on Geometric Design of Highways and Streets.*

Estimate of Problem Funding and Research Period

Recommended Funding

$500,000.

Research Period

36 months.

Urgency, Payoff Potential, and Implementation

The research topic was selected by the AASHTO Technical Committee on Geometric Design, the TRB Committee on Geometric Design, and the TRB Committee on Operational Effects of Geometrics at their combined meeting in June, 2004 as one of the 10 highest priorities for research. The research is needed to fill basic performance gaps in current ramp design practices. It will be used nationally in the design of freeways.

Problem Statement Development

TRB Geometric Design Committee.

SAFETY AND OPERATIONAL TRADEOFFS OF FREEWAY LANE AND SHOULDER WIDTHS

Research Problem Statement

Highway designers are under increasing pressure to maximize the use of available right-of-way in freeway corridors to provide safety, mobility, and capacity for growing traffic demand. With right-of-way limitations, increased use of context sensitive designs, and implementation of managed facilities (i.e., HOV, HOT, or TOTL), designers must maximize the use of freeway cross sections. While freeway cross section design guidance suggests that 12-foot lanes with 8- to 10-foot inside and outside shoulders is ideal, there is limited research findings on how deviations from these ideals individually, or in combination, will effect freeway operations and safety. Highway designers need guidance on the operational and safety impacts for cross section design trade-offs while trying to balance corridor capacity, project costs, public involvement, and environmental impacts.

In addition, there is concern over the part-time use of existing shoulders as HOV, HOT or general use facilities during peak hour. The trade-offs between operational benefits and safety need to be quantified. Further, the safety implications of violators using the shoulder during the off-peak period need to be quantified. Does this changed view of the shoulder as part of the drivable alignment also transfer to shoulder violation on adjacent facilities? The signing and striping of these shoulders for clear communication of the changed cross section use must also be quantified.

Shoulders are often used as the separation between special use lanes and the general purpose lanes. The impacts of providing or not providing barrier separation need to be determined. Further, when barriers are used, what shoulder widths are necessary adjacent to the barrier and what safety impacts result from these shoulder widths is a concern.

Literature Search Summary

Use of shoulder and lane widths to improve traffic operations has been researched for over 30 years, going back to congested corridor projects in California and Texas (McCasland, 1978; Urbanik, 1993; NCHRP 369, 1995; Bauer et al., 2004). The research has generally shown that reductions in shoulder and lane widths can be done safely and cost effectively. The research further suggests that left shoulder removals are preferred, but maintaining at least one shoulder is important. More specific results have often been limited by the confounding of the vast number of variables in the design environment. Results have been further difficult to obtain on research budgets that did not allow for a comprehensive experimental design.

Some research specifically related to freeway lane and shoulder widths was directed towards their effect on freeway free flow speed as defined in the Highway Capacity Manual (HCM). Free flow speed is used in the HCM to establish speed/ flow relationships and associated values for maximum flow rates, v/c ratio, and density for various levels of service. The research indicates that 12 ft. lanes and 6 ft. lateral clearance on the right are optimal. Reducing these widths has a negative effect on free flow speed and consequently a reduction in flow rate. There was no attempt to link accidents with either lane width or shoulder width. No research has been accomplished for freeway cross section investigating the safety and operational tradeoffs of the allocation of lane and shoulder width across the total cross section. This topic is very much related to context sensitive design, in particular associated with freeway widening or modification to increase capacity or to add HOV/managed lanes.

Research Objective

The objective of the research is to provide quantitative safety and operational outcomes for use of shoulder widths of zero to 12 feet (possible up to 14 feet for shoulders used as buffer separation for special purpose lanes) and lane widths of 10 to 12 feet (possibly up to 14 feet for special purpose lanes). The research should also quantify the impact of using these shoulder and lane widths in combination. The focus of the research should also be on existing facilities that would be rehabilitated or reconstructed. As part of this retrofit, the impact of choices of lane widths, inside and outside shoulder widths must be quantified to allow for the safest and most efficient reuse of the available cross-section width. The application of current standards to new facilities is less interesting.

Another objective of the research is to develop a tool for designers to assess the cross section design trade-offs. Existing simulation models do not properly address the issues that are requested to be investigated. Thus, a simulation model or recalibration of existing models should be accomplished based on field observations as part of this research to create a user tool for cross-section analysis.

- **Task 1:** Conduct literature search and state-of-the-art review. Conduct a survey of U.S. and state DOT experience. Identify study/research sites and data collection methodology. Develop experimental design that will address the objectives of the research and not result in past research deficiencies. Prepare an interim report
- **Task 2:** Collect data at identified sites. Based on data collected develop new or calibrate existing operational/design models to use in simulating operation on various freeway cross sections.
- **Task 3:** Prepare a final report summarizing all aspects of the research. Develop draft material for replacement of relevant sections of AASHTO’s, Policy on Geometric Design of Highways and Streets.

Estimate of Research Funding and Period

Recommended Funding

$750,000.

Research Period

36 months.

Urgency, Payoff Potential, and Implementation

The research topic was selected by the AASHTO Technical Committee on Geometric Design, the TRB Committee on Geometric Design, and the TRB Committee on Operational Effects of Geometrics at their combined meeting in June, 2004 as one of the ten highest priorities for research. The research is needed to provide guidance to highway designers on the trade-offs of shoulder and lane width selection in freeway corridors. The results will be used nationally in the design of freeways, HOV lanes, toll roads, and special use lanes.

Problem Statement Development

- TRB Geometric Design Committee and
- TRB Operational Effects of Geometrics Committee.

SAFETY, OPERATIONS, AND USABILITY TRADE-OFFS BETWEEN USER GROUPS AT INTERSECTIONS

Research Problem Statement

Current geometric design guidelines for highways and streets do not adequately anticipate or accommodate the needs of all potential users. Pedestrians and bicycles are common users of the urban and rural transportation network, especially at intersections. Designs that accommodate their needs are often viewed as retrofit or add-ons rather then as being given equal importance. There are several issues related to safety of the users and the identification of the unique problems that these users experience is of utmost importance. Therefore, having an understanding of the problems and issues for these users, solutions could be sought to reduce, if not eliminate, potential problems. A possible approach for addressing this issue is the trade off between design elements for vehicles and other users. However, there is little knowledge as to the safety consequences from such design element trade-offs.

Literature Search Summary

There is limited research in this subject area. Several studies have been conducted that dealt with the safety of the various nonvehicle roadway users but little has been done to correlate the design element trade offs that can be implemented to improve the safety and operational level for the nonvehicle roadway users. There has been limited work that could form the basis for this work, including

- NCHRP Project 15-20: Planning, Design, and Operation of Pedestrian Facilities. The objectives of this recently completed research were to develop a guide for planning and designing pedestrian facilities. The findings of the study are to be considered for incorporation in the next edition of the Green Book.
- AASHTO design guides (*A Policy on Geometric Design for Highways and Streets; Guide for Developing Bicycle Facilities*; and *Guide for the Planning, Design and Operation of Pedestrian Facilities*).
- ADA requirements and guidance.

Research Objective

The objective of this research is to develop guidelines for addressing the needs of roadway users especially at intersections. The work to be completed should address the trade offs between design elements and safety and operational performance of these facilities.

The research should include a literature review of previous research and current practice in regard to pedestrian and bicycle facilities design, development of a work plan to achieve the research objectives, collection of applicable field data and other information, evaluation of the safety and operational effects of various combinations of design elements, and preparation of a final report. The final report should include proposed changes to AASHTO Policy, if results support a change.

Estimate of Problem Funding and Research Period

Recommended Funding

$500,000.

Research Period

30 months.

Urgency, Payoff Potential, and Implementation

This research topic was selected by the AASHTO Technical Committee on Geometric Design, the TRB Committee on Geometric Design, and the TRB Committee on Operational Effects of Geometrics at their combined meeting in June 2004 as one of the high priorities for research. The research is needed to fill performance gaps in current roadway design to address and accommodate the needs of all roadway users. It will be of use in the design of highways nationwide.

Problem Statement Development

Nikiforos Stamatiadis, University of Kentucky.

OPERATIONAL AND SAFETY IMPACTS OF FOUR- AND SIX-LANE SECTIONS WITH RAISED MEDIANS VERSUS TWO-WAY LEFT-TURN LANES

Research Problem Statement

Multilane road cross sections are often designed to include some type of median, either depressed, raised, or flush. When a flush median is selected, it often includes a two-way left-turn lane (TWLTL). In urban areas, the choice is often between a raised median and a TWLTL. In some instances a designer would prefer a raised median in order to enhance mobility and safety, but abutting property and business owners express a strong preference for TWLTL.

Some have suggested various volume thresholds at what volume to convert from a five-lane design (TWLTL) to a nontraversable (e.g., raised) median. Two concerns about nontraversable median designs are the additional travel distance and time due to the indirection caused by access restrictions, and the safety effects of the increased U-turn demand.

The analysis should consider and differentiate among the following factors:

- Number of through lanes: four or six;
- Environment: rural, suburban, urban of various densities;
- Volume and speed;
- Signal density; and
- Access type and density.

Literature Search Summary

Some of the existing studies are limited in scope, or otherwise do not address a full range of conditions and combinations of variables that need to be addressed.

- *Safety Impacts of Selected Median and Access Design Features*. After determining that it was difficult to find suitable study sites, the researchers concluded that restrictive medians (flush grass or raised) were safer than nonrestrictive medians.
- *Investigation of the Impact of Medians on Roads Users*, FHWA-RD-93-130. This study examined the safety impact of raised curb medians, TWLTLs, and undivided cross sections on both vehicles and pedestrians in urban environments.
- *Median Intersection Design*, NCHRP Report 375. This report developed guidelines for the selection of median widths for at-grade intersections. It may provide insight into why there might be differences among different raised-median roadways.
- *Access Management Manual*. This manual summarized findings from a number of studies about operational and safety impacts related to access management.
- *Impacts of Access-Management Techniques*, NCHRP Report 420. This report documented the effects of various access management techniques, including median treatments.
- *Safety of U-turns at Unsignalized Median Openings*, NCHRP Project 17-21, draft final report under revision, as of October 2004. This study examined the impact of U-turns on the safety of the road.

Research Objective

The objective of this research is to better document the trade-offs involved with selecting either a raised or a TWLTL median, and differentiate between these effects in a four-lane versus a six-lane environment. The research should also incorporate the effects of different environments, volumes, speeds, signal densities, and access densities.

Estimate of Problem Funding and Research Period

Recommended Funding

$350,000.

Research Period

30 months.

Urgency, Payoff Potential, and Implementation

Design professionals need empirical data to assess and compare the safety attributes of nontraversable medians versus TWLTL's for both four-lane and six-lane roadways at various volumes, speeds, and other characteristics. The study will help determine under what conditions nontraversable medians should be required and help to sell nontraversable medians to the surrounding community when those conditions exist. With the emphasis on managing and improving traffic flow and safety, the need is urgent and the pay-off is substantial and immediate and applicable nationwide.

Problem Statement Development

- J. L. Gattis, Mack-Blackwell Transportation Center, University of Arkansas, and
- David Hutchison, Springfield Department of Public Works.

SUPERELEVATION CRITERIA FOR STEEP GRADES ON SHARP HORIZONTAL CURVES

Research Problem Statement

Steep grades on sharp horizontal curves represent a particularly dangerous situation for vehicle operators, especially heavy vehicle operators. Examples where this combination may occur are switchback curves on mountainous two-lane, two-way roads or high-speed downgrade curves on limited access roadways. At these locations, the complicating factors of vehicle off-tracking, pavement slope, and pavement friction fully tax the driver's ability to provide correct vehicle positioning without compromising control of the vehicle. Accident problems have arisen where, as a result of reconstruction, older highways with 12 to 17% superelevation have been rebuilt using 8 and 10% superelevation in accordance with current standards. Superelevation criteria, and other associated horizontal curve criteria, for situations where steep grades are located on sharp horizontal curves have not been developed.

NCHRP Projects 15-16 and 15-16A, documented in NCHRP Report 439, Superelevation Distribution Methods and Transition Designs, evaluated and recommended revisions to the horizontal curve guidance presented in the 1994 AASHTO Green Book. The two principal design elements evaluated were the use of superelevation and the transition from a tangent to a curve. The transition recommendations were incorporated into the 2001 edition of the Green Book while the superelevation recommendations will be included in the next edition.

NCHRP Report 439 noted that significant roadway downgrades deplete the friction supply available for cornering. This depletion results from the use of a portion of the friction supply to provide the necessary braking force required to maintain speed on the downgrade. The report found that both upgrades and downgrades yield an increase in side friction demand and a decrease in side friction supply. This undesirable combination results in a significant decrease in the margin of safety resulting from roadway grade, especially for heavy vehicles. Superelevation criteria and horizontal curve criteria for this situation were not developed.

The 2001 Green Book acknowledges that downgrades on horizontal curves may be problematic, and that adjustment for it may be desirable in some cases. There are no guidelines as to how this adjustment should be made for two-lane or multilane undivided roadways. The upcoming superelevation revision to the 2001 Green Book contains the following: "On long or fairly steep grades, drivers tend to travel faster in the downgrade than in the upgrade direction. Additionally, research has shown that the side friction demand is greater on both downgrades (due to braking forces) and steep upgrades (due to the tractive forces). Some adjustment in superelevation rates should be considered for grades steeper than 5%. This adjustment is particularly important on facilities with high truck volumes and on low-speed facilities with intermediate curves using high levels of side friction demand." The superelevation revision concludes that this adjustment be made by using higher design speeds. More definitive guidance on this adjustment, as well as adjustment for other elements of the horizontal curve, is needed.

Literature Search Summary

See information about NCHRP Report 439 in Research Problem Statement above.

Dr. Ronald Eck at West Virginia University has performed similar research work for the West Virginia Department of Transportation. His research report indicates there are many unanswered questions and the models developed in his work need to be critically reviewed and further enhanced, including consideration of vehicle dynamics.

Research Objective

The objective of this research is to develop superelevation criteria for steep grades on sharp horizontal curves. Other criteria associated with design of horizontal curves such as tangent-to-curve transitions, spiral transitions, lateral shift of vehicles traversing the curve, need for pavement widening, and minimum curve radii should also be considered in the development of the criteria. The criteria may be based on quantitative evidence obtained from theoretic considerations and simulations but should be supported by actual field observation.

The research should include a review of current practice, development of a work plan to achieve the research objectives, collection of data and other information, evaluation of effects of various alternatives and candidate criteria, and preparation of final criteria. The recommended criteria should be documented in the final report and also presented in a form that could be used by the AASHTO Technical Committee on Geometric Design in a future edition of the Green Book.

Estimate of Problem Funding and Research Period

Total Funds Requested

$300,000.

Research Period

24 months.

Urgency, Payoff Potential, and Implementation

This research topic was selected by the TRB Committee on Geometric Design, TRB Committee on Operational Effects of Geometrics, and the AASHTO Technical Committee on Geometric Design at their combined meeting in June, 2004 as one of the five highest priorities for research. The research is needed immediately to fill a gap in current superelevation design policy. It will be of use in the design of highways nationwide.

Problem Statement Development

- Norm Roush, West Virginia DOT;
- Jeff Jones, Tennessee DOT;
- Mark Taylor, FHWA Federal Lands; and
- Bob Schlicht, FHWA Headquarters.

GEOMETRIC DESIGN GUIDELINES FOR MAJOR INTERSECTION ALTERNATIVES TO ACCOMMODATE MULTIMODAL USERS

Research Problem Statement

Intersections on multilane arterials are becoming increasingly congested throughout the U.S. and other countries. Engineers have few good options to improve these intersections. Turn lanes, actuated signals, and signal systems have usually been employed for years. Widening and structures can be very expensive and environmentally disruptive. Transit, demand management, and intelligent transportation systems are typically years away from making a meaningful impact on congestion.

In recent years, engineers have begun employing alternatives to conventional intersections as a way to reduce congestion without great expense or other large impacts. Michigan has used the median u-turn design extensively for years, while New Jersey has used the jughandle design. New York and Maryland have successfully employed the continuous flow intersection, while Maryland has also used the superstreet design. Research has shown that there are other designs that could boost efficiency with modest extra cost or other impact, including the quadrant roadway intersection.

The American Association of State Highway and Transportation Officials' (AASHTO) *A Policy on Geometric Design of Highways and Streets* contains guidelines on the design of standard intersections and guidance on the median U-turn and jughandle alternatives. The guidance provided on the design of median U-turns and jughandles, however, is limited. There is no guidance from AASHTO, in the *Policy* or elsewhere, on the other alternatives mentioned above. This lack of guidance is likely discouraging engineers from considering one or more of the alternatives in situations where they may be appropriate. Standard guidelines and use of these designs may lead to a decrease in delay and collisions at intersections.

Literature Search Summary

Most of the previous research on major intersection alternatives has concentrated on travel time and delay for the alternatives in comparison to each other and to conventional designs. A few papers have provided collision frequencies and rates for some of the alternatives. However, there is practically no literature providing guidance on the details of the designs.

Two recent efforts have summarized the available literature on the alternative designs. The first effort was by the FHWA ("*Signalized Intersections: Informational Guide*, FHWA-HRT-04-091, dated August 2004, available at www.tfhrc.gov/safety/pubs/04091/). The second effort was by Reid ("*Unconventional Arterial Intersection Design, Management and Operation Strategies*," dated September 2003, available at www.pbworld.com/library/fellowship/reid/). Both efforts brought together the past findings on travel time and delay with the relatively sparse past finding on safety. The FHWA material was included in a larger document providing information on many different aspects of signalized intersection design and operation, and thus places the major alternatives in that context. Reid's effort was more focused on the major alternatives, and he summarizes the literature related to several more alternatives than the FHWA effort. Of the five major alternatives that have been applied most often in the U.S. and/or have the most potential for travel time savings (median U-turn, jughandle, superstreet, continuous flow intersection, and quadrant roadway intersection), both of these thorough recent reviews provide a fine foundation from which this research can build.

Research Objective

The objective of this research is to provide guidance on the geometric and traffic control details of the major intersection alternatives, including answers to questions such as

- Where should median openings be located?
- Where are the best crosswalk locations?
- What are the best median and island treatments?
- What sign designs best convey needed guidance information to unfamiliar drivers?

The research should include a review of previous research, two thorough recent reviews have been performed and this research can build upon that foundation. The main effort here will be an examination and evaluation of current practices. The researchers will likely need to visit and observe operations at the existing sites where alternatives have been employed. It will probably not be possible to conduct controlled experiments to evaluate the design choices, but the researchers should still be able to collect and analyze data from actual installations pertaining to some of those choices. The researchers may be able to utilize simulations and visualizations to analyze some of the design choices. Focus groups and expert panels of road users and professionals may also be excellent tools in these evaluations. The researchers must consider all expected users of intersections, including pedestrians, bicyclists, trucks, buses, users with disabilities and others. The final report should include proposed changes to AASHTO *Policy* as well as recommendations for changes in other standard documents such as state design manuals. The final report should also provide strategies for how to address important questions on which the quantitative evidence is currently weak.

Much of the experience with major alternatives has been outside the U.S., particularly in Mexico with the continuous flow intersection. Thus, the research effort should include visits and observations of these applications outside the U.S. Projecting how well those international experiences apply to U.S. conditions will be a critical element of the research. It should also be noted that, except where they appear as part of a larger overall scheme (as in the “Bowtie” design), roundabout design and operation are out of the scope of this project. Issues related to roundabout design and operations have been and will be addressed in other research projects.

Estimate of Problem Funding and Research Period

Recommended Funding

$400,000.

Research Period

30 months.

Urgency, Payoff Potential, and Implementation

This research topic was selected by the AASHTO Technical Committee on Geometric Design, the TRB Geometric Design Committee, and the TRB Operational Effects of Geometrics Committee at their combined meeting in June 2004 as being among the top 15 highest priorities for geometric design research. The problem of congested intersections on multilane arterials is serious in the United States and internationally, and it is getting worse with each year. The research is needed because, besides the designs to be investigated in this project, there are not many good alternatives for efficient and safe ways to improve at-grade intersections. However, many transportation agencies will not use these designs without the guidelines to be supplied during this project. Once the guidelines are distributed to transportation agencies and, perhaps, adopted by AASHTO in some appropriate form, designers should begin earnestly considering all options for intersection improvements.

Problem Statement Development

Joseph E. Hummer, North Carolina State University.

DESIGN, SAFETY, AND OPERATIONAL CONSIDERATIONS OF PEDESTRIAN TREATMENTS AT INTERSECTIONS

Research Problem Statement

A number of pedestrian treatments have been developed for inclusion in intersection design over the years but research data that provides conclusive information about their effectiveness is lacking. Treatments include intersection geometry (including curb extensions/road narrowing and reduced curb return radius), in-pavement flashers, advance signing, messaging and beacons, signal features, medians and refuge islands, various methods of crosswalk markings (conventional striping, pavement texture changes, raised crosswalks), use of barriers such as fences or shrubs to discourage pedestrians from crossing at unsafe locations, and elimination of roadside obstacles that obscure visibility between pedestrians and vehicles. Roadway designers continually make judgments about the safety and viability of pedestrian features at intersections. Transportation agencies, as well as roadway engineers and urban designers, are looking for guidance about the effectiveness of various pedestrian accommodation treatments.

Incorporating features that are perceived to enhance pedestrian comfort and safety can have impacts on the design of the roadway for vehicle operations. An example is reducing the curb return radius to shorten pedestrian travel at a crossing can have the undesirable effect of impeding right turns by larger vehicles. Inclusion of median refuge areas at intersections can affect left turn operations, and can result in the misalignment of opposing left turning vehicles, compromising sight distance and the view of oncoming traffic.

Literature Search Summary

Right-turn interactions and channelized right turns/free-right turn lane design and impacts are the focus of NCHRP 3-72 and NCHRP 3-78, both currently underway. A few studies have been conducted on the effectiveness of in-pavement flashers and advanced warning messages such as “animated eyes”.

There is substantial research that addresses good design practice to accommodate a specific mode but there is nothing found that evaluates the effect of pedestrian treatments on other intersection users.

Research Objective

Better information about the effects of pedestrian geometric intersection treatments in enhancing safety, complementing or impeding vehicle operations, and liability impacts to agencies incorporating these treatments is needed. Legal guidance is not proposed, but the research should identify what potential liability issues might exist. Objectives of the research would include guidance on design of treatments, guidance on the appropriate locations for treatments, and guidance on the trade offs between conflicting pedestrian and vehicle elements. The research should identify and develop a matrix to provide quick reference for responsible implementers on the appropriate use of pedestrian treatments at a variety of locations. Research should also consider the potential conflicts between pedestrian and bicycle treatments that occasionally arise in providing facilities for these modes.

The following tasks will need to be carried out to accomplish this project objective:

- **Task 1:** Review the existing geometric design, and other relevant literature (both domestic and international) to (*a*) document the current state of practice with respect to pedestrian geometric intersection treatments, (*b*) document the safety records of the various treatments, (*c*) assess the effectiveness of the various treatments in a qualitative manner, both in terms of vehicle operations and pedestrian comfort and safety, (*d*) assess the effects of crossing distance and curb radius on intersection capacity, vehicle delay and pedestrian and vehicle safety, and (*e*) suggest changes to treatments as a result of the research effort.
- **Task 2:** Select an appropriate number of sites with and without pedestrian safety treatments and conduct field studies that will allow the sites to be compared. Sites should be those utilized by as many different modes as possible and the interactions between the modes should be documented.
- **Task 3:** Analyze vehicle operations for the above sites and document qualitatively at each location.
- **Task 4:** Using the information generated in (2) above, model impact on vehicle operations and pedestrian safety with the goal in mind of recommending changes to designs for the treatments and guidance in the appropriateness of their use in a variety of environments.
- **Task 5:** Submit a final report that documents the entire research effort, recommends design criteria and appropriate application for the pedestrian treatments. The report should comment on the effects of its recommendations on the classes of pedestrians including children, the elderly, and people with disabilities. Where appropriate, the report should include appendices with recommended language for the AASHTO Policy on Geometric Design of Highways and Streets; the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities; and other documents as appropriate.

Estimate of Problem Funding and Research Period

Recommended Funding

$300,000.

Research Period

24 months.

Urgency, Payoff Potential, and Implementation

State and local transportation agencies, and the design communities that apply their guidance documentation, would use the information obtained from the research project to develop guidelines for the intersection design for various facilities. This would result in a transportation system that better considers all modes and provides the safest design for all users, based on site-specific conditions. Documents that would potentially be affected are the AASHTO Policy on Geometric Design of Highways and Streets; and the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities.

Problem Statement Development

- Dan Dawson, Otak, Inc., and
- J. L. Gattis, Mack-Blackwell Transportation Center, University of Arkansas.

ONE- AND TWO-WAY RAMP LOOP DESIGN

Research Problem Statement

As traffic volumes in most areas continue to grow and right-of-way and available funding to build new infrastructure becomes limited, more emphasis is placed on adding additional capacity to existing infrastructure or constructing new facilities with higher capacities. At interchanges, a potential treatment to add capacity is the conversion of one-lane loop ramps to two-lane loop ramps. Or, construction of a two-lane loop ramp in a new interchange. Loop ramps, as with other interchange ramp types, have specific design and operational characteristics that must be considered as part of a ramp system (entry and exit gore areas, ramp proper, and ramp terminal intersection) to produce a safe and efficient design. Chapter 10 of AASHTO's Green Book provides no guidance on the application or design of two-lane loop ramps.

In fact, there is little supporting research focused on the design and operational characteristics of one-lane loop ramps. A better understanding of one-lane loop ramp design and operations would be helpful in establishing design criteria for two-lane loop ramps. The only known research on one-lane loop ramps relates to accident (crash) experience, but this research did not quantify loop ramp geometry. Consequently, there is no definitive accident data associated with one-lane loop ramp design elements.

While potential two-lane loop ramp designs can be "pieced together" using many existing guidelines listed in Chapter 10 (for example, general guidance is given on the design of two-lane entrance and exit terminals), this type of design does not consider the interaction between the driver, roadway, and vehicle that occurs with a ramp system such as: exiting roadway, exit terminal, ramp proper, entrance terminal, and entering roadway. Also, new research on driver behavior in two-lane roundabouts and experiences observed on existing two lane loop ramps can be used to research some of the perceptions about drivers traveling side-by-side on a circular section. A thorough understanding with respect to capacity, operations, safety, geometry, construction considerations, capital cost, and human factors is needed so that decisions made regarding the use and design of two-lane loop ramps will be informed.

Literature Search Summary

There is no known definitive research associated with one- or two-lane loop ramp design, safety, or operational characteristics with the exception of limited and generalized accident research associated with a variety of ramp types.

Research Objective

The research objective is two fold. First, to establish more definitive design criteria for one-lane loop ramps incorporating the exit, ramp proper, and entrance. Second, to provide guidance on the proper planning and location of two-lane loop ramps and to expand the profession's knowledge and understanding of the design of two-lane loop ramps with respect to geometry, operations, and safety. A final report should include proposed changes to AASHTO Policy if results support a change.

- **Task 1:** Conduct literature search and state-of-the-art review. Conduct survey of US and State DOT experience. Identify need for additional research and select sites for data collection. Identify potential microsimulation software for calibration. Prepare interim report.
- **Task 2:** Collect additional data at selected sites identified in Phase 1. Simulate various design alternatives to study the operation of one- and two-lane loop ramps using appropriate micro-simulation software.
- **Task 3:** Prepare a final report documenting all aspects of the research. Develop draft material for inclusion in AASHTO's, *A Policy on Geometric Design of Highways and Streets.*

Estimate of Research Funding and Period

Recommended Funding

$450,000.

Research Period

30 months.

Urgency, Payoff Potential, and Implementation

AASHTO's, *A Policy on Geometric Design of Highways and Streets,* provides minimal guidance of design parameters associated with one-lane loop ramps. In terms of two-lane loop ramps, although general guidance is given on the design of two-lane entrance and exit terminals, little information is available regarding the design of a two-lane loop ramp proper. Additionally, no guidance is given on the proper planning and location of two-lane loop ramps. With more detailed information, highway designers will be better able to make informed decisions regarding the applicability and design of one- and two-lane loop ramps to various site-specific conditions. This research is urgent due to the potential savings in cost and impact (environmental, length of construction, right-of-way, etc) that may be realized through the construction of one- and two-lane loop ramps versus other alternatives (i.e. adding directional or semi-directional ramps). The research is also urgent to minimize the implementation and design of one- and two-lane loop ramp designs based on dated information and limited knowledge that may lead to operational or safety deficiencies.

Problem Statement Development

- TRB Geometric Design Committee and
- TRB Operational Effects of Geometrics Committee.

EFFECTIVENESS OF VARIOUS MIDBLOCK CROSSING TREATMENTS

Research Problem Statement

Pedestrians desire to travel from origin to destination in as near a straight line as is possible. When pedestrian travel involves crossing a street or highway, many pedestrians choose to cross at a midblock location. It has been argued that providing signs and markings at crossing locations gives pedestrians a false sense of security. There is no guarantee that driver is aware of the potential pedestrian crossing or, if aware, will exercise any caution regarding the potential crossing.

According to the MUTCD, midblock at-grade crosswalks must be marked. The traditional consensus among traffic engineers is that at-grade midblock crosswalks are typically undesirable. However, both pedestrian walking behaviors and public demand can create pressures for the installation of a midblock pedestrian crossing. Grade-separated pedestrian crossings can be costly and are often under utilized after construction.

The research should address the following issues:

- The relationship of roadway width, the inclination to cross at midblock, and the safety of crossing;
- The relationship between the distance to an intersection (to either a signalized or a non-signalized intersection) and the inclination to cross at midblock locations;
- Land use and midblock crosswalk relationships: the way that origins and destinations are placed relative to each other (such as placing a major building entry at midblock, with a parking lot directly across the street) can create a demand for midblock pedestrian movements; and
- The effectiveness of various midblock crossings treatments (no treatment, marked, activated flasher, continuous flashers, signal, raised table, grade-separated, etc.), both in terms of amount of use, disruption to motorist, and safety.

Literature Search Summary

- www.Walkinginfo.org. NHTSA developed a methodology to better define the sequence of events and precipitating actions leading to pedestrian-motor vehicle crashes in the early 1970s. In the early 1990s, this method was refined and used to determine the crash types for more than 5,000 pedestrian crashes in six states. The results showed that the midblock events were the second major grouping of crash types and accounted for 26.5% of all crashes. Among this group, the most commonly crash type (one-third of all) was the "midblock dash" where a pedestrian would run into the street and the motorist's view was not obstructed. Another 17% of these crashes were "dart-outs," where the pedestrian ran or walked into the street, but the motorist's view was obstructed until just before the impact.

- “Law Enforcement, Pedestrian Safety, and Driver Compliance with Crosswalk Laws,” *Transportation Research Record 1485*. Although not targeted solely at midblock crossings, a Seattle study found enforcement was rather ineffective in getting vehicles to stop for pedestrians.
- *Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations*, FHWA-RD-01-075. A large study based on five years of data at uncontrolled intersections found the presence of a raised median (or raised crossing island) was associated with a significantly lower pedestrian crash rate at multi-lane sites with both marked and unmarked crosswalks. Factors having no significant effect on pedestrian crash rate included: area (e.g., residential, central business district [CBD]), location (i.e., intersection vs. midblock), speed limit, traffic operation (one-way or two-way), condition of crosswalk marking (excellent, good, fair, or poor), and crosswalk marking pattern (e.g., parallel lines, ladder type, zebra stripes).
- *A Review of Pedestrian Safety Research In The United States and Abroad*, January 2004 (FHWA-RD-03-042). Summarized research on pedestrian safety in the United States with a focus on crash characteristics and the safety effects of various roadway features and traffic-control devices.
- “Innovative Pedestrian Treatments at Unsignalized Crossings,” NCHRP Project 3-71, scheduled for completion in Spring 2006. Stated objectives include finding new engineering treatments to improve safety for pedestrians crossing high-volume and high-speed roadways at unsignalized locations (particularly, public transportation) and recommend modifications to the MUTCD traffic signal pedestrian warrant.
- “Planning, Design, and Operation of Pedestrian Facilities,” NCHRP Project 15-20, revised final report delivered to AASHTO and under review by AASHTO committees. The first objective of this project was to compile the most relevant existing information related to the planning, design, and operation of pedestrian facilities, including the accommodation of pedestrians with disabilities. The second objective was to develop a guide for the planning, design, and operation of pedestrian facilities.

Research Objective

The objective of this research is to identify those factors or situations that are either conducive to, or unfavorable for, the safe operation of midblock crosswalks. These should include both pedestrian demand and traffic operations considerations. Planning and land development practices that can reduce demands for midblock crossings at inherently unsafe locations should be documented.

The project should include a literature review of previous related research, a documentation of the degree of use, and the safety experience of grade-separated crossings compared to at-grade midblock crossings. The final report should include informal warrants for the installation of grade-separated or at-grade midblock crossings and level of warning (e.g., basic warning signs and pavement markings for crosswalk, pavement markings in advance of crosswalk, crosswalk with median shelter area, continuous flashing lights, activated flashing lights, pedestrian-activated traffic control signal), and other actions to take to both better serve pedestrians and avoid creating unsafe situations.

Estimate of Problem Funding and Research Period

Recommended Funding

$250,000.

Research Period

27 months.

Urgency, Payoff Potential, and Implementation

Since there is little research guidance as to the effectiveness of various measures on reducing pedestrian crashes, and more emphasis is given to encouraging short trips to be made by walking, research is needed to provide empirical data to professionals designing streets and highways to safely accommodate both pedestrian and motor vehicle traffic.

This project will provide empirical data in an area where little data are available and for a situation that results in sizeable proportion of all traffic-related injuries, and can be expected to become increasingly prevalent. The research will be used where there are pedestrian-vehicle conflicts across the nation.

Problem Statement Development

- J. L. Gattis, Mack-Blackwell Transportation Center, University of Arkansas, and
- David Hutchison, Springfield Department of Public Works.

INTERSECTION DESIGN TO ACCOMMODATE PEDESTRIAN CROSSWALK CROSS-SLOPE

Research Problem Statement

The Americans with Disabilities Act (ADA) requires that public rights-of way, including sidewalks and crosswalks, be accessible to pedestrians with disabilities. The U.S. Access Board's ADA accessibility guidelines specify the minimum level of accessibility in new construction and alteration projects and serves as the basis for standards enforced and maintained by other agencies. ADA guidelines require that the cross-slope in crosswalks should not exceed 2% measured perpendicular to the direction of pedestrian travel. Many transportation agencies are looking for guidance on working with these proposed provisions.

Many of the potential treatments used to achieve the required cross-slope on crosswalks do not conform to existing highway design and construction standards. In addition, tabling the crosswalk or intersection would require adjustments in the vertical alignment of the roadway which would impact street drainage. Tabling crosswalks or intersections may also have unintended negative impacts on the control and safety of motor vehicles and their occupants. These concerns are heightened for emergency vehicles. Loss of control of vehicles in urban areas could have tremendous safety implications for pedestrians alongside the roadway.

Literature Search Summary

A search of TRIS online and the Research in Progress databases did not identify any research specifically addressing the interaction between roadway design and pedestrian crosswalk cross-slopes.

Research Objective

Better information is needed about the introduction of reduced street grades at pedestrian crosswalks for roadways on steep longitudinal grades. Since the cross-slope of the crosswalk is also the longitudinal grade of the street being crossed, this requirement impacts the vertical alignment of the roadway in the vicinity of the intersection. The impact that tabled intersections would have on motorist safety and street drainage needs to be examined along with potential platform designs to safely accommodate vehicles on streets with steep grades, while meeting the crosswalk cross-slope requirements.

Accomplishment of the project objective will include at least the following tasks:

- **Task 1:** Review the existing geometric design, hydraulic design, and other relevant literature (both domestic and international) to (a) Document the current state of practice with respect to tabled intersection design, drainage, vehicle dynamics, and the safety of users of all modes, (b) document the safety of various designs on the various modes, and (c) determine engineering policies and practices that may need to be revised as a result of the anticipated recommendations from this research effort.
- **Task 2:** Select an appropriate number of sites with and without tabled intersections and conduct field studies. Sites should be those utilized by as many different modes as possible and the interactions between the modes should be documented.
- **Task 3:** Analyze accident/crash reports for the above sites and document the number and type of accidents and the modes involved at each location.
- **Task 4:** Simulate the impact on various modes for different designs of tabled intersections and develop recommendations for design policy.
- **Task 5:** Submit a final report that documents the entire research effort, recommends design criteria for intersection design on various classes of roadways and in various types of terrain, and includes the products of Tasks 1 through 4. Where appropriate, the report should include appendices with recommended language for the AASHTO Policy on Geometric Design of Highways and Streets; the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities; and other documents as appropriate.

Estimate of Problem Funding and Research Period

Recommended Funding

$500,000.

Research Period

24 months.

Urgency, Payoff Potential, and Implementation

State and local transportation agencies would use the information obtained from the research project to develop guidelines for the intersection design for various facilities and with varying terrain conditions. This would result in a transportation system that better considers all modes and provides the safest design for all users, based on site-specific conditions. Documents that would potentially be affected are the AASHTO Policy on Geometric Design of Highways and Streets; and the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities.

Problem Statement Development

- Elizabeth Hilton, Texas Department of Transportation, and
- Dan Dawson, Otak, Inc.

GUIDELINES FOR THE PROVISION OF SIDEWALKS

Research Problem Statement

Agencies responsible for the development of transportation facilities are increasingly encouraged to consider provisions for all transportation modes during project development. Funds for transportation improvements are scarce and agencies are responsible for ensuring that tax dollars are spent in an efficient and prudent manner. Improved guidelines are needed pertaining to when pedestrian facilities should be provided in transportation projects and what type of pedestrian facility is appropriate, balancing the needs of all modes. For example, guidance is needed on when a sidewalk on one side of the street is appropriate and when sidewalks should be provided on both sides of the street. Research is needed to provide guidance related to land use, proximity to pedestrian generators such as schools, parks, shopping, and transit, etc. in determining whether to provide sidewalks. Guidance is also needed on the appropriate sidewalk width for various facilities in varying locations.

Literature Search Summary

Several research efforts that have been completed or are underway relating to this problem statement:

- *AASHTO Guide for the Planning, Design and Operation of Pedestrian Facilities*. July 2004. AASHTO. AASHTO Publication Code DS-GPF-1. This guide is mostly about how, rather than about where, to provide pedestrian facilities, but Section 2.3.2 gives example criteria for establishing priorities. Section 2.3.4 has a good procedure for phased development of sidewalks.
- ADA/ABA Accessibilities Guidelines (ADA/ABA-AG) July 23, 2004. This will become a standard when USDOJ and USDOT complete their notice-and-comment rulemaking procedures, which are expected to take one to two years. This document focuses on how to make pedestrian facilities accessible, not when they should be provided.

- *A Review of Pedestrian Safety Research in the United States and Abroad*. January 2004. FHWA. FHWA Publication No. FHWA-RD-03-042. This report is an update of the synthesis of safety research done in 1982 and again in 1991.
- C.V. Zegeer, C. Seiderman, P. Lagerwey, M. Cynecki, M. Ronkin, and B. Schneider. *Pedestrian Facilities Users Guide: Providing Safety and Mobility*. March 2002. FHWA Publication No. FHWA-RD-01-102. Appendix B, Recommended Guidelines/Priorities for Sidewalks and Walkways, Contains substantial criteria for new construction and retrofitting sidewalks based on vehicle speed, street classification, pedestrian crash data, school walking zones, transit routes, neighborhoods with low vehicle ownership, urban centers/neighborhood commercial areas, other pedestrian generators, and continuity of walking systems. Recommended Guidelines are illustrated in table form.
- Pedestrian Facility Design, Course Number 142045. National Highway Institute. August 2002. FHWA.
- *Designing Sidewalks and Trails for Access, Part II, Best Practices Design Guide*. November 2001. FHWA. Chapter 3: Integrating Pedestrians into the Project Planning Process, draws extensively from Planning, Design, and Operations of Pedestrian Facilities: Unpublished Draft Final Report (2000), NCHRP, Project 15-20, TRB, Washington , D.C. The chapter includes recommendations for sidewalks where land use planning anticipates pedestrian activity; connect nearby urban communities; near schools, local businesses and industrial plants that result in pedestrian concentrations in rural and suburban areas; where roadside and land development causes pedestrians to move along high-speed highways; rural areas with higher speed traffic and a lack of lighting; and along any street or highway without shoulders even if there is light pedestrian traffic. FHWA Administrator Mary Peters signed a memorandum issuing this document as FHWA guidance for designing and constructing accessible pedestrian facilities.
- *Design Guidance, Accommodating Bicycle and Pedestrian Travel: A Recommended Approach*. February 28, 2000. FHWA. In a memorandum to field offices, FHWA Administrator Kenneth R. Wykle stated that bicycling and walking facilities will be incorporated into all transportation projects unless exceptional circumstances exist. Those circumstances are spelled out in the document.
- *Florida Pedestrian Planning and Design Handbook*. April 1999. Florida Department of Transportation. This is a 181-page handbook covering all aspects of pedestrian facilities.
- *Designing Sidewalks and Trails, Part I, Review of Existing Guidelines and Practices*. August 1999. FHWA.
- *Guidance on Bicycle and Pedestrian Provisions of the Federal-Aid Program*. February 24, 1999. FHWA. FHWA Administrator Kenneth R. Wykle in a memorandum to field offices stated, we expect every transportation agency to make accommodations for bicycling and walking accommodations a routine part of their planning, design, construction, operations, and maintenance activities.
- NCHRP Project 20-07, Task 105, Planning, Design , and Operation of Pedestrian Facilities. Research for the AASHTO Standing Committee. 1999.

Research Objective

- **Task 1:** Review the existing guides and similar publications. Conduct a survey of local, state, and federal agencies to determine their practices and determine if there is a need for additional research.
- **Task 2:** If it is determined in Phase 1 that additional research is needed, conduct that research.
- **Task 3:** Develop a final report of findings. Where appropriate, the report should include appendices with recommended language for use in the AASHTO Policy on Geometric Design of Highways and Streets; the AASHTO Guide for the Planning, Design, Operations of Pedestrian Facilities; the FHWA Manual on Uniform Traffic Control Devices; and other documents as appropriate.

Estimate of Problem Funding and Research Period

Recommended Funding

$250,000 to $500,000.

Research Period

12 to 24 months.

Urgency, Payoff Potential, and Implementation

This research topic was selected by the AASHTO Technical Committee on Geometric Design, the TRB Committee on Geometric Design, and the TRB Committee on Operational Effects of Geometrics at their combined meeting In June 2004 as having high–moderate priority and needed within the next 3 years. There is a need to develop guides for the implementation of sidewalks which relate to land use, proximity to schools and transit routes, connectivity, and not just to volumes of vehicle and pedestrian traffic.

Problem Statement Development

- David S. Johnson, and
- Doug Harwood, Midwest Research Institute.

SAFETY EFFECTS OF INTERSECTION SKEW ANGLE

Research Problem Statement

The most desirable two-road intersection angle is 90 degrees. However, because of physical and other constraints, many roads meet at angles less than 90 degrees. Such locations are referred to as *skewed intersections*, and the difference between 90 degrees and the smallest acute angle between the intersection legs is referred to as the *intersection skew angle*.

The AASHTO Green Book presents a policy on design of intersections to minimize the deviation from a 90-degree intersection angle. This Green Book recommends a minimum intersection angle of 60 degrees and this guidance has been adopted in the geometric design policies of many highway agencies.

There may be skewed intersections with right-angle crossing, and there may also be right-angle intersections with oblique-angle crossing, depending on the alignment of each movement. The orientation of vehicles prior to all points of conflict, including movements such as right merges, should comply with the lateral visibility requirements. Channelized right-turn lanes require an exaggerated degree of operator head rotation to check for traffic conflicts before merging. Additionally, the paths traveled are often significantly curved, making it more difficult for drivers to estimate stopping distances along the travel path.

However, little information about the safety effects of intersection angle is available. It is likely that current design policies on intersection skew angle are based on engineering judgment rather than the results of safety research.

Literature Search Summary

McCoy et al. found, in research for the Nebraska Department of Roads (Project RES1, 1994), that accidents increase with increasing skew angle at rural two-way stop controlled intersections. Hanna et al. (TRR 601, 1976) found that three-leg Y intersections had accident rates approximately 50% higher than three-leg T intersections, suggesting an effect of intersection skew angle. A Finnish study by Kulmala (1995) found that acute and obtuse skew angles affected safety differently. Gattis and Low (1997) analyzed the right-side visibility of vehicles with opaque bodywork and applied to left-skewed intersections, proposing a maximum obliquity angle of 15 degrees so that vehicles do not increase their collision risk. Harwood et al. (FHWA-RD-99-207, 1999) selected an accident modification factor (AMF) for intersection skew angle, based on a negative binomial regression model, for application to STOP-controlled intersections on rural two-lane highways in FHWA's Interactive Highway Safety Design Model (IHSDM). Son et al. (2002) also analyzed the right lateral visibility of passenger and heavy vehicles and their influence at left-skewed intersections, but they considered intersection sight distance instead of stopping sight distance as Gattis and Low (1997), and they took the right center pillar or B-pillar as visual limitation. They reached the conclusion that obliquities greater than 25 degrees are excessive for heavy vehicles, and for cars the safety is obtained with a 20 degrees maximum angle.

A Spanish research project conducted by Garcia (2005) evaluated the impact of the available lateral visibility in merging areas at skewed intersections and safe skew angles at the both types of locations were proposed: no less than 70 degrees for crossing maneuvers, and a maximum angle of 7 degrees for merging. In Australia, research by Arndt and Troutbeck (2005) took into account the observation angle, i.e. a measure of the degree that minor road driver at the intersection need to look sideways or backwards in order to view vehicles on the major road. An increase in the observation angle will increase angle-minor accident rates.

None of this research is considered sufficiently definitive to form a basis for reevaluation of the appropriate geometric design policy for intersection skew angle. The FHWA Highway Design Handbook for Older Drivers and Pedestrians (2001) has recommended that intersection skew angles be reduced for the benefit of older drivers, but the handbook offers no quantitative estimate of the benefit to older drivers, or to motorists in general, from doing so. The new

Australian Guide to Traffic Engineering Practice -- Part 5: Intersections at Grade (Austroads 2005) limits the skew of an intersection, between 70 and 110 degrees. This guideline proposes visibility angles from vehicles, including sight restrictions due to vehicle design. The angles of vision by mirror (25 degrees) are wider than those obtained by Garcia (2005), with 20 degrees and 16 degrees, for the left and right mirror, respectively. At each point where a vehicle has to give way or is about to enter a traffic stream, the vehicle paths, and orientation should be developed with these visibility angles in mind.

Research Objective

The objective of the recommended research is to establish quantitative relationships between intersection skew angle and safety and to use those relationships to consider the need for revision of current geometric design policies concerning intersection skew angle.

The scope of the research should include a range of intersection types including rural and urban locations, three- and four-leg intersections, STOP- and signal controlled intersections, and crossing and merging maneuvers. The research should consider the effect on safety of the magnitude of the intersection skew angle and the orientation of the intersection leg to approaching traffic (e.g. acute vs. obtuse angle). The actual visibility angles from vehicles, including sight restrictions due to vehicle design and diminished capabilities of older drivers, should also be determined.

The research should focus on intersections with angles between 60 and 75 degrees and should assess whether an increase in the current minimum intersection angle of 60 degrees would provide safety benefits. The research should also assess the potential for increased construction costs and other impacts if the minimum intersection angle were to be increased. The assessment of the need for changes in intersection skew angle should consider both the costs and the benefits of any proposed change in design policy. If a change in design policy is recommended, draft text for revision of the AASHTO Green Book should be provided in the final report of the research.

Estimate of Problem Funding and Research Period

Recommended Funding

$400,000.

Research Period

36 months.

Urgency, Payoff Potential, and Implementation

This research topic was selected by the AASHTO Technical Committee on Geometric Design, the TRB Committee on Geometric Design, and the TRB Committee on Operational Effects of Geometrics at their combined meeting in June 2004 as a priority issue from among a broader set of problems considered. The research is needed to address an unresolved issue in highway geometric design. The research results can be implemented through incorporation in the AASHTO Green Book.

Problem Statement Development

Douglas W. Harwood, Midwest Research Institute

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ACCOMMODATING BICYCLES ON RURAL HIGHWAYS

Research Problem Statement

Much research has been done related to accommodation of bicycles in urban and suburban areas, but much less has been carried out that addresses bicycles on rural roads. As more rural roads are being used in various parts of the country for recreational bicycling purposes, there is some question as to when to provide special attention to bicyclists, particularly when most rural roads do not consider bicyclists in their design. Also, there is a need to better understand and communicate which design features are most appropriate for accommodating bicyclists in the rural environment.

The product of this research will be used to determine when to better accommodate bicyclists on rural roads and what design features are best to accommodate them. It will be used by state and local road officials with jurisdiction over rural roads.

Literature Search Summary

Searches in TRIS and Research in Progress did not reveal much information in this regard. However, a recent report entitled "Development of Rural Bicycle Compatibility Index" from Nebraska (Jones, E., July 2004) provides a fairly extensive literature review. Most of the literature cited by Jones, consistent with her research goal, indicates that much of the research concerns the compatibility of existing roads for use by bicyclists. Likewise, much of the research centers on urban and suburban roads and may or may not be true for rural roads. However, one obtains a good idea of the types of roadway characteristics that affect the ability of a bicyclist to safely and comfortably use a road.

Jones cites Shorton and Walsh who examined factors such as curb lane traffic volume, speed of vehicles, curb lane width, commercial driveways per mile along a street, and percentage of heavy vehicles as factors that may impact a bicyclist using a given roadway. Landis, et.al. looked at pavement surface conditions in a similar vein. Harkey and Stuart found that motorists are less likely to encroach on an adjacent lane when passing a bicyclist on a paved shoulder. As well, bicyclists will ride further from the edge of roadway when they are on a paved shoulder. Smith found that when heavy vehicle speeds are 60 mph or greater, a separation distance of 6 feet or more is necessary for tolerable riding conditions. In concluding her work, Jones states that highways with low truck volumes and wide shoulders to ride on will be more comfortable for most rides.

The current research will build on work performed by Jones and those cited in her work. The research will consider the compatibility of a roadway for bicycles, but package the "compatibility" of the roadway in a manner that clearly identifies when a road authority ought to improve the conditions of the road to make it more safely and comfortably useful by bicycles. In addition, the work will take the criteria used for compatibility and other information to establish a practical set of potential countermeasures that can be considered for application once a road is designated as in need of improvements for bicycles.

The Maine Department of Transportation (Smith, Balicki and Pesci) has an ongoing project researching safe routes to school. They are looking at short-term measures to encourage walking and bicycling to school in both urban and rural sites. They have also recommended a long-term approach that includes engineering, education, enforcement, and encouragement measures. Maine also has research in progress on gravel stabilization methods. One of the goals of the research is to examine the ability of gravel stabilization to increase bicycle access and rideability. Colorado DOT is examining advance warning (signs and pavement markings) of rumble strips for bicyclists. The ultimate goal is to develop a rumble strip warning configuration that will be used to ensure that bicyclists are not surprised by the presence of rumble strips.

The proposed research is different than the ones cited above in two ways. First, the MDOT work in the first project was entirely focused on safe routes to school whereas the current research will be more universally applicable for all bicycle users on rural roads. With regard to the second MDOT project, the work is not focused on bicycle users as is the proposed research. Specifically, in reading an abstract, it appears that bicycle safety and comfort is a potential by-product of the research rather than the primary aim. The current research would use the information as part of the practical countermeasures that could be considered in the rural environment, but it will not serve as the entire possible set of solutions that are available. Finally, the CDOT product will be a valuable tool for consideration in the current project, but again it is only one small part of the picture.

In reviewing current research, it appears that there is not sufficient information available for the rural environment to synthesize or highlight best practices. New research is needed to advance the thinking in this area.

Research Objective

The proposed research will result in a guide that provides guidance and/or warrants on when bicycles should be accommodated on rural highways and suggests sensible accommodation options that are appropriate for the rural environment. Some of the steps or tasks would be:

- Describe the whole set of possible factors that affect bicycle safety and comfort on rural roadways.
- Define scenarios in which bicycles should be prohibited on certain roadways.
- Identify criteria that should be used to determine when a road should be reviewed for possible bicycle-related improvements—vehicle and bicycle volumes, requests from the public, particular groups or organizations.
- Develop a process that can be applied to roads such that a determination can be made as to the objective need for bicycle improvements—i.e. warrants. Ideally, such warrants would be based on a substantive safety analysis if possible. Warrants would also be tied to specific countermeasures, particular the provision of shoulders.
- Identify in some priority order the set of countermeasures that are available for use in the rural environment. The detailed descriptions of the countermeasures should provide some information on the relative cost of the countermeasures and their ability to address specific types of safety problems or concerns.
- Provide a process that assists in the selection of practical and cost effective solutions for a given situation.

Some of the items relatively important for inclusion in the above are:

- Specification of when paved shoulders should be provided for bicyclists. When are “hard” shoulders sufficient?
- Consideration of constraints—e.g., narrow bridges—on rural roads and their effect on the safety of bicyclists.
- Consideration of rumble strips when accommodating bicyclists.

Estimate of Problem Funding and Research Period

Recommended Funding

$350,000.

Research Period

36 months.

Urgency, Payoff Potential, and Implementation

Given the increasing use of rural roads by bicyclists in many parts of the country, the nearly complete lack of guidance and information for accommodating bicycles on rural roads and pressure that many road officials experience from community groups and others, the research is considered to be very urgent. The payoff of the project would include a better understanding of the problem by road officials, a clearer knowledge of when they should or should not undertake improvements for bicyclists and the extent and scope of the improvements that they should undertake.

The primary product will be a manual that provides guidance and/or warrants on when bicycles should be accommodated on rural highways and suggest sensible accommodation options that are appropriate for the rural environment. Certainly, adoption by AASHTO would be a very useful end goal if the guide is to be accepted and widely applied by state and local officials with jurisdiction over rural roads. However, it may be unlikely to expect that it will be included separately in any given AASHTO guide, particularly in the short term.

Problem Statement Development

- TRB Geometric Design Committee and
- TRB Operational Effects of Geometrics Committee.

OPERATIONAL AND SAFETY IMPACTS OF ANGLE VERSUS PARALLEL VERSUS BACK-IN PARKING

Research Problem Statement

There is a sizable body of literature examining the safety effects of angle and parallel parking. What is not always evident is:

- The context within which these findings are applicable (surroundings, traffic volumes);
- The safety effects of back-in angle parking;
- The safety effects of buffer spaces between through traffic lanes and parking lanes;
- Guidelines for allocating cross-section width between bicycles and parked vehicles;
- The needed cross-section width for parallel parking; and
- The economic effects of different parking choices.

Recent experimentation examines back-in angle parking as an alternative to head-in angle parking. Current research in Rhode Island is examining tradeoffs between bike lane width and parking width. The pavement marking diagrams in recent versions of the MUTCD have called for a marked parallel parking stall that is 8 feet wide; some recent design publications have specified less width.

With the emphasis in and growth of New Urbanism and Context Sensitive Design, traffic engineers need more definitive studies and explanations of the tradeoffs and affects of prohibiting or allowing various types of on-street parking arrangements.

Literature Search Summary

Curb parking was found to be directly involved in 17% to 18% of all accidents on urban streets; the rate of parking accidents per mile was eight times greater on major streets than on minor (Box 1970). Humphreys et al. (1979) reviewed data from ten cities, finding that over 50% of nonintersection crashes involved parking. McCoy et al. (1990) surveyed 135 miles of urban state highway with curb parking. Data were collected from 22,572 parallel spaces and 6,314 angle spaces in a number of cities and towns. Overall, 26% of the nonintersection accidents on major streets and 56% on two-way, two-lane streets were parking accidents. In one study, the cost of parking accidents was found to be about half of the average (Rankin).

Edwards (2002) advocated angle parking because it provides a wider “buffer” between sidewalks and driving lanes, which helps reduce vehicle splash, noise and fumes, and helps improve the perception of safety for the pedestrian. Many consider angle parking to be more dangerous than parallel (Rankin). In a synthesis of a number of studies, Box (2002) found higher accident rates for angle parking than for parallel, with a few exceptions. A Nebraska study found higher accident rates for angle parking by any measure as compared with parallel parking (McCoy et al.). Humphreys et al. (1979) concluded the crash rate increased with land use type: the lowest being associated with residential, and increasing with multifamily, office, and retail. The level of use rather than the parking configuration appeared to be the key to the midblock accident rate: for streets with over 600,000 parking space hours per kilometer per year, parallel parking is not safer than angle parking, given similar land uses. Zeigler (1971) said that parking at an extremely flat 22.5^{O} angle with the curb was proven to be quiet safe and user-friendly.

Research Objective

The objective of this research is to more fully investigate and document the effects and tradeoffs of allowing or prohibiting on-street parking.

- **Task 1:** Issues to examine include the following:
  1. Under what conditions should on-street parking be allowed or prohibited?
  2. If parking is allowed, under what conditions should it parallel, head-in angle, or back-in angle?
  3. How much cross-section width should be allocated for a parked vehicle or for bicycles?
  4. What are the economic effects of these choices?
- **Task 2:** The project should include a literature review of previous related research.
- **Task 3**: The safety effects of on-street parking could be better examined using data from those locales that have improved their crash reporting processes by means such as using satellite crash location technology. The context of studies needs to be better defined: factors such as abutting land use type and street traffic volumes should be reported, and both data and findings should be stratified by context, so that findings taken from one environment are not applied without justification to other environments.
- **Task 4:** A necessary component to this research will be findings from agencies that have experimented with back-in angle parking, a buffer strip between travel lanes and angle parking, and the flat-angle parking advocated by Ziegler.

- **Task 5:** An examination of the effects of curb parking upon business and the community would be helpful. A confounding problem is that it is not uncommon for parking enhancements to be accompanied by other area improvements.

Estimate of Problem Funding and Research Period

Recommended Funding

$275,000.

Research Period

30 months.

Urgency, Payoff Potential, and Implementation

Traffic engineers in urban settings are sometimes pressured to permit on-street parking, which in some situations may be unsafe. Findings from this study would help them evaluate specific situations and distinguish between locations where on-street parking could be allowed and those where it should be opposed.

Additional research will be of little benefit unless an effective technology transfer method to get the information into the hands of practitioners and local political leaders is employed.

Problem Statement Development

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- Keith K. Knapp, University of Wisconsin–Madison.

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APPENDIX A

Combinations of Design Controls and Elements

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RESEARCH TOPICS

There are 12 research topics that fall under the following three categories.

Cross-Section Elements

- Cross-section elements for rural highways;
- Cross-section elements for urban arterials;
- Safety and operational effects of cross-slope;
- Rumble strips;
- Five-lane and seven-lane cross-sections on suburban arterials; and
- Alternative curb treatments in urban areas.

Horizontal Curve Design

- Safety and operational effects on cars and trucks, and
- Combined horizontal and vertical alignments.

Sight Distance

- Stopping sight distance (SSD);
- Intersection sight distance (ISD);
- Passing sight distance (PSD); and
- Decision sight distance (DSD).

RELATED RESEARCH AND LITERATURE

The primary resources summarizing the recent past and present research and literature were drawn from the following:

- FHWA-RD-99-207, *Prediction of the Expected Safety Performance of Rural Two-Lane Highways* (*1*);
- *NCHRP Report 375: Median Intersection Design* (*2*);
- Safety Models for Urban Four-Lane Undivided Road Segments (*3*);
- *NCHRP Report 330: Effective Utilization of Street Width on Urban Arterials* (*4*);

- *NCHRP Report 282: Multilane Design Alternatives for Improving Suburban Highways* (*5*);
- *NCHRP Report 395: Capacity and Operation Effects of Midblock Left-Turn Lanes* (*6*);
- *NCHRP Report 439: Superelevation Distribution Methods and Transition Designs* (*11*); and
- *NCHRP Synthesis of Highway Practice 299: Recent Geometric Design Research for Improved Safety and Operations* (*7*).

CROSS-SECTION ELEMENTS

Cross-Section Elements for Rural Highways

Lane and Shoulder Widths

The relationships between safety and lane and shoulder widths have been studied extensively in the rural environment, but the results of these studies are varied. An expert panel (*1*) recently reviewed the literature on safety for lane and shoulder widths on rural two-lane highways for the FHWA Interactive Highway Safety Design Model (IHSDM). The panel developed accident modification factors (AMFs) for lane width and shoulder width based on these past studies. Additional research is needed to develop guidelines for cost-effective combinations of lane and shoulder widths on rural highways.

Special consideration should be given to paved shoulders and their features. The following fundamental questions should be resolved for each roadway type:

- Feasibility of a paved shoulder;
- Clarification about its function as perceived by drivers;
- Proper width of a paved shoulder in relation to
  - Roadway type/functional class,
  - Adjacent lane width,
  - Average daily traffic,
  - Percent heavy vehicles,
  - Presence of slow-moving vehicles (e.g., agricultural vehicles),
  - Presence of transit,
  - Need for bus stations, and
  - Other influential factors;
- Paved shoulder treatment at intersections; and
- Feasibility and functionality of paved shoulders on ramps.

Median Cross-Section Design

The safety and operational effects of median width at signalized and unsignalized intersections were evaluated extensively by Harwood et al. in *NCHRP Report 375: Median Intersection Design* (*2*). In fact, *NCHRP Report 375* presents recommendations regarding median width at rural, three-leg and four-leg unsignalized intersections.

Median cross-section elements that have not been researched as extensively include:

- Median cross-slope (is flatter safer?);
- Drainage issues;
- Guidance for when to use a median barrier; and
- Median cross-section design to warrant SSD on passing lanes for curves to the left.

Upcoming work in NCHRP Project 15-30: Median and Median Intersection Design for High-Speed Facilities is planned to take a further look at median cross-section design issues.

Median Barrier Placement

A number of states have been revising their warrants and related policies for median barriers on freeways and other divided highways. Typical changes in state policies and practices resulting from this work have included use of barriers in wider medians than previously considered necessary (in some cases, up to 70 ft), use of guardrail near the median shoulder rather than median barrier at the center of the median for wider medians, and use of cable barrier as an alternative to median barrier or guardrail. NCHRP Project 17-14: Improved Guidelines for Median Safety has been examining these issues, but no results have yet been reported. Depending on the results of NCHRP Project 17-14, further research may be needed. In particular, further research may be needed to address the following median barrier issues:

- When is it appropriate to use a median barrier?
- What median widths are appropriate for a median barrier?
- What is the appropriate location for a median barrier (e.g., center of median, closer to shoulder)?
- What type of barrier is most appropriate for a given width of median and location of barrier?

Forgiving Roadway Design

Many states are concerned about crossover median accidents and run-off-the-road accidents on their Interstate and multilane, divided state highway system. These crashes generally result in severe injuries or fatalities. One state has found that 17% of the traffic-related fatalities on their Interstate system occur as a result of median crossover accidents. This same state has also found that 60% of their fatalities occur as a result of run-off-the-road accidents on the right side of the roadway where errant vehicles strike fixed objects, in particular trees.

The aforementioned crash statistics lead to the following questions:

- Should the clear zone concept (i.e., forgiving roadside design) be maintained in its current form or should the concept be broadened to “forgiving roadway design” with the ultimate goal to provide a roadway design that provides the best combination of safety (especially nonsevere crashes), operation, appearance, environmental impact, and construction cost?
- Could a reduced clear zone coupled with longitudinal barrier on the left and right sides of each set of directional roadways on a divided facility reduce traffic-related deaths and the overall economic costs associated with traffic-related crashes?

- Cable guardrail could be one type of barrier system considered for the forgiving roadway design. Assuming that cable guardrail captures errant vehicles in a manner that typically results in accidents no worse than property-damage-only (PDO), could a cable system reduce deaths by nearly 75%?

The increased mileage of longitudinal barrier would be expected to result in an increase in property-damage-only accidents because the clear zone would be reduced to just the width of the paved shoulder. However, the economic value placed on such crashes is negligible relative to the value of a fatal crash. This disparity is a primary reason for the need to reconsider the forgiving roadside design concept. While forgiving roadside design gives priority to "removal of obstacles" and thus the reduction of all crash types, forgiving roadway design would reflect a greater sensitivity to the reduction of severe crashes.

The clear zone concept worked well with the lower traffic volumes that existed in the 1960s and 1970s, but it may not be providing the same level of safety today due to increased volumes and the greater interaction of traffic on the roadway. With forgiving roadway design, the grass portion of the median and the grass portion of the right-of-way on the right side of the roadway would be reduced to areas for drainage and future roadway expansion. Esthetics could be improved by trees, landscaping, and other greenery, provided enough space was left for the dynamic deflection of the guardrail on both sides.

Simulation Tools to Evaluate Passing–Climbing Lanes

The *Highway Capacity Manual* (HCM) analysis procedures for rural two-lane highways include procedures for assessing the effect of passing lanes on level of service (LOS), but only address the simplest of added lanes. The traffic operational effects of passing lanes that are not isolated and for combinations or systems passing lanes along a two-lane highway can best be assessed with a computer simulation model. Microscopic computer simulation models can simulate two-lane roadway sections with any arrangement of passing and no-passing zones and added passing lanes along a highway corridor. Comparisons can be made between the existing alignment and cross-section of a highway corridor and various passing lane alternatives. Traffic operational performance measures that can be provided for each alternative evaluated include percent time spent following and average travel speed. Additional research may be needed to address wider use of simulation to evaluate passing/climbing lanes.

Cross-Section Elements for Urban Arterials

Lane and Shoulder Widths

Only a few studies have researched the relationship between lane width or shoulder width and safety in the urban environment, and the results of these studies are also varied. Some of the key studies include:

- Hauer (*3*). Statistical models were developed to predict the nonintersection accident frequency of urban four-lane undivided roads. Hauer found that lane width was associated with PDO accidents but not injury accidents; however, he notes that the relationship is weak, and lane width is only included in the model because of the traditional interest in this variable. Hauer also found the relationship between shoulder width and safety to be of marginal importance.

- Harwood (*4*). Research was conducted to determine the effectiveness of various alternative strategies for reallocating the use of street width on urban arterials without changing the total curb-to-curb width. Harwood indicated that the preferred lane width for urban arterial streets under most circumstances is 3.3 or 3.6 m (11 or 12 ft). Harwood concluded that the effect of providing full shoulders instead of a curb-and-gutter cross-section decreases the accident rate by 10%.

Two ongoing NCHRP projects address cross-section elements in urban areas. In NCHRP Project 17-26: Methodology to Predict the Safety Performance of Urban and Suburban Arterials, a methodology is being developed to predict the safety performance of the various elements (e.g., lane width, shoulder width, use of curbs) considered in planning of nonlimited-access urban and suburban arterials. In NCHRP Project 3-72: Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas, design guidance and criteria are being developed for addressing the safety and operational tradeoffs for motorists, pedestrians, and bicycles for two specific topics: selecting lane widths and using right-turn deceleration lanes at driveways and unsignalized intersections.

Future research is needed that uses crash data to document either pedestrian or bicycle safety implications of lane width, roadway width, and shoulder width. In particular, it is widely believed that reduced crossing distance results in reduced risk to pedestrians, but it has never been demonstrated that constructing a road with narrower lanes in fact reduces the frequency or severity of pedestrian collisions.

Safety and Operational Effects of Cross-Slope

Americans with Disabilities Act (ADA) requirements for the maximum grade of pedestrian crosswalks may limit pavement cross-slopes to 5%. The maximum cross-slope of a pedestrian crosswalk (grade of street) is limited to 2%. Similarly, where a paved shoulder is intended to serve as a pedestrian travel path, the shoulder cross-slope may be limited to 2%. The safety implications for motor vehicles of such changes are unknown.

Current superelevation runoff criteria should be reevaluated (particularly for wide divided highways—six lanes or more). There exist indications of inducing hydroplaning phenomena. Therefore, further research is needed to examine special treatments for preventing hydroplaning.

Rumble Strips

Shoulder Rumble Strips

Several studies have demonstrated the effectiveness of shoulder rumble strips in reducing run-off road crashes. In fact, due to the relatively low cost of providing continuous shoulder rumble strips, many states are beginning to equip their roadways with continuous shoulder rumble strips and create policies for their installation and use.

Further research is needed in the following areas:

- Safety effectiveness of shoulder rumble strips on two-lane rural highways (the majority of research has been conducted on freeways).
- Placement of shoulder rumble strips—should they be place at the edgeline or further into the shoulder? To accommodate bicyclists, who generally prefer to ride closer to the edgeline, shoulder rumble strips should be placed further into the shoulder.
- Guidelines need to be developed for the cost-effective application of rumble strips.
- Maintenance issues.

Centerline Rumble Strips

Several studies have demonstrated the effectiveness of centerline rumble strips in reducing head-on and opposite-direction sideswipe crashes on rural two-lane roads.

Further research is needed to determine

- The impact of centerline rumble strips on motorcycles.
- How wide the centerline rumble strip should be (i.e., confined to between the stripes or extended into the through lane).
- What effect does the installation of centerline rumble strips have on lateral displacement of vehicles?
- Maintenance issues.

Five- and Seven-Lane Cross-Sections on Suburban Arterials

NCHRP Report 282: Multilane Design Alternatives for Improving Suburban Highways (*5*), presents a comparison of the safety, operational, and cost characteristics of selected multilane design alternatives for use in suburban areas. Advantages and disadvantages of each alternative are provided to assist in the selection of the most appropriate design for a given condition. The report states that the five-lane two-way left-turn lane (TWLTL) design alternative is most appropriate for suburban highways with commercial development, driveway densities greater than 45 driveways per mile, low-to-moderate volumes of through traffic, high left-turn volumes, and/or high rates of rear-end and angle accidents associated with left-turn maneuvers. *NCHRP Report 330: Effective Utilization of Street Width on Urban Arterials* (*4*) evaluated various alternative strategies for reallocating the usage of street width without changing the total curb-to-curb width. The advantages and disadvantages of four-lane divided roadways and five-lane roadways with TWLTLs are presented. *NCHRP Report 395: Capacity and Operation Effects of Midblock Left-Turn Lanes* (*6*) reviewed the relative safety performance of arterials with different cross-sections.

Further research is needed to address the following issues:

- Delay reduction benefits.
- When is a 5-lane or 7-lane cross-section appropriate?
- Before/after safety study (even if not subject to regression to the mean).
- Accommodating pedestrian crossings of wide arterials.

Alternative Curb Treatments in Urban Areas

Further research is needed to address the following curb-related issues:

- Use of curb on normal cross-section;
- Use of curb on channelizing islands;
- Use of curb on turning roadways;
- Appropriate speeds for curb use; and
- Vertical versus sloping curbs.

HORIZONTAL CURVE DESIGN

Safety and Operational Effects on Passenger Cars and Trucks

In *NCHRP Synthesis of Highway Practice 299: Recent Geometric Design Research for Improved Safety and Operations* (*7*), several studies are cited that have evaluated horizontal curve design for safety and operational effects on cars and trucks. Harwood and Mason (*8*) concluded that there does not appear to be a need to modify existing criteria for determining the radii and superelevation of horizontal curves in Green Book Table III-6, as long as the design speed of the curve is selected realistically. Blue and Kulakowski (*9*) investigated the roll performance of tractor-semitrailer trucks on horizontal curves with three different types of transitions and concluded that the spiral design is superior because it provides a more gradual transition into the curve. Felipe and Navin (*10*) reported on a study that measured speed and lateral acceleration for drivers on four horizontal curves at a test track and four horizontal curves on a roadway. The results of the study indicated that pavement conditions (wet or dry) did not significantly affect the selected driver speed.

In research reported in *NCHRP Report 439: Superelevation Distribution Methods and Transition Designs* (*11*), Bonneson evaluated and recommended revisions to the horizontal curve guidance presented in the 1994 edition of the Green Book. The two principal design elements evaluated were the use of superelevation and the transition from a tangent to a curve, though all elements of a curve were considered in the analysis. The transition recommendations were incorporated into the 2001 edition of the Green Book while the superelevation recommendations were being considered for the subsequent edition.

The proper selection of design speed for horizontal curves is an important issue. Current research in NCHRP Project 15-25: Alternatives to Design Speed for Selection of Roadway Design Criteria is being conducted to recommend comprehensive improvements to the design-speed approach for setting geometric design criteria. This research is intended to apply to all types of roads.

Further research is needed to address the following issues related to horizontal curve design:

- More modern data for side friction factors;
- Cost-effective design of curved sections on structures (e.g., bridges and tunnels); and
- Implications of barrier use, bridge abutments, tunnels, etc.

More sophistication in applying horizontal curve design to various conditions (urban vs. rural, speeds, etc)

Revisit the current horizontal curve model:

$$e + f = \frac{V^2}{15R}$$

- Is a model based on lateral acceleration and “driver comfort” truly representative of what a driver needs to negotiate horizontal curves for all functional classes of roadways (including intersection turning roadways, ramps, arterial streets, etc.)?
- What role should side friction play, if any?

Combined Horizontal and Vertical Alignments

NCHRP Synthesis of Highway Practice 299 cites two studies that have examined the coordination of horizontal and vertical alignments: Smith and Lamm (*12*) and Lamm and Smith (*13*). Lamm and Smith proposed an alignment design process based on evaluating operating speed changes between successive design elements and for comparing operating speeds and design speeds of single design elements with each other. Smith and Lamm presented numerous indirect visual and safety-related issues to assist designers in avoiding horizontal and vertical designs that may diminish the driver’s feeling of comfort, certainty, and safety or that may violate the driver’s expectations. A number of other researchers have developed three-dimensional models to improve coordination of horizontal and vertical alignments (*14–17*).

Currently, nothing is known about the safety implications of combinations of horizontal and vertical alignment. Further research is needed in this area, along with research to address

- Practical applications of design consistency—how should design consistency be reflected in the Green Book?
- Speed selection on curves—implications of IHSDM driver–vehicle model research for Green Book policy.

SIGHT DISTANCE

Stopping Sight Distance

SSD was recently revised, as reported in *NCHRP Report 400: Determination of Stopping Sight Distances* (*18*).

Further research may be needed to reconsider SSD models and determine if they address the right scenarios (e.g., turning roadways, interchange ramps, sharp curves, etc).

Intersection Sight Distance

ISD was recently revised, as reported in *NCHRP Report 383: Intersection Sight Distance* (*19*).

While ISD criteria have been recently revised, not much is known about the relationship between ISD and safety. This gap in knowledge is critical given that ISD is a controlling element in the design of at-grade intersections. This lack of establishing the relationship of available ISD to accidents creates high uncertainty in evaluating alternative designs giving full consideration to any respective safety tradeoffs. An expert panel (*1*) recently reviewed the literature on safety for ISD on rural two-lane highways for the FHWA IHSDM. This panel did not find any evaluation of the effects of ISD on accidents to be more credible than any other. Therefore, a recommended AMF was determined from the panel's best judgment based on the results of Kulmala, Brüde and Larsson, and Elvik (*20–22*). Further research may be needed to quantify the relationship between safety and ISD.

Passing Sight Distance

Current PSD models are based on old data. PSD is currently being reevaluated in NCHRP Project 15-26: Passing Sight Distance Criteria.

This project will also address coordination between sight distance and the *Manual on Uniform Traffic Control Devices* markings. Further research may be needed to address older driver issues and recommendations from the Older Driver Handbook.

Decision Sight Distance

Further research may be needed to address the following DSD issues:

- Improved guidance on the use of DSD:
  - For nighttime conditions, and
  - For adjusting the basic model (are values too long?), incorporating human factors; and
- Review and updates to the DSD model.

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BREAKOUT GROUP NOTES

Research Topic: Cross-Section Elements: Rural Highways–Median Barrier Placement

Overview

A number of states have been revising their warrants and related policies for median barriers on freeways and other divided highways. Typical changes in state policies and practices resulting from this work have included use of barriers in wider medians than previously considered necessary (in some cases, up to 70 ft), use of guardrail near the median shoulder rather than median barrier at the center of the median for wider medians, and use of cable barrier as an alternative to median barrier or guardrail. NCHRP Project 17-14: Improved Guidelines for Median Safety has been examining these issues, but no results have yet been reported.

Discussion

Topic 1.1.1.1: Rural Highway Lane and Shoulder Widths The discussion focused on through lanes at interchanges for Interstates. Consider widening shoulder at entrance ramps to provide outlet for shifting through traffic to accommodate merging vehicles. This would imply a need for more shoulder on median side of a mainline at an entrance ramp to help merging traffic to avoid accidents. The United Kingdom does not allow the shoulder to be used as extra width. This relates to other issues, such as increasing the adjacent lane width to the merge. This may be more applicable for lower-speed urban reconstruction projects and not new construction.

Topic 1.1.1.2: Rural Highway Median Barrier Could adjusting the shoulders as described in Topic 1.1.1.2 have the potential to lead to more accidents at interchanges, in particular, those downstream from an on-ramp? Shoulder width may be related to flattening the cross-slope for vehicle recovery. If median is made flatter, what deters cross traffic? If the median is flat, how is it drained? A nearly flat (but not flat) median may help with vehicle recovery. What slope should be used? Clear zone should be considered. Would it be safer to provide a barrier instead?

Topic 1.1.1.3: Barrier Issues in Urban and Rural Environments We think this would apply to highway medians greater than 12 ft. The research may also apply to medians in a cloverleaf ramp (the location between the loop ramp and the outer ramp). Should the median barrier be made of earthen mounds, cable, or something else? Can we have something that is not manmade? Would landscaping be more forgiving than a manmade barrier? There was concern that a cable median treatment would cause vaulting issues. The question was posed on how much force/weight cable barriers can hold back/redirect.

Topic 1.1.1.4: Forgiving Roadside We found that Topic 1.1.1.4 was directly related to the above discussion. The research should be applied to both rural and urban environments. We recommend that the research be conducted with a variety of vehicle types, especially trucks and motorcycles. There was much concern as to what a cable would do to a motorcycle rider if impacted. The location of the barrier should be investigated. How close should the barrier be to the edge of the roadway?

Research Needs

Basic research required.

Discussion: Need comprehensive research. Only a little bit of existing research is available.

Research Methodology

Field.

Priority

High/moderate.

Urgency

Next 1–3 years.

Discussion: Different states are doing different things. We need a method to justify what the states should be doing.

Duration of Research

24–36 months.

Funding Requirement

Moderate ($250,000–$500,000.

Discussion: There may be some other barrier testing information that could be used.

Funding Agency

NCHRP.

Product/Objective

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

Summary and Recommendation

High-priority.

Research Topic: Cross-Section Elements: Rural Highways–Simulation Tools to Evaluate Passing/Climbing Lanes

Overview

The HCM analysis procedures for rural two-lane highways include procedures for assessing the effect of passing lanes on LOS, but only address the simplest of added lanes. The traffic operational effects of passing lanes that are not isolated and for combinations or systems passing lanes along a two-lane highway can best be assessed with a computer simulation model. Microscopic computer simulation models can simulate two-lane roadway sections with any arrangement of passing and no-passing zones and added passing lanes along a highway corridor. Comparisons can be made between the existing alignment and cross-section of a highway corridor and various passing lane alternatives. Traffic operational performance measures that can be provided for each alternative evaluated including the percent of time spent following and average travel speed. Additional research may be needed to address wider use of simulation to evaluate passing/climbing lanes.

Discussion: Techniques already exist. We feel this is an implementation issue and not a research issue.

Research Needs

None.

Discussion: Implementation required

Research Topic: Cross-Section Elements: Urban Arterials–Lane and Shoulder Width

Overview

Only a few studies have researched the relationship between lane width or shoulder width and safety in the urban environment, and the results of these studies are also varied. Future research using crash data to document either pedestrian or bicycle safety implications of lane width, roadway width, and shoulder width is needed. In particular, it is widely believed that reduced crossing distance results in reduced risk to pedestrians, but it has never been demonstrated that constructing a road with narrower lanes in fact reduces the frequency or severity of pedestrian collisions.

Discussion

We believe pedestrians are likely covered under other research topics. This would also apply to the bicycle portion of the topic. There may be a relationship between lane width and bicycle safety.

Research Topic: Cross-Section Elements: Safety and Operational Effects of Cross-Slope

Overview

Superelevation transitions and hydroplaning.

Discussion

Site specific. Designer needs to be aware of drainage issues. Need to elaborate in Green Book revision. No research required.

Research Topic: Cross-Section Elements: Safety and Operational Effects of Cross-Slope

Overview

ADA requirements for the maximum grade of pedestrian crosswalks may limit pavement cross-slopes to 5%. The maximum cross-slope of a pedestrian crosswalk (grade of street) is limited to 2%. Similarly, where a paved shoulder is intended to serve as a pedestrian travel path, the shoulder cross-slope may be limited to 2%. The safety implications for motor vehicles of such changes are unknown.

We are only taking this as a pathway for an accessible route.

May adversely impact hydroplaning, thus this should only be in low-speed situations. Doesn't make sense in rural areas with steep grades; may lead to removal of sidewalk. In general, the shoulder should not be considered as a pedestrian facility. Instead provide a separate pathway. At what level does this need to be implemented? Instead, group this with Urban Streets research needs.

Summary and Recommendation

The Urban Streets Subcommittee should make this a priority.

Research Topic: Rumble Strips

Overview

There is European information available on benefits to use rumble strips. Placement (location with respect to the lane) is already established in Europe. There may be a need to determine what to do with bicycles. The United States may require a separate bike path, which would be too expensive. Can heavy vehicle operators feel the rumble strip? Research conducted in the United Kingdom indicates that the heavy vehicle driver may not feel the rumble strips. Therefore, heavy vehicles would still cause accidents, defeating the purpose of the rumble strips. Do the vehicle operators hear the noise or feel the vibration?

Research Needs

Minimal additional research to supplement available research.

Priority

Low.

Summary and Recommendation

This is not a high priority, unless it is not covered adequately in the ongoing NCHRP Project 17-32: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips.

Research Topic: Horizontal Curve Design: Combined Horizontal and Vertical Alignments (Superelevation Criteria for Steep Grades on Sharp Horizontal Curves)

Overview

NCHRP Synthesis 299 cites two studies that have examined the coordination of horizontal and vertical alignments: Smith and Lamm (*12*) and Lamm and Smith (*13*). Lamm and Smith proposed an alignment design process based on evaluating operating speed changes between successive design elements and for comparing operating speeds and design speeds of single design elements with each other. Smith and Lamm presented numerous indirect visual and safety-related issues to assist designers in avoiding horizontal and vertical designs that may diminish the driver's feeling of comfort, certainty, and safety or may violate the driver's expectations. A number of other researchers have developed three-dimensional models to improve coordination of horizontal and vertical alignments (*14–17*). Currently, nothing is known about the safety implications of combinations of horizontal and vertical alignment. Further research is needed in this area. Also, further research is needed to address

- Practical applications of design consistency—how should design consistency be reflected in the Green Book?
- Speed selection on curves—implications of IHSDM driver–vehicle model research for Green Book policy.

Discussion

Examine combination of maximum vertical curve and horizontal curve portion of above overview only. Develop superelevation criteria for steep grades in conjunction with sharp curves. Research needs to look at trucks.

Research Needs

Moderate additional research to supplement available research.

Discussion: Basil Psarianos is aware of some research related to this topic. Jim Bonneson did some previous superelevation research for grades less than 5% grades. West Virginia University has started this project with West Virginia Department of Transportation.

Research Methodology

Combination field/simulation.

Priority

High/moderate.

Urgency

Next 1–3 years.
Discussion: High priority for mountainous states.

Duration of Research

24–36 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agency

NCHRP.

Product/Objective

Research report.

Summary and Recommendation

We recommend this research as described above (not the entire overview, only the part identified).

Research Topic: Horizontal Curve Design: Safety and Operational Effects on Passenger Cars and Trucks

Overview

Further research is needed to address the following issues related to horizontal curve design:

- More modern data for side friction factors.
- Cost-effective design of curved sections on structures (e.g., bridges and tunnels).
- Implications of barrier use, bridge abutments, tunnels, etc.
- More sophistication in applying horizontal curve design to various conditions (urban versus rural, speeds, etc.).
- Revisit the current horizontal curve model.
- Is a model based on lateral acceleration and "driver comfort" truly representative of what a driver needs to negotiate horizontal curves for all functional classes of roadways (including intersection turning roadways, ramps, arterial streets, etc.)?
- What role should side friction play, if any?

Discussion

Why not use tire manufacturer data to revise friction as new data becomes available? The industrial average could be used.

Don't we need to design for the bald tire? What friction factor should we pick for appropriate safety?

We think the model may be okay; we suggest that we look at the values for the variables.

What about the pavement variables? Is the worn asphalt–concrete different than what was used in the Green Book?

Basil suggests using a regression analysis in the research and suggested contacting the World Road Association for additional information.

Bridges and tunnels may need to be examined to see if there would be differences.

Applying the model to different speeds: do we really need to design to driver comfort? Should we change the criteria to evaluate driver comfort and safety? How does this work with traffic calming?

Project 1: Examine horizontal curve design. Test/evaluate friction factors, including modern worn asphalt, modern tires, and if there should be a different design requirement for tunnels and bridges.

Research Needs

Basic research required.

Research Methodology

Field; combined test track and laboratory.

Priority

High/moderate.

Urgency

Next 1–3 years.

Duration of Research

12–24 months.

Funding Requirement

Minimal (less than $250,000).

Funding Agency

NCHRP.

Products/Objectives

- Research report and
- AASHTO criteria.

Summary and Recommendation

We recommend this research.

Research Topic: Horizontal Curve Design: Safety and Operational Effects on Passenger Cars and Trucks

Overview

Further research is needed to address the following issues related to horizontal curve design:

- More modern data for side friction factors.
- Cost-effective design of curved sections on structures (e.g., bridges and tunnels).
- Implications of barrier use, bridge abutments, tunnels, etc.
- More sophistication in applying horizontal curve design to various conditions (urban vs. rural, speeds, etc.).
- Revisit the current horizontal curve model.
- Is a model based on lateral acceleration and "driver comfort" truly representative of what a driver needs to negotiate horizontal curves for all functional classes of roadways (including intersection turning roadways, ramps, arterial streets, etc.)?
- What role should side friction play, if any?

Discussion

Project 2: Examine the importance of driver comfort and minimum values of superelevation and friction in conjunction with margins of safety.

What is comfortable? The design may end up limiting the speeds and thus discomforting the drivers. Suggest evaluating passenger cars only for comfort.

Applying the model to different speeds. Do we really need to design to driver comfort? Should the criteria change to evaluate driver comfort and safety. How would traffic calming impact this evaluation?

Research Needs

Basic research required.

Discussion: John Mason may have some comfort research available.

Research Methodology

- Field and
- Test track.

Priority

High/moderate.

Urgency (years)

Next 1–3 years.

Duration of Research

12–24 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agencies

- FHWA and
- NCHRP

Products/Objectives

- Research report and
- AASHTO criteria.

Summary and Recommendation

We recommend this topic for research.

APPENDIX B

User and Vehicle Controls

DOUGLAS HARWOOD
Midwest Research Institute

This paper addresses strategic highway geometric design research needs in three areas related to user and vehicle controls:

- Design controls related to human operator characteristics and capabilities;
- Design controls related to accommodating the current vehicle fleet; and
- Multimodal highway design—enhancing balance among travel modes in the design process.

Each of these topics is discussed below.

DESIGN CONTROLS RELATED TO HUMAN OPERATOR CHARACTERISTICS AND CAPABILITIES

A comprehensive review of human performance characteristics of motor vehicle drivers specifically related to geometric design elements was conducted in 1983 (*1*). While this review was conducted some time ago, human performance characteristics change much more slowly than vehicle characteristics. A current Transportation Research Board (TRB) committee effort, supplemented by current funded research in NCHRP Project 17-18(8), and further planned research in NCHRP Project 17-31, is developing a Human Factors Guide that will contain much useful information on driver performance characteristics. When the development of the Human Factors Guide is complete, the information contained should be thoroughly reviewed to determine any implications for geometric design.

Much recent attention has focused on the needs of older drivers because, as the baby boom generation moves into retirement, the proportion of the driving population constituted by older drivers is increasing. Older drivers have reduced performance capabilities compared to middle-aged and younger drivers. The FHWA's *Older Driver Highway Design Handbook* (*2*,*3*) provides a series of recommendations on highway design and traffic control criteria to better accommodate older drivers. The Handbook recommendations concerning geometric design policy were reviewed for AASHTO in NCHRP Project 20-7(139): Supplemental Guideline for Highway Design to Accommodate Older Drivers and Pedestrians (*4*). The following recommendations made in the Older Driver Handbook were identified in the Supplemental Guideline as needing further research since all information needed to assess their potential incorporation in the Green Book were not available:

- In the design of new facilities, or redesign of existing facilities, where right-of-way is not restricted, all intersecting roadways should meet at a 90-degree angle
- In the design of new facilities, or redesign of existing facilities, where right-of-way is restricted, intersecting roadways should meet at an angle of not less than 75 degrees

- To accommodate age-related difficulties in judging gaps and longer decision-making and reaction times exhibited by older drivers, the most conservative minimum required passing sight distance values, as shown in the 1994 Green Book (Table III-5), are recommended.

Research on the passing sight distance issue is underway in NCHRP Project 15-26. No research has been conducted on whether current policy on intersection skew angle should be revised.

A recent review of strategies to improve safety for older drivers was conducted in NCHRP Project 17-18(3): Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. This guide will soon be published as a volume in the *NCHRP Report 500* series. Nineteen strategies for improving safety for older drivers were identified, 11 of which relate directly to geometric design. Most of the strategies in the guide have been ranked as tried or experimental, rather than proven, indicating that there are no reliable safety effectiveness estimates for the strategies. Strategies for improving safety for older drivers that are in need of evaluation include:

- Provide advance warning signs;
- Provide advance guide signs and street name signs;
- Increase size and letter height of roadway signs;
- Provide all-red clearance intervals at signalized intersections;
- Provide more protected left turn signal phases at high-volume intersections;
- Provide offset left-turn lanes at intersections;
- Improve lighting at intersections, horizontal curves, and railroad grade crossings;
- Improve roadway delineation;
- Reduce intersection skew angle; and
- Improve traffic control at work zones.

Consideration of all transportation modes is being increasingly emphasized in geometric design. The consideration of pedestrians has been mandated by law in all transportation projects, and many projects now incorporate bicycle facilities, as well. Specific research needs related to pedestrian and bicycle transportation:

- Improved guidelines for where sidewalks are needed would be desirable. There is no general agreement about what types of streets should have shoulders on both sides of the street and what types of streets could be well served by a sidewalk on one side of the street.
- Improved guidance is needed concerning minimum sidewalks widths. Forthcoming ADA public rights-of-way regulations have proposed a minimum sidewalk width of 4 ft. Many state pedestrian coordinators would prefer a minimum sidewalk width of 5 ft. Research is needed to determine the circumstances under which 4- and 5-ft sidewalk widths would be appropriate, and when larger values are appropriate.
- Better information is needed concerning the relationship between pedestrian crossing distance and safety. There is evidence that pedestrian accident rates at crossings increase as the number of lanes crossed increases. However, there is no evidence as to whether, for a given number of lanes to be crossed, the lane width at a crossing affects the risk of accidents to pedestrians. In addition, guidance is needed on the crossing width at which provision of median refuge becomes critical.

- Better information is needed about the effects of channelized right-turns on urban arterial streets on motor vehicle, pedestrian, and bicycle safety. Forthcoming ADA public rights-of-way regulations may require pedestrian signals at all channelized right turns to accommodate pedestrians with vision impairments. Research in NCHRP Project 3-78 will be investigating crossing solutions for pedestrians with vision impairments at channelized right turn roadways. Whatever the degree of success of that research, which has just begun, one response of highway agencies to the forthcoming regulation may to be remove existing channelized right turns and avoid constructing new ones. There are no reliable data on whether such actions would be positive or negative for safety. Highway engineers have always presumed that channelized right turns provided safety benefits for both motor vehicles and pedestrians, but a recent synthesis report prepared in NCHRP Report 3-72 found no reliable evidence to document this presumption. Research is needed to help determine whether channelized right turns do or do not enhance safety for motor vehicles, pedestrians, and bicycles as well as whether signalization of channelized right turns would enhance safety for motor vehicles, pedestrians, and bicycles.
- Improved guidance is needed concerning the circumstances in which shoulders should be considered a pedestrian facility. Is occasional shoulder use (e.g., by motorists from disabled vehicles) sufficient for a shoulder to be considered a pedestrian facility or should a shoulder be considered a pedestrian facility only where it is part of a planned pedestrian route? This will become a critical issue because forthcoming ADA public rights-of-way requirements will limit the cross-slope of pedestrian facilities to 2%, which would restrict the use of steeper shoulder cross-slopes on shoulders that are also considered to be pedestrian facilities.
- Better information is needed about the introduction of reduced street grades at pedestrian crosswalks for roadways on steep longitudinal grade. Forthcoming ADA public rights-of-way requirements will limit the cross-slope of all pedestrian crosswalks and, therefore, the longitudinal grade of the street to 2%. Potential platform designs to safely accommodate vehicles on streets with steep longitudinal grade, while meeting the crosswalk cross-slope requirement, need to be developed.
- A range of bicycle treatments at signalized intersections have been proposed but it is not known which of these treatments operates most safely and efficiently. Research to evaluate bicycle treatments at signalized intersections and develop guidelines is needed.
- There is no general agreement on the best way to accommodate bicyclists at roundabouts. Research is needed to evaluate bicycle treatments and develop guidelines at roundabouts.
- Improved criteria for developing bicycle routes need to be developed. The criteria should incorporate safety implications, known relationships between roadway elements and safety, and interactions between bicycles and other transportation modes.

DESIGN CONTROLS RELATED TO ACCOMMODATING THE CURRENT VEHICLE FLEET

Geometric design criteria are based on accommodating specific vehicle types on the roadway. One or more design vehicles are chosen as the basis for design of each project. The dimensions and characteristics of these design vehicles are presented in the AASHTO Green Book. Recent research in *NCHRP Report 505: Review of Truck Characteristics as Factors in Roadway Design* (*5*) has recommended specific changes in the Green Book design vehicles to better accommodate the current truck fleet. Revised design vehicle dimensions are recommended for the following design vehicles:

- Changes in the dimensions of two current Green Book design vehicles, the WB-19 (WB-62) and the WB-20 (WB-71) single-semitrailer trucks were recommended.
- Two current Green Book design vehicles, the WB-15 (WB-50) and the WB-20 (WB-65) are not needed and should be dropped.
- Single-semitrailer design vehicles larger than the WB-19 (WB-62) are appropriate for inclusion in the Green Book, but are needed only for offtracking design in situations where trucks operate with their rear axles positioned at the rear of the truck. In states where the kingpin-to-center-of-rear-tandem distance is limited to 12.5 m (41 ft) or where truckers pull their rear axles forward for greater maneuverability, even where not required, the WB-19 (WB-62) is an appropriate design vehicle for offtracking design. The full vehicle length is appropriate for use in other design situations, such as design on sight-distance for railroad–highway grade crossings.
- Two new design vehicles are recommended for addition to the Green Book: a three-axle single-unit truck with a 12-m (25-ft) wheelbase and a Rocky Mountain Double with a 14.6-m (48-ft) semitrailer and an 8.7-m (28.5-ft) full trailer.
- Dimensions for four design vehicles that are not needed at this time have been specified so that they can be considered for inclusion in the Green Book if such vehicles become common at some future time: a single-semitrailer truck with a 17.4-m (57-ft) trailer; a double-trailer truck with two 10.1-m (33-ft) trailers; a Turnpike Double truck with two 16.2-m (53-ft) trailers; and a B-Train Double truck with a 8.5-m (28-ft) semitrailer and a 9.6-m (31.5-ft) semitrailer.

These recommendations are currently being considered by the AASHTO Technical Committee on Geometric Design. No further research on truck design vehicles is needed until AASHTO acts on these recommendations or identifies new issues to be considered.

NCHRP Report 505 has recommended several changes in geometric design criteria to better accommodate trucks and has recommended further research on specific issues that could not be resolved. For example, based on a recommendation in *NCHRP Report 505*, new research is being planned in NCHRP Project 15-31 to assess the need for changes in acceleration and deceleration lane lengths to better accommodate trucks.

There is concern that current geometric design policies may not properly address safety of trucks on horizontal and vertical curves near the end of long, steep downgrades. Several research studies, including *NCHRP Report 505*, have commented on this issue, but no research has been conducted. Research is needed first to review accident data to determine whether there is evidence that this concern is real and, if so, to determine how geometric design criteria might be changed in response.

The appropriate consideration of trucks in roundabout design needs to be further explored. The FHWA *Roundabout Guide* (*6*) contains guidance on consideration of truck design vehicles, but it would be desirable to verify the relationship between the center radius of the roundabout and truck operations and the appropriate design for truck operation on multilane roundabouts.

Changes in passenger car characteristics have been evolutionary in nature. Passenger cars have been substantially shorter over the past 40 years. There are few passenger cars today with lengths that approach 19 ft. A review of current passenger car lengths is critical to investigating the need for a decrease in the length of the passenger car design vehicle in the Green Book.

Driver eye height is a key consideration in the design of vertical curves to provide SSD. Driver eye height is a combined vehicle–driver factor, but changes in driver eye height over time related more to changes in a vehicle characteristic (the height of the driver seating position within the vehicle) than to the relevant human dimension (the height from the driver's seat to the driver's eye). The most recent review of driver eye height for the current vehicle fleet, presented in *NCHRP Report 400: Determination of Stopping Sight Distances* (*7*), found the need for only modest changes in the driver eye height for passenger cars used in vertical curve design. Driver eye height should be reviewed approximately once every 10 years to monitor changes in the vehicle fleet. Thus, new driver eye height measurements would be desirable at some point between 2005 and 2010.

MULTIMODAL HIGHWAY DESIGN: ENHANCING THE DESIGN PROCESS TO BALANCE THE NEEDS OF ALL TRAVEL MODES IN THE HIGHWAY RIGHT-OF-WAY

Highway design is increasingly focusing on multimodal concerns. Highway design must find effective ways to accommodate passenger vehicles, trucks, buses and other transit vehicles, recreational vehicles, motorcycles, pedestrians, and bicyclists—not necessarily on the same facility—but within the same right-of-way. A particular issue for consideration is the emergence of new intersection designs being used or proposed to serve motor vehicle traffic more efficiently. Such gains in efficiency, and the resulting reduction in congestion, are greatly needed in many areas, but the best method for safely and efficiently accommodating all modes in these design needs to be considered.

There has been substantial attention devoted to emphasizing the importance of this area, but little has been done in the way of identifying a specific set of research needs beyond those identified above which address a single mode, or the interaction between two modes, rather than all modes together. A focus at the Williamsburg symposium on research needs to address this issue would be desirable.

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BREAKOUT GROUP NOTES

Research Topic: Multimodal Highway Design for "Complete Streets"

Overview

The increasing focus of highway design is on multimodal concerns. Highway design must find effective ways to accommodate passenger vehicles, trucks, buses and transit vehicles, recreational vehicles, motorcycles, pedestrians, and bicyclists—not necessarily on the same facility—but within the same right-of-way. A particular issue for consideration is the emergence of new intersection designs being used or proposed to serve motor vehicle traffic more efficiently. Such gains in efficiency, and the resulting reduction in congestion, are greatly needed in many areas, but the best method for safely and efficiently accommodating all modes in these design needs to be considered.

Discussion

There has been substantial attention devoted to emphasizing the importance of this area, but little has been done in the way of identifying a specific set of research needs beyond those identified above which address a single mode, or the interaction between two modes, rather than all modes together. A focus at the Williamsburg symposium on research needs to address this issue would be desirable. Scoping-type project.

Research Needs

Moderate additional research to supplement available research.

Research Methodology

Discussion: Synthesis, surveys, policy and procedure development.

Priority

High/moderate.

Urgency

Next 1–3 years.

Duration of Research

12–24 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agency

NCHRP.

Products/Objectives

Guideline for professional practice.

Research Topic: Guidelines for Provision of Sidewalks

Overview

Consideration of all transportation modes has an increasing emphasis in geometric design. Improved guidelines are needed for when pedestrian facilities should be provided and what type of pedestrian facility is appropriate, balancing the needs of all modes. For example, guidance is needed on when sidewalks are needed on one versus both sides of the street. Research is needed to provide guidance related to land use, proximity to pedestrian generators, etc., in determining the need for sidewalks. Guidance is needed on the appropriate sidewalk width for various facilities in varying locations.

Research Needs

Moderate additional research to supplement available research.

Discussion: Relationship to land use, not just volumes of traffic and/or pedestrians. Proximity to school, transit routes, etc., and connectivity.

Research Methodology

Other: Literature/survey/city and state agency policy review (ordinances, zoning, etc.).

Priority

High/moderate.

Urgency

Next 1–3 years.

Discussion: Supplement to AASHTO Pedestrian Guide.

Duration of Research

12–24 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agency

NCHRP.

Products/Objectives

- Guideline for professional practice and
- AASHTO critera.

Research Topic: Safety Effects of Intersection Skew Angle

Overview

The Green Book recommends that intersecting roadways should meet at an angle of not less than 75 degrees for the design of new facilities or when right-of-way is not restricted, and not less than 60 degrees for the design of new or existing facilities where right-of-way is restricted. The *Supplemental Guideline for Highway Design to Accommodate Older Drivers and Pedestrians* [NCHRP 20-7(139)] recommends that intersecting roadways meet at a 90-degree angle when right-of-way is not restricted, and not less than 75 degrees when right-of-way is restricted.

Research Needs

Moderate additional research to supplement available research.

Discussion: Effects on pedestrian crossings (length of pedestrian crosswalk, speed of turning vehicles, skew of pedestrian crosswalk).

Research Methodology

Field plus accident study.

Priority

Moderate.

Urgency

Next 1–3 years.

Duration of Research

12–24 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agency

NCHRP.

Products/Objectives

AASHTO criteria.

Research Topic: Intersection Design to Accommodate Pedestrian Crosswalk Cross-Slope

Overview

Better information is needed about the introduction of reduced street grades at pedestrian crosswalks for roadways on steep longitudinal grades. ADA requirements limit the cross-slope of crosswalks to 2%. Since the cross-slope of the crosswalk is also the longitudinal grade of the street being crossed, this requirement impacts the vertical alignment of the roadway in the vicinity of the intersection. The impact of tabling intersections on motorist safety needs to be examined and potential platform designs to safely accommodate vehicles on streets with steep grades, while meeting the crosswalk cross-slope requirements, need to be developed.

Research Needs

Moderate additional research to supplement available research.

Research Methodology

Combination field/simulation; simulation of vehicle dynamics.

Priority

High/moderate.

Urgency

Next 1–3 years.

Duration of Research

12–24 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agency

NCHRP; plus other partners: U.S. Access Board.

Products/Objectives

- Guideline for professional practice and
- AASHTO criteria.

Research Topic: Right-Turn Interactions and Channelized Right Turns

Overview

Better information is needed about the effects of channelized right-turn lanes on urban arterial streets on motorist, pedestrian, and bicyclist safety. Many agencies use channelized right-turn lanes to improve operations at urban arterial intersections. NCHRP project 3-72 found no reliable evidence to verify the assumption that channelized right-turn lanes provide safety benefits to both motor vehicles and pedestrians. Recently, concerns about the accessibility of these turn lanes to pedestrians with vision impairments have arisen. Research is needed to determine whether channelized right-turn lanes do or do not enhance safety for motorists, pedestrians and bicyclists.

Research Needs

Moderate additional research to supplement available research.

Discussion: Plan from NCHRP Project 3-72 can go into this problem statement and add language about other modes.

Research Methodology

Combination field/simulation; accident studies.

Priority

High/moderate.

Urgency

Next 1–3 years.

Duration of Research

12–24 months.

Funding Requirement

Moderate ($250,000–$500,000).

Discussion: Use part of what was done in NCHRP Project 3-72 (synthesis).

Funding Agency

NCHRP.

Products/Objectives

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

APPENDIX C

Rethinking the Design Process

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Accomplishing the design of a highway—its three-dimensional features (alignment and cross-section) and appurtenances to provide for drainage, traffic control, and safety, requires a well-defined process. AASHTO and its predecessor, AASHO, developed a defined highway design process has been essentially unchanged since it was formalized in the 1940s. The current process can be briefly outlined as follows.

- It is dimensionally based, with design values for physical dimensions (width, horizontal alignment, vertical alignment) directly derived from tables and charts.
- The process requires establishment of fundamental design controls that are "fixed" and represent the context in which the highway exists. These include location (urban, rural), terrain (level, rolling, mountainous), functional classification (freeway, arterial, collector, and local) and traffic volume.
- The process requires certain choices to be made by the designer for other design controls such choices from within an established range. Foremost among these is design speed. Another significant choice represents design traffic, which includes not only volume, but also type of vehicle.
- The central technical input to the highway design process is speed; in particular, design speed. The design process requires selection of a design speed from which most other physical dimensions are obtained.
- The process and technical guidance produce recommendations for minimum dimensions (e.g., lane width, curve radius, grade) and/or maximum dimensions as appropriate for the design controls and assumptions. Within this framework, designers learn to "design to the minimum," with the underlying assumption being the minimum is good enough and anything greater is inherently more expensive and hence "wasteful."
- Acceptable performance (in terms of measures of mobility such as speed and LOS, and safety) is presumed to be produced through proper application of the process and technical guidance, but is nonetheless an indirect outcome of the process, which produces physical design dimensions.
- The process relies on relatively simple mathematical design models as the basis for derivation of dimensional values. These models combine knowledge from research on operations and safety. The models are simplified and are assumed to apply across a wide range of

conditions. They also are based on assumptions about what constitutes minimal, acceptable, and/or tolerable performance (e.g., the horizontal curve model is comfort-based).

- The process recognizes the presence of a range of vehicle types; but most of the fundamental design models from which core design values are obtained are based on passenger car operation.
- Design models and other technical guidance are continually reviewed and researched, with updates issued periodically to reflect advances in knowledge.

There is an underlying philosophy and understanding about the design process and AASHTO policies that adds to this well-defined process.

- The design process and roles of highway design professionals have long been viewed as centrally focused on providing the highest levels of mobility possible or feasible. Within this framework, speed is viewed as a surrogate for quality, as a well-designed highway is one that is considered to enable drivers to drive as fast as possible given the circumstances, and hence to minimize their travel times.
- Cost-effectiveness, particularly, minimizing construction costs, is central to execution of the process. Following the process and selecting minimum design values is assumed to produce the intended operational quality. Consequently, in most cases designers are trained to select the minimum dimension and nothing more.

A CRITIQUE OF THE DESIGN PROCESS

With few exceptions, the design process inevitably results in the determination of a single threshold value that the designer must meet. Designers learn that their design is acceptable (is nominally safe) if this value is achieved; but is not acceptable if the threshold value can not be met. As Neuman has pointed out, this decision making mischaracterizes the true effect of the design value. The substantive safety or substantive operational quality produced by any geometric value varies much more subtly with marginally differing design dimensions below a minimum threshold. (Indeed, our current knowledge base does not allow us to actually measure or estimate such marginal effects in most cases!) Yet, our current process has no good way to accommodate such understanding (other than through the design exceptions process).

Clearly, our understanding of how drivers respond to the three-dimensional alignment is much greater than many years ago. Advances in understanding of traffic operations and driver behavior have resulted in design concepts that influence the practice. These include notions of design consistency (relating to changes in speed and speed behavior), driver workload, and DSD. While these have been known for many years and are referenced in the AASHTO policies and other research, their incorporation within formal design policy has been spotty.

Much has changed in the vehicle fleet over the past 60 years, such as, knowledge about driver characteristics, and safety and operations. AASHTO has committed to continually update the AASHTO policies. Yet, for the most part, such updates have not altered the fundamental process or even, in most cases, the basic design models. For example, the definition of design speed has changed yet its importance and role relative to the fundamental execution of the process remains essentially unchanged from the 1940s. Design models for horizontal and vertical alignment (the AASHTO horizontal curve model, the SSD model) have undergone dimensional revisions over the years, yet the fundamental model forms and assumptions (many of them simplifying) have not changed.

The changing tasks of designers involve the issues of construction, reconstruction, and rehabilitation. In the 1930s and 1940s, continuing into the 1960s, most of the work performed by highway engineers involved construction of highways on new alignment. While such work continues, for the most part most highway agencies' programs are heavily weighted to reconstruction or rehabilitation, and not construction on new alignment.

Current design policy and processes treat new construction the same as complete reconstruction. As is readily apparent, the two are inherently different in terms of the context in which the designer is operating. Reconstruction along an existing alignment by definition means retention of the basic alignment within existing right-of-way, with its possible expansion or minor revision. In the former case, the constraints and controls that influence the design are fixed and must be dealt with. Also, there is (or should be) a known operational and substantive safety record that can inform important parts of the design decision-making process. For new alignments, there is no history of operational performance, and assumptions and reference to similar facilities or conditions in the area drive decision-making. But, designers are selecting a right-of-way from a wide range of corridor choices. Under current AASHTO policy, both new construction and reconstruction are considered equivalent and one treated identically. It would appear that the substantial differences between the two types of problems warrant their separation within the design process.

Finally, the highway design process is now recognized as being intertwined with environmental and public stakeholder input processes. Decisions involve investigation of options or choices, interaction with other technical disciplines, and a collaborative approach to decision making. (This relatively new aspect of the design process causes problems with many in the design community.)

EMERGING ISSUES

A number of key issues have emerged over the past 20 years that influence the design process and its success in application to the full range of problems. These can broadly be characterized as technological advances, design philosophy changes, and contracting mechanisms.

Design Technology Advances

The highway planning and design task has been completely automated. It is now possible through the use of computer-aided engineering tools and techniques to quickly develop and evaluate a proposed alignment or design solution. In addition to the tools such as Inroads and Geopak, there is a wide range of computerized design assistance tools including traffic operational simulation models, environmental models, visualization packages, and geographic information system databases. One proprietary program, Quantum, can quickly determine a minimal cost solution given a wide range of options and fundamental design criteria.

Finally, considerable investments are being made to develop and refine new tools such as FHWA's IHSDM. Such tools are intended to enable design decisions to be made with better understanding of the traffic operational and safety effects of such decisions, both in total and at specific locations along a corridor.

The cumulative effect of technology is to better enable the efficient consideration of a full range of distinctly different design solutions in an interactive manner.

Advances in design technology reduce the time needed to produce a plan and enable or greatly enhance the ability to assess alternatives and optimize a solution across theoretically many different metrics. How should the highway design process recognize and incorporate such tools?

In-Vehicle Technology Advances

In-vehicle technologies are now a common feature that assists the driving task. These include airbags and automatic restraints, in vehicle navigational systems using Global Positioning System technology, and overall improvements in the safety of vehicles (including active control, improved safety devices).

Information from the vehicle stream offers additional data and capabilities to refine designs. How should the design process incorporate such information?

Advances in Knowledge on Traffic Operations

Research has continued to confirm that many of the traditional design models and assumptions do not completely describe traffic operations. As our knowledge base grows, we are aware that driver speed behavior is much more complex than presented by AASHTO, and that speed consistencies and inconsistencies along the highway are a source of concern. Indeed, it is apparent that positive speed management (i.e., accomplishing a speed that may be lower than was previously sought) represents an optimal solution. We are also aware that vehicles with high centers of gravity present inherently different risk profiles than passenger cars, and that such risk also vary significantly depending on the context.

Changes in Stakeholder Values and Perceptions of Value

Context-Sensitive Design The highway design process places vehicular mobility and safety at the center of design decision making. CSD represents a fundamentally different approach to project development. The notion behind CSD is that mobility and safety may be valued differently in different contexts, or defined in different ways. One significant point here deals with speed, with many situations demanding a solution that proactively produces lower speeds. Moreover, other nontransportation values such as cultural preservation and environmental sensitivity should play a direct role in developing an optimal design solution.

Will the institutionalizing of CSD mean or require a fundamental change in the design process? Or, can we be successful at CSS/CSD by simply adjusting or refining the design policies and processes currently in use, or by better educating designers on the best practices pertaining to existing procedures?

Reliability and Sustainability Notions of reliability (assurance of a given level of performance throughout the day and year) are increasingly more important, particularly to commercial users of the highway system. Sustainability refers to the use of resources not only for construction, but for long-range maintenance and operation of the facility. Certain design dimensions (e.g., wide shoulders) may have value relative to maintenance considerations, but these are not well defined or understood.

How well do the current design policies reflect changed views about highway system performance, or what is considered to be cost-effectiveness? To what extent do we, or should we, select geometric design values based on explicit considerations for maintenance functions; or for long-term sustainability of the roadway? How does the geometric design process support important operational functions such as law enforcement?

Contracting Mechanisms and Issues

Design–Build–Operate and Outsourcing and Privatization The historic project delivery model is owner controlled through design, bid, and build. Emerging trends in the highway business reflect changes in delivery and indeed ownership of highway systems. The design–build model places the builder in a position of influencing the designed product. Often, the design is completed by the owner to 30% (basic three-dimensions), but then subject to revision in the field by the constructor.

In some cases, highway ownership (or at least long-term lease) is contracted to a party responsible for the design and long-term operation of the facility. This model is common in other infrastructure operations (e.g., wastewater treatment facilities) but just now emerging in the traditional U.S. highway market. Such a model would tend to blur or combine decisions or actions that influence initial construction and long-term maintenance or operation (e.g., law enforcement).

In the design–build market and design–build–own–operate (DBOO) market, many design decisions formerly treated as givens through design standards or standard details are revisited or revised based on assessment of the total economics of an approach. The privatization of activities and/or highway systems is a trend that may continue. Does DBOO suggest revisions to the design process?

Pavement Warranties Some agencies have not only contracted the reconstruction of highways, but also long-term pavement maintenance. The contracting body is provided performance specifications only; the contractor decides how to meet those specifications. Some have suggested that a logical extension of pavement warranties could apply to other key performance measures such as operational performance and/or safety performance.

Pavement warranties offer a potential model for highway design in that the focus of the end product of the design process is on a performance-based outcome versus a specified physical solution. Does the potential institutionalization of performance warranties suggest eventual changes in the design process?

Legal Liability The loss of sovereign immunity within most states triggered a potential liability resulting from crashes attributable to alleged poor or inadequate designs. The current design process, including specific design values as codified by AASHTO policies and state DOT design standards, provides a benchmark against which many states are clearly shielded from potential lawsuits, as long as their actions are within published policies.

Design outcomes that incorporate design exceptions, or that are a result of stakeholder negotiations that produce what might be viewed as less than optimal solutions from a safety perspective, may increase tort risk exposure to an agency. Design processes that incorporate more choices or options, or that are less reliant on specific dimensional values, may shift the burden of proof away from a plaintiff and more heavily onto the owning agency.

One specific area of concern—establishment of a design speed for a project—represents a clear case in many states of tort risk influencing decision making. Many designers will only select a design speed based on the legal maximum posted speed, in effect negating the notion of choice as part of the designer's basic task. Such a decision then influences all subsequent geometric decisions.

In any event, any process that involves multiple choices and decision points (versus execution of a process that leads to one prescriptive value or solution) will meet with concerns over the long term agency risks. Such risks are associated with (*a*) the decision itself; (*b*) documentation of the decision; and (*c*) its possible interpretation by the courts in a future tort claim.

Tort laws differ across the country. Also, understanding the risk of tort action and agency reaction to such risk through administrative and policy actions varies significantly.

To what extent are real (as well as unfounded) fears of tort liability or tort risk influencing the design process? To what extent are they influencing outcomes? Is such influence appropriate? Are such influences properly understood and reasonably accounted for?

ALTERNATIVE DESIGN PROCESSES

For the purposes of discussion, it is asserted that the appropriate focus of any highway design process should be performance. Performance can be characterized in terms of traffic operational measures, safety measures, and maintenance measures. It is also asserted that a design process more directly focused on performance versus design dimensions will require more knowledge than is currently available about performance.

Performance-Based Design

Mahoney has written about the need for and value of performance-based design. Design values would be based on an explicit determination of their performance (rather than the indirect manner as is currently the case). Such an approach more closely mirrors other engineering and technical disciplines. Some research efforts (most notably, those dealing with development of AASHTO design criteria for very low volume local roads) have acknowledged a performance basis for determination of criteria where risk is low. So, the notion of relating basic design dimensions to some measure of performance or risk is not new.

Design Domain

Robinson has written of the concept of design domain, which is now part of Canadian geometric design practice. This concept recognizes that "a well-designed facility necessarily provides a balance between a number of design objectives such as level of service, cost, environmental impact, and its level of safety."

Because such a balance must reflect local values and policies, it will not necessarily be uniform across all jurisdictions or road agencies. Nor will it be constant with time.

The concept of design domain, introduced in the new (Canadian) guide, is intended to ask the designer to select design criteria from ranges of values considering the costs and benefits of the selected criteria.

The design domain can be thought of as a range of values that a design parameter might take—as illustrated in Figure 1.

Designers must choose a solution reflecting consideration of explicit value-based trade-offs. According to Robinson: “In the lower regions of the domain for a single design parameter, resulting designs are generally considered to be less efficient or less safe—although also perhaps less costly to construct. In the upper regions of the domain, resulting designs are generally considered to be safer and more efficient in operation, but may cost more.”

The notion behind design domain is that it requires designers to make explicit choices, reflecting specific conditions and referencing relevant, site-specific data and information. Proponents of the design domain assert that:

- It is more directly related to the true nature of the roadway design function and process, since it places a greater emphasis on developing appropriate and cost-effective designs rather than those which simply meet standards;

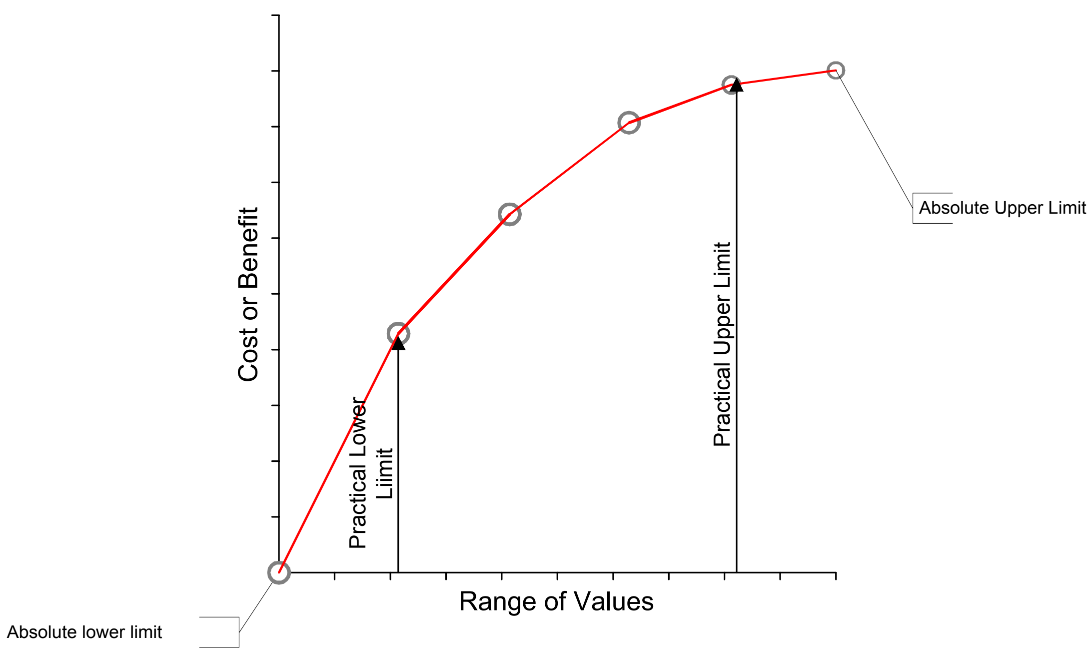

FIGURE 1 The design domain concept. (Note: The value limits for a particular criterion define the absolute range of values that may be assigned to it. The design domain for a particular criterion is the range of values, within these limits, that may practically be assigned to that criterion. Source: *1999 Canadian Geometric Design Guide: Road Safety Initiatives*, J. B. L. Robinson, Delphi Systems Inc., Canada, Gerald Smith, UMA Engineering Ltd. Canada.)

- It directly reflects the continuous nature of the relationship between service, cost and safety, and changes in the values of design dimensions. It reinforces the need to consider the impacts of trade-offs throughout the domain, and not just when a 'standard' threshold is crossed;
- It provides an implied link to the concept of Factor of Safety—a concept which is commonly used in other civil engineering design processes where risk and safety are important.

Design Through Optimization

There are analytical processes (e.g., multiattribute utility analysis) that incorporate widely disparate values weighed directly into an optimization of any given decision. Such processes are ideally suited to the complex context-sensitive world. So, for example, deriving an optimal solution for a specific project may involve an analytical approach that includes value functions for optimizing traffic throughput, minimizing crashes, minimizing footprint encroachments on specific land uses, minimizing noise, optimizing pedestrian access, and minimizing costs. This process would directly incorporate external factors within the design process itself (rather than in a reactive or external manner as is the case today). Such a process would inevitably produce roadway designs and footprints that would differ from one location to the next, reflecting differences in local context, project objectives, and relative values.

OVERVIEW OF KNOWLEDGE GAPS IN DESIGN, SAFETY, AND OPERATIONS

It is asserted that whether the current process is sufficient, or some revised process introduced, advances in knowledge of the operational effects of design values is essential. There has been much research in the area of capacity, speed, and to some degree, accidents related to highway features. The list of relevant research is far too great to summarize here. Key recent efforts include *NCHRP Synthesis of Highway Practice 299*, *NCHRP Report 374: Safety Effects of Highway Geometric Elements*, and the body of research that has led to FHWA's IHSDM. Recent research sponsored by AASHTO has led to revisions in design policy in the areas of SSD (*NCHRP Report 400*) and ISD (*NCHRP Report 383*). *NCHRP Report 439* addressed some aspects of horizontal curve design, including recommended changes to policy. Research is ongoing in key areas dealing with urban and suburban arterial design, including both segments and intersections.

Other notable efforts have focused on the design process; most notably, research syntheses dealing with design exceptions have been published by NCHRP.

RESEARCH NEEDS

Recognizing that there are ongoing efforts, as well as programmed efforts, the following is an assessment of the most pressing knowledge gaps in the geometric design field.

- Design speed: Does the concept of design speed still work, or are there situations where it is not sufficient or does not address the real problems? What alternatives are there to design speed? Can we successfully separate design speed from posted speed and tort liability concerns?

- Horizontal curve design: AASHTO's horizontal curve model has remained essentially unchanged for many years. It is based on comfort, but reflects outdated assumptions about the vehicle fleet and driver behavior. It is volume insensitive, and except for very low speed conditions, context insensitive. Coupled with the current policy wherein agencies can select different superelevation rates, the AASHTO model produces inconsistent (i.e., different) results for the same nominal design assumptions in different jurisdictions. (A subset here of the horizontal curve issue is the design guidance for interchange ramp design speeds, which needs a fresh look.)

There is strong evidence that driver response to horizontal alignment is much less severe than the current AASHTO model assumes. Drivers feel comfortable operating on sharper curves at much higher speeds than designers believe or assume. More knowledge is needed regarding

1. What constitutes driver comfort today;
2. Should comfort be the basis of design; and
3. When should vehicles other than passenger cars form the basis for design of curves?

- Urban roadside design: Designers and other stakeholders struggle with designing the border areas of urban streets and arterials. Many agencies extend the concept of the clear zone to the urban area, and run into conflicts with desires to plant trees, provide lateral space for pedestrians and bicycles, and accommodate on-street parking. Does the clear zone concept have any meaning in urban areas? What are the relative risks of objects in combination with curbs at varying speeds? What risks and costs are incurred (e.g., to pedestrians, roadside businesses, etc.) through clear roadside design treatments in urban areas?
- Urban cross-section values: Urban arterial and street design is arguably the most difficult to accomplish given the generally limited right-of-way, complexity of issues, and higher traffic volumes. Ongoing research, and other recent research highlights

1. The importance of type and presence of medians;
2. The effect of driveways and intersections; and
3. A less clear picture of the safety effects of variable design dimensions. Hopefully, ongoing NCHRP work will help resolve this last issue; but even so, it remains an issue to establish appropriate design dimensions given a specific context (right-of-way, cost, presence of pedestrians, speed, capacity, etc).

- Design consistency: Often, accomplishing a design solution requires changes in cross-section along the alignment due to the context. Many designers are reluctant to change design dimensions for a short segment or at a specific location, citing consistency for the driver as a concern. Yet, the measurable effects of varying dimensions to fit a design are not well understood. At the project level, how much flexibility is appropriate for design policy for lane and median widths? What process or direction would be best to accomplish designs for such projects? Are such projects inherently different so as to warrant a different design approach?
- Accomplishing measurable speed reductions without resorting to traffic calming solutions: Most designers now acknowledge that slowing traffic is desirable in some conditions. Classical examples of this include a high-speed road through a small town. Current knowledge focuses on the effects of traffic calming devices. Many of these solutions are suitable only for local or collector streets. In any event, little is known about how to effectively combine alignment, grade and cross-section to produce a safe but effective, meaningful reduction in speed.

A subset of this issue is the effect of lane width on speed for higher speed highways. Some research has documented such an effect, anecdotal evidence suggests there is an effect and designers intuitively believe it; but FHWA's IHSDM does not contain such an effect in the design consistency module.

- SSD: Despite recent NCHRP efforts and subsequent changes to the AASHTO policy, questions and problems remain with SSD design. Most notably, there are clearly cases given the current AASHTO models in which SSD dimensional requirements are recognized as being excessive. There are also concerns about the relative risk of SSD for the full range of design conditions. Providing for SSD requires design in all three dimensions. The current model does not offer a robust risk-based approach that acknowledges fundamental differences in risk associated with traffic volume, with basic facility type, nor with location-specific conditions.
- Relationship of measures of congestion [volume to capacity (v/c), delay, LOS, etc.] to quantitative safety: The design process requires that designers make choices to provide or not provide a certain level of mobility. Such choices generally influence sizing of a highway (number of lanes, intersection channelization). Design policies and resultant design dimensions, though, are typically independent of such choices. Much is known about the operational effects of varying design dimensions; but there is little knowledge that directly relates congestion measures to safety. Such knowledge would better inform designers.
- Effects of design dimensions on highway maintenance practices: Little is published on the explicit maintenance considerations relating to design dimensions. Issues such as the benefits of paved shoulders (remove edge drop-offs), paved versus unpaved roads, and superelevation practices are generally understood, but more knowledge would be useful, particularly given our need to understand the full value of any dimension held out as a minimum threshold.
- Discretionary decision making, tort law, and risk management—synthesis of state status and practice: It would be useful to assemble and synthesize the current status of tort laws and court precedents relative specifically to discretionary decision making. This is an area widely misunderstood, with resultant poor decision making. Many designers firmly believe that going outside published standard represents an unacceptable tort risk. Conversely, there is a misunderstanding that adherence to a minimal standard constitutes 100% protection from a suit. Indeed, there is a level of concern among many in the design community that the engineering profession has lost control over design decisions, that we have become overly defensive in both our practices and our outcomes.
- Geometric and traffic data needs to support substantive safety analysis: A major issue of concern with the Highway Safety Manual Task Force is the amount, extent and quality of geometric and traffic data maintained by state DOTs. Most agree that DOTs and other agencies do not maintain sufficient data to enable performance-based design decisions. Data shortcomings include roadway and roadside data, guardrail, and other barrier information, traffic volume data including turning movements, and basic geometric data. Expectations of re-authorization and advances in safety research will drive a greater interest in the need for such data. There is a need to define the amount, type, and nature of data required to support any performance-based design decision making.

OTHER RESEARCH NEEDS

While not strictly research, it would seem that there are other pressing needs that also relate to the fundamentals of the design process itself. Does our design process merely need adjustments or tinkering? Is it sufficient? Or do we need to look in another direction. The approaches suggested above offer a starting point. The following questions should be addressed in a formal, structured setting, involving a full range of designers, academic experts, federal and state policy makers, and nontechnical stakeholders.

- The design process—does it work? Should it change? If so, in what ways?
- Is the concept of design speed as the fundamental input still valid for all highways in all conditions? If not, what might replace it? Interestingly, if we find or understand that operating speeds are relatively insensitive to geometric design elements, and it becomes clear that we need to be able to design for a full range of speeds, that suggests that reliance on design speed as a central focus of the process may be problematic.
- Should the ultimate goal of the design process be acknowledged as performance driven? If not, why not? If so, how do we get there?
- Should important, but non-highway-related factors such as environmental considerations, preservation of resources, etc., be more directly incorporated into the process? If so, how should that be done?
- What is meant by consistency? Is this a value in and of itself? How do we measure it? Is there really a problem with a design outcome (different cross-section, alignment values) that vary from mile to mile depending on the local context?
- New construction versus reconstruction—should AASHTO design policy values and approaches differ?
- How well does the design exception process work? Is this a sufficient means of addressing unusual or unique cases? Should the process explicitly differ for new construction versus reconstruction?

BREAKOUT GROUP NOTES

Research Subtopic: Performance-Based Geometric Design Analysis

Overview

Performance measures for geometric design decisions (e.g., safety, traffic operations, enforcement, maintenance, and sustainability) would include research related to the following:

- Identifying performance measures for geometric design features, including measures of speed, safety, etc.:
  - Defining and measuring sustainable performance (e.g., maintainability, durability and constructability issues), and
  - Defining and measuring design consistency.
- Data needs to enable performance measuring.

This topic is focused on informing decisions, and has value even if the current design process is maintained. The Highway Safety Manual (HSM) and HSM on-going research are acknowledged as inputs to this effort.

Discussion

This topic is separate from the broader “Investigation of Alternative Geometric Highway Design Processes” research topic, which focuses on design decision support (decision making). Because major changes to the process will be difficult for some to accept, it is assumed that others would be less uncomfortable with this analytical topic than with research focused on an “alternative design process.” Performance-based design is not in conflict with the current process, but rather complements it.

“Geometric Data Needs to Support Performance-Based Decisions” and “Maintenance and Sustainability Effects of Geometric Design” were initially considered as individual research topics. However, both were collapsed into the broader “Performance-Based Geometric Design Analysis” topic. Regarding “Geometric Data Needs to Support Performance-Based Decisions,” performance measures are needed before data needs can be identified.

Performance-based analyses can be done at different levels, e.g., systemwide planning, project-level, etc. Analysis capabilities are heading towards quantification (e.g., the HCM, the future HSM, and air quality analysis), but the current design process doesn’t support bringing those items into decision making. An opinion is that all knowledge we have should find its way into the AASHTO criteria.

Performance-based measures would allow the effects on all users (drivers, pedestrians, bicyclists, etc.) to be considered. Decisions might be more difficult compared with the current process, since more information will need to be processed and more engineering judgment will be required. However, having more complete information will allow designers to consider “all” factors, with the end result being better decisions.

Research Needs

Basic research required.

Research Methodology

Combination field/simulation.

Priority

High/moderate.

Urgency

Next 1–3 years.

Duration of Research

Greater than 36 months.

Funding Requirement

High (greater than $500,000).

Funding Agencies

- AASHTO and
- FHWA.

Products/Objectives

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

Research Subtopic: Investigation of Alternative Geometric Highway Design Processes (Design Decision Support)

Overview

Components of this multipart research topic (program) include

- Critique of the AASHTO process and models*, including design year and design controls:
  - Evaluation of the design speed concept, including consideration of design speed as an output of the design process. (Note: ongoing work related to design speed will provide direction and/or address some of the issues.)
- Identification and assessment of alternative processes* (e.g., design domain, performance-based design)
  - Consideration of legal liability issues and implications*;
  - Different processes for different contexts (e.g., 3R, 4R, new construction; scale and scope-based); and
  - Evolution and transition issues and implications.
- Incorporating external values and factors into geometric highway design decisions.

[* Indicates a potential separate ("stand alone") topic; see discussion below.]

Discussion

The consensus of the group is that "Investigation of Alternative Geometric Highway Design Processes" is the most significant research issue, as well as the longest term. It could be viewed as a general research program, with other research topics feeding into and supporting it.

In general, this broad research topic is a critique of what we are doing now, and an examination of possible alternatives, including assessment of performance-based design, the design domain concept, inclusion of external factors into highway design decisions, and other components. The critique would address whether the current process is sufficient. As a whole, the research could be considered "groundbreaking." Of note, this topic is focused on design decision support (decision making), versus the analytical "Performance-Based Geometric Design Analysis" research topic.

A concern is that the vision outlined by the research agenda will be viewed as too much of a departure from the current highway design process ("too far out there"). If the broad vision is rejected as a general program, then components should be looked at individually to prevent everything from being discarded.

The "Critique of the AASHTO Process and Models" component is seen as fundamental, with great value regardless of whether the other components are addressed. The "Identification and Assessment of Alternative Processes" and "Consideration of Legal Liability Issues and Implications" components can also stand alone, and should be considered as viable research topics even if the broad vision is rejected. A critique of the proposed concept to separate reconstruction and new construction ("different processes for different contexts") could be part of the "Identification and Assessment of Alternative Processes" component.

Initially, "Synthesis of Tort Liability Issues and Implications"; "A Critique of AASHTO Design Models"; "Design Speed—Does It Work?"; and "Incorporating External Values into Roadway Design Decisions" were considered as individual potential research topics. However, all were collapsed into the broader, "Investigation of Alternative Geometric Highway Design Processes," topic. Discussion points related to the individual topics:

- Synthesis of Tort Liability Issues and Implications
  - The exception process forces systematic thinking; there is an educational aspect.
  - Higher-level thinking takes more experience and requires additional tools (e.g., IHSDM)—the current process does not force this type of higher-level thinking.
  - Documentation is the most useful part of the exception process (based on a survey of States); without the current process (i.e., without black/white guidelines/standards), lines will blur and the process becomes more complex.
  - Re Tort claim that designs must meet prevailing criteria—documentation is important; it is within the purview of a state to make decisions. Would be good to have a database of tort cases; how many and what type?
- Regarding design speed-related research, it was noted that currently many criteria are speed-based; if the general process changes, then speed-based criteria will change.
- Incorporating External Values into Roadway Design Decisions: We have good ways to measure many external values. The issue is how to bring them into the design process.

Other issues raised during the discussion include:

- Is a fundamental shift needed? If yes, then proceed with this research program.
- Is performance the ultimate goal? (The group believes so.)
- Should external factors become more directly included in design process? (The group believes so). A concern is working around policy values by making value judgments. The CSD approach can be used to either establish alternative criteria, or document why decisions were made.

The approach is much different. Address whether it is better not to have to go through exception process.

- What are the real consequences of decisions?
- We are conditioned to believe that design speed is directly related to quality. If we lower the speed, is the perception that we are lowering quality?

Research Needs

Basic research required.

Research Methodology

Other.

Priority

High/moderate.

Urgency

Beyond 5 years.

Duration of Research

24–36 months.

Funding Requirement

High (greater than $500,000).

Discussion: Entire program would be greater than $500,000; if broken into pieces, smaller pieces might be less than $500,000.

Funding Agencies

- AASHTO, and
- FHWA.

Products/Objectives

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

APPENDIX D

Rural Highways

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The identification of the rural highways research topics began in August 2000, nearly 1 year prior to the 2001 joint summer meeting of the AASHTO Geometric Design Task Force and the TRB Geometric Design and Operational Effects of Geometrics Committees. Those first topics were input to the joint research workshop held in Santa Fe, New Mexico, in the summer of 2001. As a result of this workshop, and through information gathered from members of the Task Force and TRB committees, the topic list has been refined and modified to reflect those issues requiring basic research and/or development.

The general research topics are discussed below. Additionally, past and present research literature is cited. Proposed basic research is suggested and a sample research problem statement is included in Appendix B of this document.

RESEARCH TOPICS

There are seven research topics which fall under the following four categories:

1. Design speed issues:
   - Speed prediction, and
   - Transition zones—design from high-speed to low-speed sections.
2. Safety:
   - State of the research related to rural highways.
3. Medians:
   - Types and design,
   - Placement of signs, lighting, traffic control in median, and
   - Landscaping for medians.
4. Incorporation of bicycle lanes.

SURVEY RESULTS

A questionnaire was developed to rate the importance of the research topics cited above. Each questionnaire respondent was asked to assign a numerical score from 0 (research not needed) to 4 (high priority research need) for each topic. Results from the rural highway questionnaire (26 responses) are summarized in Table 1.

TABLE 1 Rural Highway Questionnaire Results

Research Topic	Average Rating	Mode
Speed prediction	2.50	3
Transition zones	2.81	2
State of safety research	2.04	2
Median types and design	2.58	3
Placement of signs, traffic control, and lighting in medians	2.08	2
Landscaping for medians	2.20	3
Incorporation of bicycle lanes	2.44	2

Based on the results shown in Table 1, respondents consider rural highway safety research, placement of signs, traffic control, and lighting in medians, and incorporation of bicycle lanes as low-priority research needs (average rating near 2.0 and mode of 2). All other research topics shown in Table 1 are considered medium-priority research needs as evidenced by a rating exceeding 2.50 and a mode of 2 or 3.

ASSOCIATED RESEARCH AND LITERATURE

The primary resources summarizing the recent past and present research and literature were drawn from the following:

1. Fitzpatrick, K., and M. Wooldridge. *NCHRP Synthesis 299: Recent Geometric Design Research for Improved Safety and Operations*. TRB, National Research Council, Washington, D.C., 2001.
2. Fitzpatrick, K., D. W. Harwood, I. B. Anderson, and K. Balke. *NCHRP Report 440: Accident Mitigation Guide for Congested Two-Lane Rural Highways*, TRB, National Research Council, Washington, DC, 2000.
3. Fitzpatrick, K., et al. *Speed Prediction for Two-Lane Rural Highways*. Report No. FHWA-RD-99-171. FHWA, McLean, Va., 2000.
4. Vogt, A., and J. G. Bared. *Accident Models for Two-Lane Rural Roads: Segments and Intersections*. Report No. FHWA-RD-98-133. FHWA, McLean, Va., 1998.
5. Harwood, D. W., et al. *Prediction of the Expected Safety Performance of Rural Two-Lane Highways.* Report No. FHWA-RD-99-207. FHWA, McLean, Va., 2000.
6. Neuman, T., et al. *NCHRP Report 500: A Guide for Addressing Head-on Collisions, Vol. 4.* Transportation Research Board of the National Academies, Washington, D.C., 2003.
7. Neuman, T., et al. *NCHRP Report 500: A Guide for Addressing Run-off Road Collisions, Vol. 6.* Transportation Research Board of the National Academies, Washington, D.C., 2003.

DESIGN SPEED RESEARCH TOPICS

The design speed research topics focus on speed prediction and transition zones.

Speed Prediction

Speed prediction research on rural highways has been focused on ensuring a roadway alignment that is consistent with driver expectancy. A roadway design is considered consistent if operating speeds between successive geometric elements are relatively constant. Speed profile models are the most common method to evaluate geometric design consistency. The response (dependent) variable most commonly cited in the literature is the 85th-percentile operating speed. Common independent variables used to predict passenger car operating speeds are degree of curvature, radius of curve, length of curve, deflection angle, superelevation, and the rate of vertical curvature.

The FHWA's IHSDM includes a design consistency module. Research included in the model is based on a study that predicts the 85th-percentile operating speed of free-flow passenger cars on rural two-lane highways. Radius (1/R) of curve is the only statistically significant independent variable related to 85th-percentile speeds on alignments that included a horizontal curve on grade. As radius increases, the predicted vehicle operating speeds increase. When predicting passenger car speeds on horizontal tangents with limited sight-distance vertical curves, the rate of vertical curvature (1/K) provides the best model form. As the rate of vertical curvature increases, predicted vehicle operating speeds increase.

Speed prediction models for trucks on two-lane rural highways have also been developed, but not incorporated into the IHSDM. These models also used 85th-percentile operating speeds as the dependent variable. Radius of curve, grade of approach and departure tangents, and length of approach and departure tangents were input to the model (i.e., independent variables). As the radius increases, the predicted operating speed increases. Increasing vertical grades were found to decrease operating speeds. Increasing the length of the approach tangent was found to increase vehicle operating speeds, while decreasing the length of the departure tangent had a nominal influence on vehicle operating speeds.

Speed prediction models for rural multilane highways have not been developed.

Proposed Research

Basic research should be conducted on speed prediction for multilane rural highways. Passenger cars, trucks, and recreational vehicles should be considered in the data collection and analysis effort. Additionally, both vertical and horizontal alignment features should be included in the research.

Enhance the current two-lane rural highway speed prediction research by including a larger sample of heavy vehicles and the effects of horizontal curve spacing and vertical grades. The presence of driveways and intersections should also be considered in future research.

Transition Zones

Transitions from high-speed design to a lower-speed section have not been researched. AASHTO's Green Book contains general guidelines related to taper design when transitioning from two-lane operation to four-lane operation. Transition taper design is a function of speed and the amount of cross-section width being added to or removed from a roadway section. The MUTCD provides additional information about taper design for passing sections on two-lane highways.

NCHRP Project 15-22: Safety Consequences of Flexibility in Highway Design is on-going and is addressing the issue of transition zones between high-speed operations in undeveloped surroundings and lower-speed operations in a developed area.

Proposed Research

The above referenced project (NCHRP 15-22) is focused on safety. A similar research effort should be considered to address the relationship between design and operations in transition zones. The research should be focused on methods to reduce vehicle operating speeds using changes in alignment and cross-section features.

RURAL HIGHWAY SAFETY RESEARCH

Extensive research has been conducted for rural two-lane highway road segments. Most recently, a set of crash prediction models were developed for inclusion in the IHSDM. The roadway segment models considered traffic volumes, roadway section length, lane width, shoulder width, roadside hazard rating, driveway density, and horizontal and vertical alignment. AMFs are applied to a base crash prediction model to determine the expected accident frequency on a roadway segment. Results from the IHSDM research related to rural two-lane highway road segments are as follows.

- Expected accident frequency decreases as the lane width increases.
- Expected accident frequency decreases as the shoulder width increases.
- Expected accident frequency is less when shoulders are paved compared to gravel, composite, or turf shoulders.
- Expected accident frequency is higher on curved roadway sections than on tangent sections.
- Expected accident frequency increases when the superelevation deficiency exceeds 0.01. Superelevation deficiency is defined as the difference in the required superelevation recommended by the AASHTO Green Book minus the amount of superelevation provided. The deficiency occurs when the amount of superelevation provided is less than that recommended by AASHTO.
- Expected accident frequency increases as roadway grade increases.
- Expected accident frequency increases as the driveway density increases.
- Expected accident frequency decreases when adding conventional passing lanes or climbing lanes in one direction of travel. Expected accident frequency also decreases when adding short four-lane passing sections.
- Expected accident frequency increases as the number of hazards in the roadside increases.

Comprehensive crash prediction models have also been developed for several intersection configurations on rural two-lane highways. Included are: (*a*) models for three-leg intersections with stop-control on the minor approach; (*b*) models for four-leg intersections with stop control on the minor approach; and (*c*) models for four-leg signalized intersections.

NCHRP Project 17-29: Methodology to Predict the Safety Performance of Multilane Rural Highways is currently underway.

Proposed Research

Future two-lane rural highway segment research should consider the effects of bridge width, vertical curve design, and stopping sight distance on safety.

MEDIANS

Median research topics include: (*a*) types and design; (*b*) placement of signs, traffic control devices, and lighting; and (*c*) landscaping.

Types and Design

Medians may be depressed, raised, or flush. A depressed median is the most common type on rural highways. A significant amount of research has been conducted relating depressed median design to safety. The AASHTO Green Book indicates that median barriers are not normally considered when the median width exceeds 30 ft. Several states have funded studies to evaluate the need for median barriers based on median width and traffic volumes. California and Maryland install median barriers on divided highways with median widths up to 75 ft wide depending on the traffic volume. Florida installs longitudinal barriers on all divided highways that have medians less than 64 ft wide. North Carolina installs median barriers on all divided freeways with medians less than 70 ft wide. Washington State installs median barriers on access-controlled, divided highways (speed limit of 45 mph or greater) when the median is less than 50 ft wide.

The Pennsylvania DOT funded a study to evaluate cross-median collision on Interstate and expressways. A prediction model found that cross-median crashes decrease as the median width increases. NCHRP Project 17-14: Improved Guidelines for Median Safety is considering median width and median side slopes to recommend revised median barrier warrant criteria. Additionally, NCHRP Project 17-11: Determination of Safe/Cost Effective Roadside Slopes and Associated Clear Distances is ongoing. The objective of this research is to develop relationships between recovery area distance and roadway and roadside features, vehicle factors, encroachment parameters, and traffic conditions for the full range of highway functional classes and design speeds.

Proposed Research

Future research should be considered to determine the safety effects of median side slopes. In addition to the side slopes, soil conditions, vegetation, seasonal weather conditions, and other environmental factors should be considered in the research to determine what median design configurations best prevent cross-median crashes or reduce median encroachment distances.

In-service performance and other safety-related evaluations of median barrier systems should be considered to determine which are most cost-effective given site conditions.

Placement of Signs, Traffic Control Devices, and Lighting in Medians

The placement and mounting height of signs, traffic control devices, and lighting supports in medians is governed by the MUTCD. Research regarding placement has generally focused on the need for longitudinal barrier, crash cushions, or breakaway hardware to protect sign or luminaire supports.

It is generally considered more cost effective to locate roadway lighting supports in the median on divided highways because the lighting source is further away from the most heavily traveled lanes. All lighting supports in the median should be protected with longitudinal barrier. NCHRP Project 5-19: Development of Warrants for Roadway Lighting Based on an Evaluation of Safety Benefits is anticipated for FY2005. The project is intended to develop an analytical tool (including benefit–cost ratios) for various lighting designs across all functional class roadways.

Proposed Research

Guidance related to the placement of signs, traffic control devices, and lighting in medians is general. Future research should focus on user information needs. For example, it would be helpful to know what travel information (e.g., guide signs, regulatory signs, etc.) drivers prefer be located in the median on divided rural highways. Research should then be conducted to determine the operational and safety effects that sign placement and lighting installations have on motorist behavior.

Landscaping for Medians

Limited research has been conducted related to landscaped medians on rural highways. Future research efforts should be focused on landscaping (planting and preservation) that is aesthetic and safe. For instance, NCHRP Project 15-30: Median and Median Intersection Design for High-Speed Facilities is anticipated for FY2005 and will address median design and landscaping.

For additional information on landscaping, see AASHTO's *Guide for Transportation Landscape and Environmental Design* (1994).

Proposed Research

Future research should be focused on landscaping designs that prevent cross-median crashes or reduce median encroachment distances. Refer to the proposed research in the Types and Design section.

INCORPORATION OF BICYCLE LANES

Shoulders that are at least 4 ft wide can accommodate bicyclists on rural highways. Wider shoulders should be used to accommodate bicyclists in the presence of a longitudinal roadside barrier, curb, or where traffic speeds and volumes are high. Because rural environments do not typically restrict traveled way widths, it is not common to provide wide travel lanes (e.g., 14 ft) for bicycle accommodation. Bicycles should travel in the same direction as motor vehicles because wrong-way riding is a major cause of bicycle crashes.

Shared-use paths that are separate from the traveled way typically accommodate many nonmotorized users. These paths should be 10 ft wide to consider two-way travel. Additional information on bicycle facilities can be found in AASHTO's *Guide for Development of Bicycle Facilities* (1999).

Proposed Research

A comprehensive research effort should be undertaken to provide guidance about how to select the most suitable bikeway design given a set of field conditions. Bicyclists typically use the shoulder, a wide travel lane, or separate path in the rural transportation network. Each of these types should be compared using benefit–cost analysis and by assessing bicyclists perception of each bikeway design type. Traffic volumes, crash or conflict data, travel speeds, and other operational measures should be considered in the analysis.

BREAKOUT GROUP NOTES

Research Topic: Design Speed Issues: Speed Prediction

Overview

Speed prediction research on rural highways has been focused on ensuring a roadway alignment that is consistent with driver expectancy. A roadway design is considered consistent if operating speeds between successive geometric elements are relatively constant. Speed profile models are the most common method to evaluate geometric design consistency. The response (dependent) variable most commonly cited in the literature is the 85th-percentile operating speed. Common independent variables used to predict passenger car operating speeds are degree of curvature, radius of curve, length of curve, deflection angle, superelevation, and the rate of vertical curvature.

During the discussions at the workshop, it was noted that two-lane rural highway speed-prediction models exist. One suggestion was to focus future research on models for multilane rural highways. Questions were raised about the need for these models and how they would be used. It was concluded that development of such models was not a high priority.

Another suggestion was research to help determine how often to provide passing opportunities on two lane rural highways. At least two state DOT representatives indicated that this was an issue in their state. Older drivers also need to be considered. It was noted that the white paper for another breakout group suggested a research need related to the use of simulation to evaluate passing lanes. Although speed is a factor in passing operations, it was not considered primarily related to this topic of speed prediction.

Another possible topic is self-explaining roads and how to design highways to elicit the desired speed behavior. It was noted that an ongoing NCHRP project is reconsidering the broad issue of design speed. The consensus was to wait to see what the ongoing NCHRP project will produce.

Research Needs

Moderate additional research to supplement existing research.

Research Methodology

Field.

Priority

Low.

Urgency

Next 3–5 years.

Discussion: Filling the identified gaps was considered a low priority. NCHRP Project 15-25: Alternatives to Design Speed for Selection of Roadway Design Criteria may address some of the gaps and additional research should await completion of this project.

Duration of Research

24–36 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agency

Not listed.

Product of Research

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

Research Topic: Design Speed Issues: Transition Zones

Overview

Transitions from high-speed design to a lower-speed section have not been researched. AASHTO's Green Book contains general guidelines related to taper design when transitioning from two-lane operation to four-lane operation. Transition taper design is a function of speed and the amount of cross-section width being added to or removed from a roadway section. The MUTCD provides additional information about taper design for passing sections on two-lane highways. NCHRP Project 15-22: Safety Consequences of Flexibility in Highway Design is on-going and is addressing the issue of transition zones between high-speed operations in undeveloped surroundings and lower-speed operations in a developed area.

Discussion

During the discussions at the workshop, it was noted that rural highways are built to a high design speed. Transitioning into the suburban–urban environment and through small towns is a problem. How to make the transition safer is a concern. There is a need to evaluate whether and how combinations of horizontal, vertical alignment, and cross-section influence speeds to be what we want them to be.

Research Needs

Basic research required.

Research Methodology

Combination field/simulation.

Priority

High/moderate.

Urgency

Next 3–5 years.

Duration of Research

24–36 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agencies

- AASHTO,
- FHWA,
- NCHRP, and
- Other partners via pooled funds.

Products/Objectives

- Research report,

- Guideline for professional practice, and
- AASHTO criteria.

Research Topic: Rural Highway Safety Research

Overview

Extensive research has been conducted for rural two-lane highway road segments. Most recently, a crash prediction model was developed for inclusion in the IHSDM. The roadway segment models considered traffic volumes, roadway section length, lane width, shoulder width, roadside hazard rating, driveway density, and horizontal and vertical alignment. AMFs are applied to a base crash prediction model to determine the expected accident frequency on a roadway segment.

Discussion

During the discussions at the workshop, it was noted that crash prediction models for two-lane rural highways have been extensively researched and incorporated into IHSDM. State DOT representatives identified two features (bridge width and vertical curves) on which we are spending a lot of money but do not have good quantitative results on their safety impact. This raises questions about whether we are spending the money wisely. It was noted that TRB *Special Report 214*: *Designing Safer Roads: Practices for Resurfacing, Restoration, and Rehabilitation* addresses the vertical curve issue, but that there is desire to update it. It was also noted that 60% of crashes occur on two-lane roads, which suggests this topic may be high priority. There is a need for better quantitative safety information so that we can better analyze safety cost-effectiveness and assess whether safety investment in vertical curve flattening and/or bridge widening is the best use of the safety funds. Results would be incorporated into IHSDM and HSM.

Research Needs

Moderate additional research to supplement available research.

Research Methodology

Field.

Priority

Moderate.

Urgency

Next 3–5 years.

Duration of Research

12–24 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agencies

- FHWA and
- NCHRP.

Products/Objectives

Research report.
Combination: Results (AMFs/models) incorporated into IHSDM and the HSM.

Research Topic: Medians: Types and Design (and Safety)

Overview

Medians may be depressed, raised, or flush. A depressed median is the most common type on rural highways. A significant amount of research has been conducted relating depressed median design to safety. The AASHTO RDG indicates that median barriers are not normally considered when the median width exceeds 30 ft. Several states have funded studies to evaluate the need for median barriers based on median width and traffic volumes. California and Maryland install median barriers on divided highways with median widths up to 75 ft wide depending on the traffic volume. Florida installs longitudinal barriers on all divided highways that have medians less than 64 ft wide. North Carolina installs median barriers on all divided freeways with medians less than 70 ft wide. Washington State installs median barriers on access-controlled, divided highways (speed limit of 45 mph or greater) when the median is less than 50 ft wide.

Discussion

During the discussions at the workshop, several people indicated that median safety and design is an issue for states. It was argued that we don't understand the dynamics of driver–vehicle interaction with median design or how to address cross-median excursions. With respect to the dynamics of median excursions, we do not have a good understanding of what causes them and what can we do to prevent them. One state's experience indicated a need to consider the tradeoffs between steep slopes that result in single-vehicle crashes versus flattened slopes that turn single vehicle crashes into cross median crashes.

The issue of raised medians on two-lane highways was also raised. Examples were cited of projects in two states where such a treatment is being considered.

Ongoing NCHRP Project 17-14 is addressing median barrier warrants, but the breakout group argued there's more to median design than barriers. For example, the NCHRP Project 17-14 is considering width and volume, but not considering horizontal and vertical alignment.

Additional research should focus on crossover crashes and design treatments (e.g., combinations of slopes). Addressing crossover crashes is a high priority, while design treatment research is a moderate priority. The breakout group decided to combine landscaping issues (and other items, like signs in medians) into this topic.

The crossover issue involves vehicles encroaching into the median and head-on collisions in the opposing lane. Issues considered should include slopes, vertical grade, horizontal curvature, and proximity to interchanges. Research should include observations of vehicle encroachments to capture vehicle dynamics. For example, what happens when a vehicle transitions from adjacent foreslope to opposing foreslope? One state noted that their biggest problem is with 40-ft median, with 4:1 slope, and little or no ditch bottom. The research should deal comprehensively with median cross-section and geometry while considering tradeoffs between single-vehicle accidents on steeper slopes and head on crashes with flatter slopes.

Design treatment research should include flexible versus rigid barriers as well as landscaping issues and raised median designs. Moderate additional research on design treatments is required.

Research Needs

Basic research required.

Research Methodology

- Field,
- Simulation, and
- Test track.

Discussion: Simulation indicates finite element modeling.

Priority
High/moderate.

Urgency

Next 1–3 years.

Duration of Research

12–24 months.

Funding Requirement

High (greater than $500,000).

Funding Agencies

- FHWA and
- NCHRP.

Products/Objectives

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

Research Topic: Medians: Placement of Signs, Traffic Control Devices and Lighting in Medians

Overview

The placement and mounting height of signs, traffic control devices, and lighting supports in medians is governed by the MUTCD. Research regarding placement has generally focused on the need for longitudinal barrier, crash cushions, or breakaway hardware to protect sign or luminaire supports. It is generally considered more cost effective to locate roadway lighting supports in the median on divided highways because the lighting source is further away from the most heavily traveled lanes. All lighting supports in the median should be protected with longitudinal barrier. NCHRP Project 5-19: Development of Warrants for Roadway Lighting Based on an Evaluation of Safety Benefits is anticipated for FY2005. The project is intended to develop an analytical tool (including benefit–cost ratios) for various lighting designs across all functional class roadways.

Discussion

During the discussions at the workshop, one issue raised was driver information needs and what signs they prefer being placed in medians. Some suggested the issue should be broader while others suggested the focus should be on the safety impacts of these objects in the median. It was noted that there has already been lots of work on this topic. It was agreed to eliminate the driver information needs aspect. It was recommended that issues related to the placement of signs in medians should be considered as part of the research topic on medians: placement of signs, traffic control devices and lighting in medians. It was concluded that there are no other major research needs in this area.

Research Needs

None.

Research Topic: Medians: Landscaping for Medians

Overview

Limited research has been conducted related to landscaping medians on rural highways. Future research efforts should be focused on landscaping (planting and preservation) that is aesthetic and safe. For instance, NCHRP Project 15-30: Median and Median Intersection Design for High-Speed Facilities is anticipated for FY2005 and will address median design and landscaping.

Discussion

During the discussions at the workshop, it was observed that with CSD being a hot topic, this issue needs serious consideration. One state representative reported cross-median crash problems on steep grades. In addition to NCHRP Project 15-30, NCHRP Project 17-14 is also underway. It was argued that we should wait upon the outcome of those studies before suggesting additional research. It was noted that NCHRP Project 15-30 only reviews current information and recommends modifications for AASHTO. The breakout group concluded that landscaping issues should be considered and addressed within the proposed study on medians—types and designs.

Research Needs

Discussion: Combined with the research topic on medians: placement of signs, traffic control devices and lighting in medians.

Research Topic: Incorporation of Bike Lanes

Overview

Shoulders that are at least 4 ft wide can accommodate bicyclists on rural highways. Wider shoulders should be used to accommodate bicyclists in the presence of a longitudinal roadside barrier, curb, or where traffic speeds and volumes are high. Because rural environments do not typically restrict traveled way widths, it is not common to provide wide travel lanes (e.g., 14 ft) for bicycle accommodation. Bicycles should travel in the same direction as motor vehicles because “wrong way” riding is a major cause of bicycle crashes.

Discussion

During the discussions at the workshop, the rural highways breakout group concluded this topic was a high priority. Current guidance available to states is vague regarding where and how to accommodate bicyclists (e.g., “where traffic volumes are high”). The research needs to lead to practical guidance, like warrants. Guidance is needed on what combination of vehicular and bicycle volumes, as well as other factors, justify wider shoulders. Guidance is also needed on where bicycles should be prohibited, i.e., what combinations of factors justify bicycle prohibitions? The research should include the rumble strip issue. It needs to consider bridges with narrow shoulders. It needs to consider two-lane and four-lane rural highways. It should address whether the shoulder needs to be paved or just hard, to be used as a bicycle facility. It was suggested that since the AASHTO Bicycle Guide covers separate bicycle facilities that are primarily urban, this problem statement should focus on rural and shared facilities. Additional research is needed; there isn't sufficient information to synthesize or highlight best practices. An ongoing NCHRP 20-7 project is looking at gaps and additional research needs in the Bicycle Guide. Basically, we're talking about developing warrants for wider shoulders for use as a bicycle facility as well as when bicycle use should be prohibited. The research should consider benefit–cost analysis, bicyclists' perceptions, and constraints (e.g., narrow bridges).

Research Needs

Basic research required.

Research Methodology

- Field,
- Test track, and
- Bicycle survey/focus group.

Priority
High/moderate.

Urgency

Next 1–3 years.

Duration of Research

24–36 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agencies

- FHWA and
- NCHRP.

Products/Objectives

- Research report, and
- AASHTO criteria.

APPENDIX E

Freeways and Interchanges

JOEL LEISCH
Consultant

The identification of the freeway and interchange research topics began in August 2000 nearly 1 year prior to the 2001 joint summer meeting of the AASHTO Geometric Design Task Force and the TRB's Geometric Design Committee and Operational Effects of Geometrics Committee. Those first topics were input to the joint research workshop held in Santa Fe, New Mexico, in the summer of 2001. As a result of the workshop in Santa Fe and through discussions and input from members of the Task Force and the TRB committees the topic list has been refined and modified to reflect those issues that require basic research and/or development. Below, the research topics are generally discussed; the associated past and present research and literature is cited; proposed basic research is suggested; and a sample research problem statement presented.

RESEARCH TOPICS

There are 12 research topics, which fall under the following three categories.

Freeways

1. Lane widths: safety and operational impacts;
2. Shoulder widths: safety and operational impacts; and
3. Allocation of lane widths and shoulder widths across the total cross-section—safety and operational tradeoffs.

Interchanges

1. Diamond interchange forms: geometric and operational characteristics;
2. Partial cloverleaf interchange forms: geometric and operational characteristics;
3. Interchange spacing: impact on safety, operations and land development (tradeoffs); and
4. High-occupancy vehicle (HOV) and managed lane interchanges including "online" bus stations: forms, design elements, and operational characteristics.

Ramps

1. Ramp design as a system: exit/ramp proper/entrance;

2. One-lane and two-lane ramp design for safe and efficient operation: exit/ramp proper/entrance;
3. Design for metered and multi-use (HOV, bus, etc.) ramps;
4. Design for three-lane exit ramps: exit/ramp proper/entrance; and
5. Design of parallel versus tapered exits (diverge) and entrances (merge) to achieve similar operational characteristics.

ASSOCIATED RESEARCH AND LITERATURE

The primary resources summarizing the recent past and present research and literature related to freeways, interchanges, and ramps were drawn from the following:

1. Fitzpatrick, K., and M. Wooldridge. *NCHRP Synthesis of Highway Practice 299: Recent Geometric Design Research for Improved Safety and Operations.* TRB, National Research Council, Washington, D.C., 2001.
2. Other research not cited in *NCHRP Synthesis of Highway Practice 299*; and
3. From NCHRP: three recent and future funded research projects.

A comprehensive reference list is contained in *NCHRP Synthesis of Highway Practice 299* (Item 1). Lists for Items 2 and 3 are below:

Item 2: Other Research

1. Curren, J. E. *NCHRP Report 369: Use of Shoulder and Narrow Lanes to Increase Capacity*. TRB, National Research Council, Washington, D.C., 1995.
2. Zegeer, C. V., and F. M. Council. *Safety Effectiveness of Highway Design Features, Volume III*: *Cross Sections*. Report No. FHWA-RD-91-046. FHWA, U.S. Department of Transportation.
3. Downs, H. G. and D. W. Wallace. *NCHRP Report 254: Shoulder Geometrics and Use Guidelines*. TRB, National Research Council, Washington, D.C., 1982.

Item 3: Present and Future NCHRP Research

1. NCHRP Project 3-60: Capacity and Quality of Service of Interchange Ramp Terminals. Completion Date: September 2004.
2. NCHRP Project 3-75: Analysis of Freeway Weaving Sections. Begin Date: 2004.
3. NCHRP Project 15-31: Design Guidelines for Acceleration and Deceleration Lanes for Freeways. Begin Date: FY 2005.

FREEWAY RESEARCH TOPICS

The freeway research topics focus on cross-section—freeway lane and shoulder widths. From a review of the research and other literature on these topics it appears that most of the cross-section research has been directed towards rural highways and low-volume roads. There is limited information relating accident experience to freeway geometric elements.

Lane Width

The lane width research indicates that 11- and 12-ft lanes produce better and safer operation than 9- and 10-ft lanes. Further, this research indicates that wider shoulders on "high-type," high-speed roadways where a vehicle parked on the shoulder is at least 1 ft (0.3 m) from the traveled way results in reduced accidents. While these research studies were not specifically related to freeway cross-section they certainly confirm what the profession has assumed for many years.

Lane and Shoulder Width

The only research specifically related to freeway lane and shoulder widths was directed towards their effect on freeway free-flow speed as defined in the HCM. Free-flow speed is used in the HCM to establish speed–flow relationships and associated values for maximum flow rates, v/c ratio, and density for various LOS. The research indicates that 12-ft lanes and 6-ft lateral clearance on the right are optimal. Reducing these widths has a negative effect on free flow speed and consequently a reduction in flow rate. There was no attempt to link accidents with either lane width or shoulder width.

No research has been accomplished for freeway cross-section investigating the safety and operational tradeoffs of the allocation of lane and shoulder width across the total cross-section. This topic is very much related to CSD, particularly freeway widening or modification to increase capacity or to add HOV/managed lanes.

Proposed Research

Conduct basic research on freeway cross-section related to safety (accident–crash experience) and operational tradeoffs of lane and shoulder widths and the allocation of these dimensions across the total cross-section.

INTERCHANGE RESEARCH TOPICS

There is little known concerning accident experience related to interchange forms. The existing research dates primarily to the 1960s. Any interchange research undertaken should include accident–crash experience related to interchange type (form).

Diamond Interchange Forms

There has been a considerable amount of research and literature published in the last 15 years concerning diamond interchange forms. The focus has been primarily on the Single Point Urban Interchange (SPUI) and the comparison of the SPUI with the Tight Urban Diamond Interchange. With the publication of the FHWA Roundabout Guide and continuing research and study of the design and operation of roundabouts it does not appear that additional research is required related to the design and operation of diamond interchanges with roundabout treatments at the intersection of the ramps with the crossroad. An extensive discussion of all diamond interchange forms and their design and operational characteristics is forthcoming in ITE's *Freeway and Interchange Geometric Design Handbook* to be published in 2005. Enough research and literature has been accomplished or is in process so that an extensive publication on diamond interchanges including one-way frontage road operations can be developed without additional research.

Partial Cloverleaf Interchanges

The primary resource for the design and operation of partial cloverleaf interchanges exists in interchange design study reports, Interchange Justification Reports and in the forthcoming ITE publication referenced above. A publication on the design and operational characteristics of partial cloverleaf interchanges can be developed based on existing literature and experience. A single publication incorporating both diamond and partial cloverleaf service interchange forms would be appropriate.

Interchange Spacing

This is a topic for which there has been no research and very little literature published. FHWA and most of the state DOTs have established general guidelines for urban and rural areas. To a certain extent these guidelines are arbitrary, although related to a certain extent to freeway operations, particularly in urban areas. Based on recent research it is evident that a majority of freeway accidents occur within interchanges. Closely spaced interchanges (less than 1 mi) in urban areas often have weaving between entrance and exit ramps that usually have higher accident rates than basic freeway segments. The spacing of interchanges is dependent upon a number of highway network, traffic, geometric, and operational characteristics. The type and density of land use is one of the prime determinants of traffic volume. There are tradeoffs between safety, operations and the accommodation of traffic related to interchange spacing in urban areas. This issue is a complex issue and consequently a potential candidate for basic research.

HOV and Managed-Lane Interchanges

A variety of exclusive HOV and bus rapid transit (BRT) interchanges have been designed and constructed in the last 10 years. These are now operating on both barrier-separated and concurrent-flow systems. The *NCHRP Report 414: HOV Systems Manual* has concept designs for several types of HOV interchanges. In a few locations "bus stops" have been constructed on interchange ramps. To the author's knowledge no online bus stations (stops) have been constructed although a design was developed for a proposed HOV/BRT barrier-separated facility in Atlanta, Georgia, partially based on the concept design in the *HOV Systems Manual*. Based on operational experience with the designed and constructed interchanges a minimal research project could be undertaken to develop a more extensive guide for the design and operation of "special use" interchanges.

Proposed Research

Conduct basic research on the tradeoffs between safety, operations, and land development related to interchange spacing in urban areas. For the other topics listed above the recommendation is to conduct these as development projects based on experience and the research and literature available.

RAMPS RESEARCH TOPICS

As with the previous research topics there is little data relating accident experience with ramp types and merge and diverge areas. Any ramp research conducted should include tasks to relate accident experience to ramp types, ramp proper geometry, and merge–diverge areas.

Ramp Design as a System

There has been much research conducted related to the three individual elements that comprise the ramp (exit, ramp proper, entrance). There are guidelines for the relationship of the design speed of the ramp to the design speed of the "mainline" roadway. The ramp, in the development of its design however, has not been viewed as a system comprised of three elements and part of a greater system including the ramp exiting roadway and the ramp entering roadway. Further, ramp design should be related to driver expectations associated with anticipated speed reduction dependent on the classification of the two interchanging facilities, the interchange form, and the area environment (rural versus urban). This topic should be considered for basic research to provide the designer with a tool to design a ramp as part of a system reflecting driver expectations.

One-Lane and Two-Lane Loop Ramp Design

The AASHTO policy gives very little guidance with respect to one-lane loop design and none for two-lane loop design. No basic research has been accomplished for the design of either one-lane or two-lane loop design. There are a great many one-lane loops and a few two-lane loops presently in operation. The only literature assessing the design of two-lane loop ramps is cited in the list of research and literature in the appendix. This work gives some excellent guidance based on observation for design of five two-lane loop ramps. It does not constitute basic research adequate to develop criteria for design and operation of the variety of situations where two-lane loop ramps can either be implemented or existing one-lane or two-lane loop ramps modified to produce better and safer operation. Basic research is proposed to develop design criteria and guidelines for the design of both one-lane and two-lane loop ramps reflecting the classification and design speed of the interchanging facilities, the interchange form, and driver expectations associated with ramp speed reduction. Accident experience related to loop ramp geometrics needs to be one of the tasks.

Design of Three-Lane Exit Ramps

There is becoming an increasing need at system interchanges (freeway to freeway) in urban areas to construct or reconstruct ramps with three-lane exits (diverge) to accommodate the heavy turning volumes. A few of these have been designed and constructed utilizing the present criteria for two-lane exits. This approach may be satisfactory, however, a “limited” research and design development project is recommended to develop guidelines for three-lane exits.

Design and Operation of Tapered Versus Parallel Exits and Entrances

The AASHTO policy provides guidelines (criteria) for the design of ramp merge and diverge areas for both tapered and parallel designs. In review of these two designs (taper/parallel) the criteria produce differing operational characteristics. There is a significant variation among state DOT’s as to which design (parallel versus taper) is used. There is an NCHRP-funded research project to be awarded in FY2005 to study parallel and tapered exit and entrance designs and their safety and operational characteristics. This research, hopefully, will result in designs that will produce similar operation of the tapered and parallel exit and entrance designs through the merging and diverging maneuver areas.

Proposed Research

Basic research to be conducted on the following:

1. Ramp design as a system;
2. Design and operation of two-lane loop ramps; and
3. Support and provide guidance for the research on tapered and parallel exits and entrances.

Conduct a “limited” research and development project to establish design criteria for three-lane freeway exits.

SUMMARY

There are four basic research projects that have been proposed as described above.

1. Safety and operational tradeoffs of the allocation of lane and shoulder width across the freeway cross-section.
2. Safety, operational, and land use tradeoffs associated with interchange spacing in urban areas.
3. Ramp design as a three element system.
4. Designs and operation of two-lane loop ramps.

The other eight topics described could be addressed as either development projects based on current research and literature or as limited research and development projects requiring little data collection and analysis.

A sample research problem statement for No. 4—designs and operation of two-lane loop ramps—is shown below:

DRAFT RESEARCH PROBLEM STATEMENT: PLANNING, DESIGN, AND OPERATIONAL ISSUES ASSOCIATED WITH TWO-LANE LOOP RAMPS

Joel Leisch, Larry Sutherland, John Adams, and Karl Passetti

Problem Statement

As traffic volumes in most areas continue to grow and right-of-way and available funding to build new infrastructure become limited, more emphasis is placed on adding additional capacity to existing infrastructure or constructing new facilities with higher capacities. At interchanges, a potential treatment to add capacity is the use of two-lane loop ramps. Loop ramps, as with other interchange ramp types, have specific design and operational characteristics that must be considered as part of a ramp system (entry and exit gore areas, ramp proper, and ramp terminal intersection) to produce a safe and efficient design. Chapter 10 of AASHTO's *A Policy on Geometric Design of Highways and Streets* (2001) provides little guidance on the application and design of two-lane loop ramps.

Although potential two-lane loop ramp designs can be "pieced together" using many existing guidelines listed in Chapter 10 (for example, general guidance is given on the design of two-lane entrance and exit terminals), this type of design does not consider the interaction between the driver, roadway, and vehicle that occurs between the elements in the ramp system which includes exiting roadway, exit terminal, ramp proper, entrance terminal, and entering roadway. NCHRP 15-31: Design Guidelines for Acceleration and Deceleration Lanes for Freeways (FY2005) which includes design of two-lane entrances and exits could provide some of the data for this effort. Also, new research on driver behavior in two-lane roundabouts and experiences observed on existing two-lane loop ramps can be used to understand driver's perceptions traveling side-by-side on a circular section of roadway. A thorough understanding with respect to capacity, operations, safety, geometry, construction considerations, capital cost, and human factors is needed so that "informed" decisions regarding the use and design of two-lane loop ramps may be made.

Research Objective

The research objective is to provide guidance on the proper planning and location of two-lane loop ramps and to expand the profession's knowledge and understanding of the use of two-lane loop ramps with respect to geometry, operations, and safety.

Research Tasks

Phase 1

- Conduct literature search and state-of-the-art review.
- Conduct survey of U.S. and state DOT experience.
- Identify need for additional research.
- Prepare interim report.

Phase 2

- Select appropriate sites for additional data collection and analysis as identified in Phase 1.
- Simulate various design alternatives to study the operation of two-lane loop ramps using appropriate microsimulation software.
- Prepare interim report.

Phase 3

- Prepare a final report summarizing all aspects of the research.
- Develop draft material for replacement of relevant sections of Chapter 10 of AASHTO's *A Policy on Geometric Design of Highways and Streets* (2001).

Time Period and Funding

- Phase 1: 6 months, $50,000.
- Phase 2: 9 months, $250,000.
- Phase 3: 3 months, $50,000.

Urgency, Payoff Potential, and Implementation

Chapter 10 of AASHTO's *A Policy on Geometric Design of Highways and Streets* (2001) provides an adequate overview of the general considerations and design parameters associated with single-lane loop ramps. In terms of two-lane loop ramps, although general guidance is given on the design of two-lane entrance and exit terminals, little information is available regarding the design of a two-lane loop ramp proper. Additionally, no guidance (outside of the discussion on cloverleaf interchanges) is given on the proper planning and location of two-lane loop ramps.

With more detailed information, highway designers will be better able to make informed decisions regarding the applicability and design of two-lane loop ramps to various site-specific conditions. This research is urgent due to the potential savings in cost and impact (environmental, length of construction, right-of-way, etc) that may be realized through the use of two-lane loop ramps versus other alternatives (i.e. adding directional or semi-directional ramps). The research is also urgent to minimize the implementation of two-lane loop ramp designs based on dated information and limited knowledge that may lead to operational or safety deficiencies.

BREAKOUT GROUP NOTES

Research Topic: Interchanges: Ramp and Interchange Spacing

Overview

This is a topic for which there has been no research and very little literature published. FHWA and most of the state DOTs have established general guidelines for urban and rural areas. To a certain extent, these guidelines are arbitrary, although related to a certain extent to freeway operations, particularly in urban areas. Based on recent research it is evident that a majority of freeway accidents occur within interchanges. Closely spaced interchanges (less than 1 mi) in urban areas often have weaving between entrance and exit ramps that usually have higher accident rates than basic freeway segments. The spacing of interchanges is dependent upon a number of highway network, traffic, geometric, and operational characteristics. The type and density of land use is one of the prime determinants of traffic volume. There are tradeoffs between safety, operations and the accommodation of traffic related to interchange spacing in urban areas. This issue is complex and a potential candidate for basic research.

Discussion

This project should include the impacts of ramp spacing both within an interchange and between interchanges. This should be undertaken for both urban and rural locations and between service ramps and system ramps. This should include spacing of on-ramp to on-ramp, on-ramp to off-ramp, and off-ramp to off-ramp.

The impact of interchange spacing on development in an urban environment should be examined.

The implications of interfacing successive on-ramps or successive off-ramps with the freeway mainline as either single or dual interface points must be quantified.

The consideration of signing on the proposed ramp spacing criteria needs to be considered and guidance proposed.

The safety implications of the proposed ramp and interchange spacing guidelines must be quantified.

Research Needs

Basic research required.

Research Methodology

Combination field/simulation.

Priority

High/moderate

Urgency

Next 1–3 years.

Duration of Research

24–36 months.

Funding Requirement

High (greater than $500,000).

Funding Agencies

- AASHTO,
- FHWA,
- NCHRP, and
- U.S. DOT.

Products/Objectives

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

Research Topic: Ramps: Ramp Design as a System

Overview

Much research has been conducted related to the three individual elements that comprise the ramp (exit, ramp proper, entrance). There are guidelines for the relationship of the design speed of the ramp to the design speed of the "mainline" roadway. In the ramp design development, however, there has not been a system comprised of three elements as part of a greater system including the ramp exiting roadway and the ramp entering roadway. Further, ramp design should be related to driver expectations associated with anticipated speed reduction dependent on the classification of the two interchanging facilities, the interchange form, and the area environment (rural versus urban). This topic should be considered for basic research to provide the designer with a tool to design a ramp as part of a system reflecting driver expectations.

Discussion

The examination of the ramp terminal intersection segment of the ramp design should be expanded to include a comparison of the safety impacts of the different intersection forms. Analysis should quantify the crash exposure and severity of crashes for ramp terminal intersection forms.

Research Needs

Basic research required.

Research Methodology

Combination field/simulation.

Priority

High/moderate

Urgency

Next 1–3 years

Duration of Research

Greater than 36 months.

Funding Requirement

High (greater than $500,000).

Funding Agencies

- AASHTO,
- FHWA,
- NCHRP, and
- U. S. DOT

Products/Objectives

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

Research Topic: Ramps: One-Lane and Two-Lane Loop Ramp Design

Overview

The AASHTO policy gives very little guidance with respect to one-lane loop design and none for two-lane loop design. No basic research has been accomplished for the design of either one-lane or two-lane loop design. There are a great many one-lane loops and a few two-lane loops presently in operation. The only literature assessing the design of two-lane loop ramps is cited in the list of research and literature in the appendix. This work gives some excellent guidance based on observation for design of five two-lane loop ramps. It does not constitute basic research adequate to develop criteria for design and operation of the variety of situations where two-lane loop ramps can either be implemented or existing one-lane or two-lane loop ramps modified to produce better and safer operation. Basic research is proposed to develop design criteria and guidelines for the design of both one-lane and two-lane loop ramps reflecting the classification and design speed of the interchanging facilities, the interchange form, and driver expectations associated with ramp speed reduction. Accident experience related to loop ramp geometrics needs to be one of the tasks.

Discussion

Entrance and exit loop ramp design criteria differences must be dealt with implicitly as part of this research. Further, guidance in the use of curve transitions should be provided. Capacity of one- and two-lane loop ramps should be quantified based on provided radius. The safety impacts of the interaction of loop ramp lanes and radius must be identified.

Research Needs

Basic research required.

Research Methodology

Combination field/simulation.

Priority

High/moderate.

Urgency

Next 1–3 years.

Duration of Research

12–24 months.

Funding Requirement

Moderate ($250,000–$500,000).

Funding Agencies

- AASHTO,
- FHWA,
- NCHRP, and
- U.S. DOT.

Products/Objectives

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

Research Topic: Freeways: Lane and Shoulder Width (Safety and Operational Tradeoffs)

Overview

The lane width research indicates that 11- and 12-ft lanes produce better and safer operation than 9- and 10-ft lanes. Further that wider shoulders on "high-type", high-speed roadways where a vehicle parked on the shoulder is at least 1 ft (0.3 m) from the traveled way results in reduced accidents. While these research studies were not specifically related to freeway cross-section they certainly confirm what the profession has assumed for many years.

The only research specifically related to freeway lane and shoulder widths was directed towards their effect on freeway free flow speed as defined in the HCM. Free-flow speed is used in the HCM to establish speed–flow relationships and associated values for maximum flow rates, v/c ratio, and density for various LOS. The research indicates that 12-ft lanes and 6-ft lateral clearance on the right are optimal. Reducing these widths has a negative effect on free-flow speed and consequently a reduction in flow rate. There was no attempt to link accidents with either lane width or shoulder width. No research has been accomplished for freeway cross-section investigating the safety and operational tradeoffs of the allocation of lane and shoulder width across the total cross-section. This topic is very much related to context sensitive design, in particular associated with freeway widening or modification to increase capacity or to add HOV/managed lanes.

Discussion

There is concern over the part-time use of existing shoulders as HOV, high occupancy toll (HOT) lanes, or general use facilities during the peak hour. The trade-offs between operational benefits and safety need to be quantified. Further, the safety implication of violators using the shoulder during the off-peak period needs to be quantified. Does this changed view of the shoulder as part of the drivable alignment also transfer to shoulder violation on adjacent facilities? The signing and striping of these shoulders for clear communication of the changed use must also be quantified.

For special use lanes (e.g. HOV, HOT) what are the impacts of providing or not providing barrier separation. Further, for these barriers, what shoulder widths are necessary adjacent to the barrier and what are the safety impacts of these shoulder widths?

Focus of the research should be on existing facilities that would be rehabilitated or reconstructed. As part of this retrofit the impact of choices of lane widths, inside and outside shoulder widths must be quantified to allow for the safest and most efficient reuse of the available cross-section width. The application of current standards to new facilities is less interesting.

Examine the safety impacts of shoulder widths that are between 4 and 8 ft. For all shoulder widths, the impacts to capacity and operating speed should be examined as well. Other than short-term impacts, are the free-flow speed impacts and, thus, capacity impacts of narrow shoulders really true?

Research Needs

Basic research required.

Research Methodology

Combination field/simulation.

Discussion: Existing simulation models do not properly address the issues that are requested to be investigated. Thus, a simulation model or recalibration of existing models would be accomplished based on field observations as part of this research to create a user tool for cross-section analysis.

Priority

High/moderate.

Urgency

Next 1–3 years.

Duration of Research

- 24–36 months, or
- More than 36 months.

Funding Requirement

High (greater than $500,000).

Funding Agencies

- FHWA and
- NCHRP.

Products/Objectives

- Research report,
- Guideline for professional practice, and
- AASHTO criteria.

Discussion: A simulation model for cross-section design is also required.

APPENDIX F

Intersections

KARL PASSETTI
Kittelson and Associates, Inc.

RESEARCH TOPICS

There are 12 research topics that fall under the following three categories.

Design

- Accessible Design (3.00),
- High-speed intersection design (2.85),
- Design consistency principles (2.85),
- Continuous flow intersections (2.65),
- Left-turn treatments (2.60), and
- Skewed angles at intersections (2.46).

Safety

- Safety impacts for varying alignment and sight distance (3.00),
- Safety impacts for varying capacity (2.92),
- Access control (2.65),
- Design to accommodate intelligent transportation system at intersections (2.50),
- Lighting of intersections: safety benefits (2.42), and
- Lighting of intersections: warrants (2.23).

Roundabouts

- Two-lane design (2.92),
- Use at freeway interchanges (2.81),
- Warrants (2.77),
- Landscaping and operational effects (2.31),
- Pedestrian issues for all types of intersections (2.92), and
- Older driver issues for all types of intersections (2.38).

DESIGN

Accessible Design

The ADA has minimum design standards that are to be applied in all public environments, including public right-of-way. The standards, listed in the Americans with Disabilities Act Accessibility Guidelines (ADAAG) are the foundation for designing all pedestrian environments. Intersection Safety Issue Briefs 11: Pedestrian Design for Accessibility Within the Public Right-of-Way (FHWA and ITE, April 2004) provides a concise discussion of issues associated with designing for ADA.

Primary Resources

- Accessible design for the blind. Research, guidance, and instructional materials on the use of accessible pedestrian signals (APS) and detectable warnings: http://www.accessforblind.org.
- Barlow, J. M., P. Cannon, D. Dawson, et. al. *Building a True Community: Final Report.* Public Rights-of-Way Access Advisory Committee, U.S. Access Board, February 2001. http://www.access-board.gov

Specific ADA issues associated with intersection design relate to right-turn-on-red, roundabouts, and channelized right-turn lanes and other features designed to move traffic through intersections without having to stop or come to a complete stop. The lack of stopping is hazardous for people who depend on the sounds of traffic to judge adequate gaps in traffic. In NCHRP Project 3-72: Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas, design guidance and criteria are being developed for addressing the safety and operational tradeoffs for motorists, pedestrians, and bicycles for two specific topics: selecting lane widths and using right-turn deceleration lanes at driveways and unsignalized intersections.

NCHRP Project 3-78: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities (FY2004) will build on research being conducted in NCHRP Project 3-65; Applying Roundabouts in the United States and the research to be conducted in NCHRP Project 3-72: Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas to recommend a range of geometric designs, traffic control devices, and other treatments that will make pedestrian crossings at roundabouts and channelized turn lanes useable by pedestrians with vision impairment. Exploration of the proper balance among the needs of passenger cars, trucks, pedestrians (including pedestrians with vision impairments), and bicycles is central to achieving the objectives of the research.

Proposed ADA requirements for the maximum grade of pedestrian crosswalks may limit pavement cross-slopes to 2% at some locations. Similarly, where a paved shoulder may be used as a pedestrian travel path, the shoulder cross-slope may be limited to 2%. The safety implications for motor vehicles of such changes are unknown.

High-Speed Intersection Design

The following general areas are often considered in relation to high-speed intersection design.

- Speed reduction treatments at high-speed intersections; and
- Guidance and consideration for intersections designed to operate at high speeds.

Speed Reduction Treatments at High-Speed Intersections

NCHRP Project 3-74: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections is just beginning with the objectives of this project to (*a*) identify or develop treatments and (*b*) develop guidelines for their selection to reduce the operating speed of vehicles approaching intersections, thereby reducing the frequency and severity of crashes. For the purpose of the project, the research will focus on at-grade, signalized and unsignalized intersections with operating speeds of 45 mph or greater, and on treatments that focus on geometric design and other physical features, but also include consideration of traffic signs and pavement markings. Potential treatments to be studied may include the following:

Treatment	**General Category**	**Notes**
Reduced lane width	Visual	Ongoing research, human factors considerations, bicycle considerations, AASHTO coordination
Shoulder treatments	Visual	Physical treatments possible, human factors considerations, AASHTO coordination
Speed tables	Physical	Access traffic calming research, functional classification issues
Rumble strips in the traveled way on intersection approaches	Physical	Access prior synthesis summaries, noise issues in urban environment, maintenance considerations
Roadside treatments (cross-sectional changes, “gateways”); landscaping	Visual	Human factors considerations, consider pedestrian and bicycle needs
Approach reverse curvature	Physical	Curve radii and length considerations, bicycle lane encroachment issues, divided highway applications
Roundabouts	Operational	NCHRP 3-65 results pending, new versus retrofit considerations
Wider longitudinal pavement markings (e.g., edge lines, centerlines)	Visual	Human factors considerations, MUTCD coordination, climate and maintenance considerations
Transverse pavement markings on roadway or shoulder	Visual	Human factors considerations, MUTCD coordination, climate and maintenance considerations
Roundabout treatments for application to conventional intersections	Physical	Functional classification issues, new versus retrofit considerations
Dynamic warning signs activated by speed of approaching vehicle	Operational	Coordinated with other treatments, rural versus urban considerations, MUTCD coordination
Dynamic warning signs activated by potentially conflicting vehicles on an intersection approach	Operational	Coordinated with other treatments, rural versus urban considerations, MUTCD coordination

A questionnaire will also be used to seek input about alternative speed reduction treatments.

Intersections Designed to Operate at High Speeds

Little research was found that deals specifically with intersections designed to operate at high speeds (most research and emphasis has been focused on reducing speeds through intersections and treatments to better inform drivers of upcoming intersections). Topics that need to be researched to generate design criteria for such facilities will need to be discussed.

Continuous Flow Intersections

The FHWA draft report Signalized Intersections: Informational Guide provided a discussion on continuous flow intersections (CFI) and crossover displaced left turn (XDL) intersections that focused mostly on the description of the treatment and the operational characteristics and potential safety issues of the treatment.

Intersection Safety and Congestion Relief Using Mostly Nontraditional Treatments, a presentation created by Joe Bared of the FHWA, presented an operational analysis of CFIs/XDLs using a simulation model. The operational analysis presented results in terms of delay, stops, and queues for three variations of configurations (each configuration had slightly different geometric features in terms of turn lane lengths and spacing of intersections).

The paper, Development and Applications of an Intelligent Intersection: A Summary of the Benefits and Drawbacks, by Fuess, Cadena, Szplett, and Mier focused on introducing the concept of CFIs and discussing the operational and cost issues associated with the treatment. Although the authors apparently designed a CFI intersection, a detailed discussion of the issues faced during the design process was not included.

The design features of CFIs/XDLs are an area where few guidelines exist. Potential research topics could include:

- Separation distance (median width) between through lanes and turning lanes;
- Effective design and placement of channelization; and
- Multimodal design considerations.

Left-Turn Treatments

The FHWA published Safety Effectiveness of Intersection Left- and Right-Turn Lanes in July 2002 (FHWA-RD-02-089), which presented the results of research of providing left- and right-turn lanes for at-grade intersections. The research showed a significant reduction in crashes at intersections with exclusive turn lanes.

The FHWA draft report Signalized Intersections: Informational Guide, provided a discussion on in-direct left-turn treatments that included jughandles, median U-turn crossovers, CFI/XDL intersections, quadrant roadway intersections, super-median crossover, and grade-separation techniques. The discussion focuses on the description of the treatment, the operational characteristics and potential safety issues of the treatment, multimodal considerations, and design guidance if a standard reference exists. For example, the design of jughandles, based on the New

Jersey DOT design manual, and the design of median U-turn intersections, based on the Michigan DOT guidelines is presented.

Other Topics

The FHWA draft report, Signalized Intersections: Informational Guide, included the development of a research problem statement to address the accommodation of turning traffic at high-volume signalized intersections. The draft problem statement follows.

Research Project Statement #2: Accommodation of Turning Traffic at High-Volume Signalized Intersections

Turning traffic at signalized intersections presents several safety and efficiency problems that have not been adequately addressed in the literature. While a substantial amount of research has been performed on the general questions of capacity and safety for turning movements, there are two important issues that commonly arise: (*a*) nationwide standardization of the design criteria for turning lanes and (*b*) resolution of the conflict between right turns and U-turns when both movements receive simultaneous green arrow displays. There is an immediate need for further research on both of those issues.

Background Summary

Some of the most significant issues with respect to turning traffic have been reported as follows.

- The recommended taper length and deceleration lane length for turning lanes provided in DOT design manuals varies between states.
- Research on separate effects of turning bays, raised medians, and channelization islands to control access is limited.
- Offsets between opposing left-turn lanes have been shown to produce safety benefits, but findings are based only on a very limited research and research itself has limitations such as choice of test drivers, experiment time, restricted drivers sample size, etc.
- There is limited research on channelization and delineation schemes for right turns Inconsistent findings for volume warrants for exclusive right-turn lanes. Some states such as Colorado set a minimum right turn threshold of 25 vph, while other state DOTs, such as Washington and Oregon, provide curves that account for the right-turn volume and approach volume.
- Prohibiting right-turn-on-red (RTOR) during periods of the day (i.e., 7 a.m.-7 p.m.) has been shown to reduce the number of stop line violations, but only limited studies have been performed (Insurance Institute for Highway Safety, 2001).
- No research on safety effect of exemptions from banned turns.
- Right turn versus U-turn conflicts: Results for eight-lane and four-lane arterials are not statistically significant because of small sample size. Some factors such as driveway ingress or egress volumes, right turn and U-turn overlaps are not considered. No effect on mobility is studied.

Note that this problem statement may overlap in part with the findings from the ongoing NCHRP 3-72 Project: Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas.

Research Objectives

Expand and refine the existing guidelines for accommodating turning traffic at high-volume signalized intersections to improve safety and efficiency for all traffic modes.

Project Tasks

1. Review the standards and practices employed by different state DOTs for turning lanes with respect to warrants, taper length, storage length, RTOR prohibition, exemption from banned turns, deceleration lane length, and delineation schemes. Develop and implement a study plan, including site selection, data collection, and analysis methodology. Based on the findings of the study, recommend a set of uniform criteria for each of the above items.
2. Review the standards and practices employed by different state DOTs with respect to simultaneous accommodation of U-turns that conflict with protected right turns. Questions to be addressed include:
   - Criteria for prohibiting U-turns that conflict with protected right turns;
   - Recommended signal displays for both movements;
   - Regulatory and advisory signs for the U-turning movement;
   - Signal phasing considerations (leading, lagging, etc.); and
   - Pedestrian safety considerations.

   Develop and implement a study plan, including site selection, data collection, and analysis methodology. Recommend a set of uniform criteria for each of the above items based on the findings of the study.
3. Review the treatment of turning traffic in HCM and the current microsimulation models commonly used in the United States. Based on the findings of all of the tasks in this project, make specific recommendations for enhancement of turning movement modeling in the next-generation simulation (NGSIM) program and future editions of the HCM.

Urgency, Payoff Potential, and Risks

Urgency

Many high-volume, at-grade intersections in the United States are in critical need of safety improvements, capacity improvements, or accessibility improvements. Proper accommodation of turning traffic is a critical factor in promoting these improvements.

Payoff Potential

The results of this study could be directly incorporated into standard references, including the AASHTO Green Book (for geometric configurations) and the MUTCD (unique signing, pavement markings, and signalization needs). In addition, the information could be used to update guidebooks such as *Signalized Intersections: Informational Guide*. The quantitative findings could also provide valuable technical inputs to the FHWA's NGSIM program.

Risks

The primary risks are a potential shortage of study sites and difficulties in extrapolating the site-specific findings from this project to cover a broad enough range of physical, geographical, and social conditions.

Impact on Practice

The findings of this project will be directly applicable to the planning, design, and operation of high-volume signalized intersections. They will be of interest to a number of TRB committees and have the potential to provide new material for such authoritative references as the HCM, MUTCD, and the AASHTO Green Book, as well as various state standards and guidelines. They could also provide technical input to the FHWA's NGSIM program.

Estimated Funding and Time Requirements

To be determined.

SAFETY

Safety Impacts for Varying Alignment and Sight Distance

ISD was revised in the 2001 Green Book based on the research in *NCHRP Report 383: Intersection Sight Distance*. The research resulted in a change of methodology to ISD values based on gap acceptance.

Further research may be needed to address the following ISD issues:

- The impact of revised ISD values on crash experience, and
- Crash–conflict analysis of intersections that do not meet ISD values.

Safety Impacts for Varying Capacity

Many recent workshops and conferences have focused on the issue of improving safety at intersections, such as the Intersection Safety Workshop (Milwaukee, Wisconsin, November 2001).

In his paper, Engineering Safer Intersections, Bonneson identifies a need for a uniform evaluation of safety performance to accompany the process for the uniform evaluation of intersection efficiency. *NCHRP Report 457: Evaluating Intersection Improvements: An Engineering Study Guide* also discusses concept of engineering for safety based on control type (signalized versus unsignalized).

Other resources include:

- AASHTO Strategic Highway Safety Plan: Goal 17: Improving the Design and Operation of Highway Intersections.
- Harwood paper at Intersection Safety Workshop.

ROUNDABOUTS

The FHWA published *Roundabouts: An Informational Guide* (2000) to provide guidance on the planning, traffic analysis, geometric design, signing and marking, and special applications of roundabouts. This document was largely based upon the practice in Europe and Australia to provide transportation professionals with a toolbox of general principles for implementing roundabouts in the United States. In the time since publication, several state DOTs have developed supplemental guides that provide further design guidance consistent with local practice and reflect the most recent advances in roundabout design.

NCHRP Project 3-65: Applying Roundabouts in the United States is currently ongoing (expected completion in the summer of 2005) with the goal to develop methods to estimate the safety and operational impacts of U.S. roundabouts and to refine design criteria. The anticipated outcome of this project is an approach to evaluating roundabout operations and design that is tailored to U.S. driving conditions based upon data collected at roundabouts currently operating in the U.S. data collection and evaluation efforts include both single-lane and two-lane roundabouts in a broad range of geographic locations and geometric configurations.

The Insurance Institute for Highway Safety released a study in March 2000 titled “Crash Reductions Following Installation of Roundabouts in the United States.” The findings of this study provide additional evidence of potential crash reduction from the installation of a roundabout at locations with previous stop control or signalization. This study of U.S. roundabouts estimated a 39% reduction in crashes for all severity types and a 76 % reduction in injury crashes. The study was based upon the evaluation of 24 intersections of various sizes/types in eight states and has since been expanded by approximately 40% through work completed by New York State DOT, with additional safety data available upon completion of NCHRP 3-65.

Further research in the following areas may be needed to address the following design issues for roundabouts.

- Treatments for aiding visually impaired pedestrians.
- Design of bicycle facilities at roundabouts.
- Design of roundabouts at high truck volume locations, particularly multilane roundabouts. Research may include evaluation of designs accommodating side-by-side WB-67 trucks through a multilane roundabout and the corresponding design implications such as effect on speed control for entering vehicles and inscribed circle diameter.
- Friction factors used to predict speeds based upon the fastest path procedure outlined in the FHWA publication *Roundabouts: An Informational Guide.*
- Sight-distance needs approaching and within a roundabout.
- Bypass lane design at roundabouts.
- Vertical profiles and cross-sections both on the approach and within the roundabout itself. Research may include evaluation of the effect of grades on drainage, speed control, and sight distance.

PEDESTRIAN ISSUES FOR ALL TYPES OF INTERSECTIONS

The accommodation of pedestrians needs to be considered when alternatives are being studied that may increase vehicular efficiency (adding lanes, creating free-flow movements, etc.) and when the safety of intersections is being analyzed. The 2003 MUTCD offers guidance on the following based on recent research:

- Use of in-pavement lights to alert motorists to the presence of a pedestrian crossing or when someone is preparing to cross the street.
- Use of pedestrian signs and signals at intersections (including accessible pedestrian signals).

The FHWA published *A Review of Pedestrian Safety Research in the United States and Abroad* in January 2004 (FHWA-RD-03-042) to summarize research on pedestrian safety in the United States with a focus on crash characteristics and the safety effects of various roadway features and traffic-control devices. Although many treatments are identified and discussed, guidance or geometric design criteria of pedestrian-related treatments are not included in the report.

Signalized Intersections: Informational Guide, soon to be published by the FHWA, also addresses many treatments to improve pedestrian safety at intersection (curb extensions, refuge areas, etc.). Although the treatments are identified and discussed, guidance or geometric design criteria of pedestrian related treatments is not included in the report.

Further research may be needed to address the following design issues associated with pedestrians at intersections.

- ADA issues previously noted.
- Guidelines for the design and application of textured crosswalks, bulb-outs/curb extensions, and pedestrian refuge islands (i.e., acceptable materials, dimensions, and colors).
- The safety benefit of reducing pedestrian crossing distances. This research could include safety benefits of bulb-outs/curb extensions and the safety benefit of pedestrian refuge islands and intersection medians.
- The use of barriers such as fences or shrubs to discourage pedestrians from crossing at unsafe locations

The FHWA draft report *Signalized Intersections: Informational Guide* included the development of a research problem statement to address accommodating pedestrians and bicycles at high-volume signalized intersections. The draft problem statement is attached.

Research Project Statement #4: Accommodation of Pedestrians and Bicycles at High-Volume Signalized Intersections

Research Need Statement

Because of their vulnerabilities, pedestrians and cyclists are involved in a disproportionate number of serious collisions at intersections. Their treatment at high-volume signalized intersections is especially critical, because of the competing demands on the available signal time, conflicts with heavy turning traffic, long crosswalk exposure distances, etc.

Because nonmotorized users are playing an increasing role in the development of sustainable communities, measures to promote pedestrian and bicycle safety are receiving increased attention. Several pedestrian and bicycle safety treatments have been identified and applied in various locations throughout the United States. Some of these treatments have proven to be more successful than others. There is a definite need for research to identify the most promising treatments and to promote their nationwide adoption.

Note 1: The treatment of pedestrian and bicycle clearance has been included in this project statement in addition to the statement dealing with clearance interval requirements because of the commonality of the subject matter. If both projects are pursued then some modifications will be required to avoid duplication.

Note 2: A federally supported study on pedestrian safety countermeasures is now underway, with field studies being conducted in Miami, Las Vegas, and San Francisco. The tasks described in this project statement have therefore been developed to avoid duplication with that study.

Background Summary

Some of the most significant issues with respect to pedestrian and bicycle accommodations have been reported as follows:

- Safety effect of bicyclist-targeted offsets of stop lines is not studied in the United States, especially if RTOR is in place. No research on safety effect of truncated cycle lane versus separate cycle lane to the stop-line.
- Safety effect of incorporation of toucan crossings into the intersection design is not known.
- No research on driver behavior, safety and mobility effects of tighter curb radii, pedestrian-friendly right turn slip lanes, and setback crosswalks.
- Research on the safety effect of pedestrian signalization is outdated.
  - No research has been performed on the safety effect of larger pedestrian signal heads or educational signs.
  - The types of locations in which automated pedestrian detectors are best suited need to be determined (Hughes et al., 2000).
  - No research has been performed on the safety effect of lagging pedestrian intervals.
  - Exclusive pedestrian intervals can reduce pedestrian crashes by 50% in some locations (Zegeer, Seideman, 2001), but can increase waiting time either for pedestrians or motorists. In the first case, pedestrians often choose to ignore the signal (Zegeer et al, 1983). No quantitative analysis providing guidance on the imposing of the exclusive pedestrian phase is present in the literature.
- A large potential to promote bicycle use lays in the field of traffic signal control systems with provisions for bicyclists
  - Only limited research on traffic signal control systems accounted for bicycles in United States is available. No quantitative analysis has been found regarding safety implications of such systems for bicyclists.

- TRB's Bicycle Transportation Committee has identified a need for research on innovative intersection treatments for bicycles.
- Imposing bicycle traffic signals benefited bicyclists in several specific cases, however, many drawbacks of their use exist (capacity issues, increased delay for cyclists, possible high noncompliance rate, nonuniformity of control). If bicycle traffic signals enter the MUTCD as an intersection treatment option, then strong warrants must be developed (Moer, 1999).

Research Objectives

Identify the computational methods and implementation practices used throughout the United States to enhance the safety of pedestrians and cyclists at high-volume signalized intersections. Determine their effect on safety and efficiency for all users at signalized intersections. Recommend a standardized practice for nationwide application.

Project Tasks

1. Review the standards and practices employed by different state DOTs with respect to the criteria for the treatment of pedestrian clearances at high-volume signalized intersections. Questions to be addressed include:
   - Under what conditions pedestrian displays should be implemented on signalized crosswalks?
   - What is the minimum required length of the walk display based on pedestrian expectancy?
   - How should the required pedestrian clearance interval length be determined? If walking speed is a factor, then what is the appropriate value to use?
   - When the pretimed split in a coordinated system exceeds the sum of the minimum walk and pedestrian clearance intervals, what criteria should be used to distribute the slack time between these intervals?
   - Do pedestrian countdown signals affect the pedestrian clearance time requirements, especially if the "ped recycle" feature is active?

   Develop and implement a study plan, including site selection, data collection, and analysis methodology. Recommend a set of uniform criteria for each of the above items based on the findings of the study.
2. Review the standards and practices employed by different state DOTs with respect to the criteria for the treatment of bicycle clearances at high-volume signalized intersections. Questions to be addressed include:
   - What differences exist in state statutes with respect to bicycles and their relationship to other vehicles in the traffic stream, and how do these differences affect the need for bicycle clearance times?
   - Does the ITE intergreen model accommodate the speed, length deceleration, and reaction time of a typical bicycle and its rider? If not, can the parameters be adjusted or is a different model required to ensure safe clearance of cyclists when the signal changes?
   - What criteria are, or could be, applied at very large signalized intersections to require the cyclist to dismount and assume the role of a pedestrian crossing the intersection?

- What special bicycle displays have been, or could be, used to accommodate bicycle clearance when the normal vehicular displays do not provide adequate clearance time?

Develop and implement a study plan, including site selection, data collection, and analysis methodology. Recommend a set of uniform criteria for each of the above items based on the findings of the study.

3. Review the standards and practices employed by different state DOTs with respect to the special pedestrian signalization treatments at high-volume signalized intersections. Questions to be addressed include:
   - What are the safety effects of larger pedestrian signal heads or educational signs and when should these devices be used?
   - What conditions are best suited to automated pedestrian detectors and what safety benefits are these devices likely to produce?
   - What are the safety and operational benefits of leading and lagging pedestrian intervals and when should such intervals be incorporated into the signal operation?
   - What are the safety and operational benefits of exclusive pedestrian intervals and when should such intervals be incorporated into the signal operation?
4. Review the standards and practices employed by different state DOTs with respect to the special bicycle signalization treatments at high volume signalized intersections. Questions to be addressed include:
   - What special bicycle signals have been, or could be, used to provide safer accommodations for bicycles at high volume signalized intersections? Under what conditions are these devices likely to prove beneficial?
   - What standards, guidance, options and support should be incorporated into the MUTCD to cover warrants and design features of special bicycle signals?
5. Review the treatment of pedestrians and bicycles in the HCM and the current microsimulation models commonly used in the United States. Based on the findings of all of the tasks in this project, make specific recommendations for enhancement of the pedestrian and bicycle modeling in the NGSIM program and future editions of the HCM.

Urgency, Payoff Potential, and Risks

Urgency

Many high-volume, at-grade intersections in the United States are in critical need of safety improvements, capacity improvements, or accessibility improvements. Refinement and standardization of the treatments for accommodating pedestrians and bicycles will be a critical factor in promoting these improvements.

Payoff Potential

The results of this study could be directly incorporated into standard references, including the AASHTO Green Book (for geometric configurations) and the MUTCD (unique signing, pavement markings, and signalization needs). In addition, the information could be used to update guidebooks such as *Signalized Intersections: Informational Guide*. The quantitative findings could also provide valuable technical inputs to the FHWA's NGSIM program.

Risks

The primary risks are a potential shortage of study sites and difficulties in extrapolating the site-specific findings from this project to cover a broad enough range of physical, geographical, and social conditions.

Impact on Practice

The findings of this project will be directly applicable to the planning, design, and operation of high-volume signalized intersections. They will be of interest to a number of TRB committees and have the potential to provide new material for such authoritative references as the HCM, MUTCD, and the AASHTO Green Book, as well as various state standards and guidelines. They could also provide technical input to the FHWA's NGSIM program.

Estimated Funding and Time Requirements

To be determined.

OLDER DRIVER ISSUES FOR ALL TYPES OF INTERSECTIONS

The *Highway Design Handbook for Older Drivers and Pedestrians*, published by FHWA in 2001 (FHWA-RD-01-103) provides information that associates older road user characteristics to highway design, operational, and traffic engineering recommendations. A chapter of the handbook is about intersections and addresses topics such as: intersecting angle, receiving lane width for turning operations, channelization, ISD requirements, curb radius, and pedestrian crossing design.

Further research may be needed to update the following design issues associated with older drivers at intersections:

- An analysis of the impact of the values recommended in *NCHRP Report 383: Intersection Sight Distance* on older drivers.
- Update of the information contained in the handbook about issues associated with older drivers using roundabouts.

BREAKOUT GROUP NOTES

Research Topic: Design: Accessible Design

Overview

The ADA has minimum design standards that are to be applied to all public environments, including public right-of-way. The standards, listed in the ADAAG are the foundation for designing all pedestrian environments. *Intersection Safety Issue Briefs 11: Pedestrian Design for Accessibility Within the Public Right-of-Way* (FHWA and ITE, April 2004) provides a concise discussion of issues associated with designing for ADA. Proposed ADA requirements for the maximum grade of pedestrian crosswalks may limit pavement cross-slopes to 2% at some locations. Similarly, where a paved shoulder may be used as a pedestrian travel path, the shoulder cross-slope may be limited to 2%. The safety implications for motor vehicles of such changes are unknown.

Discussion

- Provide signal phase for pedestrians only when needed.
- Channelized right turns major issue; current study stops short:
  - Where do you want to put the crosswalk?
  - Reserve the right to develop a topic depending upon how NCHRP Project 3-72 ends up.
- Median refuges for pedestrians at signalized intersections.
- Curb extensions and other pedestrian-friendly techniques. Need design guidance on specific treatments.
- Look at design user of intersection. How to decide on who design user is. Primary and secondary users.
- Cross-slope issue as well.

Research Topic: Design: High-Speed Intersection Design—Intersections Designed to Operate at High Speeds

Overview

Little research was found that deals specifically with intersections designed to operate at high speeds (most research and emphasis has been focused on reducing speeds through intersections and treatments to better inform drivers of upcoming intersections). Topics that need to be researched to generate design criteria for such facilities will need to be discussed.

Discussion

- Special concern where speed limits have been raised.
- Raise vertical and skew criteria for these cases? Do all of those issues get down to sight distance.
- May be some pedestrian issue.
- Lots of traffic control devices questions; is there a geometric design issue?
- NCHRP Project 3-74 will help.
- Potential for synthesis document.

Research Topic: Design: Continuous Flow Intersections

Overview

The design features of CFIs/XDLs are an area where few guidelines exist. Potential research topics could include:

- Separation distance (median width) between through lanes and turning lanes.
- Effective design and placement of channelization.

Discussion

Would like more multimodal design considerations.

- Pedestrian crossing concerns.
- Global look—where do they fit?
- Informational guide like roundabout guide—may be premature.
- Need to know operational effects of geometrics.
- CFI is one of a category of treatments and has high interest.
- Make more generic pre-interchange designs. Requires design detail.

Also would like geometric design guidelines for major intersection alternatives to accommodate multimodal users.

Research Topic: Safety: Safety Impacts for Varying Alignment and Sight Distance

Overview

ISD was revised in the 2001 Green Book based on the research in *NCHRP Report 383: Intersection Sight Distance*. The research resulted in a change of methodology to ISD values based on gap acceptance.

Further research may be needed to address the following ISD issues:

- The impact of revised ISD values on crash experience and
- Crash–conflict analysis of intersections that do not meet ISD values.

Discussion

There is limited safety data to support use of ISD. There is safety data for insufficient SSD.

- How much of the median to keep clear to allow sight of oncoming vehicle?
- New ISD procedure changed the numbers. Uses 50% gap.
- Have crashes changed? Would be very difficult to collect those data. Possible simulator experiment.
- Does landscaping change speeds?

Research Topic: Older Driver Issues for All Types of Intersections

Overview

The *Highway Design Handbook for Older Drivers and Pedestrians*, published by FHWA in 2001 (FHWA-RD-01-103) provides information that associates older road user characteristics to highway design, operational, and traffic engineering recommendations. A chapter of the handbook is about intersections and addresses topics such as: intersecting angle, receiving lane width for turning operations, channelization, ISD requirements, curb radius, and pedestrian crossing design. Further research may be needed to update the following design issues associated with older drivers at intersections:

- An analysis of the impact of the values recommended in *NCHRP Report 383: Intersection Sight Distance* on older drivers.
- Update of the information contained in the handbook about issues associated with older drivers using roundabouts.

Discussion

Do not need separate documents.

Integrating bikes, pedestrians, older drivers, and other nonstandard users into Green Book and MUTCD is needed.

Disincentives to pedestrians: safety and usability tradeoffs of intersection designs for all user groups.

APPENDIX G

Urban Streets

JAMES GATTIS
University of Arkansas

The following urban street topics had previously been identified for discussion.

- Design speed versus operating speed;
- TWLTL (five-lane versus. divided roadway);
- Midblock pedestrian crossings;
- Accessible design for the disabled;
- Parking on arterial streets; and
- Access management.

Due to the related nature, TWLTL (five-lane versus divided roadway) has been merged into the broader topic of access management.

DESIGN SPEED VERSUS OPERATING SPEED

Those charged with designing and operating the roadway system have observed that the speed a road is designed for, the posted speed limit, and the speeds at which drivers operate may differ. With increasing opposition by some to the speeds experienced on urban streets, and interest in CSD, there has been a renewed interest in relating design assumptions to the resulting operating speeds.

Previous Findings

Studies have found the following variables related to operating speed.

- Suburban highways: radius, deflection angle, rate of vertical curvature, access density and development.
- Urban streets: limited sight distance, type of land use, introduction of cross-section elements such as curb, vegetation.
- Low-speed urban streets: lane width, degree of curve, hazard rating, and trip function (local versus through trip).

On suburban–urban nonfreeway roads with speed limits from 25 mph to 55 mph, 86% of drivers were within the legal speed plus 10 mph (Fitzpatrick).

Current Research and Related Activity

There recently have been a number of studies examining the speeds that drivers choose on horizontal curves. Other studies have reexamined how speed limits are set.

Questions to answer include the following.

- What factors can be identified and quantified that will predict the operating speed?
- What problems actually result in various urban environments when operating speed exceeds design speed?
- How should intended speed and speed limits be set? To reflect the intended speeds of most drivers, or the restrictions desired by those in the area surrounding the roadway?

References

Fitzpatrick, K., P. Carlson, M. A. Brewer, M. D. Wooldridge, and S. P. Miaou. *NCHRP Report 504*: *Design Speed, Operating Speed and Posted Speed Practices.* Transportation Research Board of the National Academies, Washington, D.C., 2003.

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ACCESS MANAGEMENT AND TWLTL

Access management is the systematic control of the location, spacing, design, and operation of interchanges, medians and median openings, and driveway and street connections to a roadway. In practice, an access management program entails the combination and integration of administrative, planning, design, operations, right-of-way, and legal aspects. In addition, roadway planning and design needs to be coordinated with land planning and site development.

Although the concept evolved decades ago, access management is still a "new" topic in that it has not been widely adopted and implemented. Possible reasons for this include not being aware of the concepts, not understanding the concepts, not accepting the concepts as valid, or finding that the concepts are difficult to apply for administrative, political, or other reasons.

The choice of median type (none, five-lane with TWLTL, or nontraversable) is an aspect of access management. Similarly, access management is sometimes considered to be an aspect of corridor management.

Previous Findings

A wide variety of different types of studies have reported that access management reduces the crash rate and delay to travelers. There has been some variation in suggested thresholds, such as at what volume to convert from a five-lane design (TWLTL) to a nontraversable median.

NCHRP Report 420: Impacts of Access-Management Techniques documents the effects of various geometric methods. *NCHRP Synthesis of Highway Practice 304: Driveway Regulation Practices* stated that "responses clearly indicate that politics is a significant factor in driveway regulation."

Attempts to understand the economic impacts have not been as successful, since the success or failure of a business can be affected by a number of variables which are at work at any give time.

Current Research and Related Activity

Since the aggregate practice of access management incorporates literally dozens of concepts, there are many issues to understand. NCHRP projects related to access management scheduled to be completed within a year or newly completed include the following.

- Project 3-60: Capacity and Quality of Service of Interchange Ramp Terminals;
- Project 3-72: Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas;
- Project 8-44: Incorporating Safety into Long-Range Transportation Plans;
- Project 8-46: A Guide for Including Access Management in Transportation Plans;
- Project 17-21: Safety of U-turns at Unsignalized Median Openings. Nearing completion;
- Synthesis 34-12: Access Location on Crossroads in the Vicinity of Interchanges—final draft is completed;
- 35-03: Crash Reporting and Processing—the intent is to create/collect better data to understand what factors contribute to crashes; AND
- 35-06: Access Rights—particularly, the acquisition of access rights.

Other research issues needing to be addressed include the following.

- The development guidelines for the design of driveways.
- Best practices for the development of small sites abutting major roadways.
- Economic impacts of access management treatments on businesses.
- Best practices in access management: determine to what extent states and local governments have implemented access management, and identifying barriers and assistance they require.
- Traffic simulation software for assessment of access management options.
- The national frequency and costs of access related crashes.
- How to incorporate access management in 3R projects.
- Improving the quality of data about crash location and cause, and about the description of the roadside environment in which a particular set of data were collected.

MIDBLOCK PEDESTRIAN CROSSINGS

The traditional consensus among traffic engineers is that midblock crosswalks are usually undesirable. According to the MUTCD, the only way a crosswalk can exist at a midblock location is if it is marked. The way that origins and destinations are placed relative to each other (such as placing a major building entry at midblock, with a parking lot directly across the street) can create a demand for midblock pedestrian movements.

Previous Findings

Although it varies from year to year, over 10% of all motor vehicle-related fatalities in the United States are pedestrians (NHTSA). In 2001, there were 4,882 pedestrian fatalities and 78,000 pedestrian injuries resulting from traffic crashes in the United States (Cui, 2003). On average, a pedestrian is injured in a traffic crash every 7 min and killed every 111 min (Walkinginfo.org, 2004). About 85% of pedestrian collisions occur in urban areas (FHWA, 1992). The U.S. DOT reports that in 1994, children under age 15 constituted 33% of all pedestrian crashes (Health Policy Guide, 2004).

In the 1970s, a methodology for typing pedestrian crashes was developed by the NHTSA to better define the sequence of events and precipitating actions leading to pedestrian-motor vehicle crashes. In the early 1990s, this method was refined and used to determine the crash types for more than 5,000 pedestrian crashes in six states. The results showed that the mid-block events were the second major grouping of crash types and accounted for 26.5% of all crashes. Among this group, the most commonly crash type (one-third of all) was the midblock dash in which the pedestrian ran into the street and the motorist's view was not obstructed. Another 17% of these crashes were dart-outs, i.e., the pedestrian ran or walked into the street, but the motorist's view was obstructed until just before the impact (Walkinginfo.org, 2004).

Although not targeted solely at midblock crossings, a Seattle study found enforcement was rather ineffective in getting vehicles to stop for pedestrians (Britt et al., 1995). A large study (Zegeer et al., 2002) based on 5 years of data at uncontrolled intersections found the presence of a raised median (or raised crossing island) was associated with a significantly lower pedestrian crash rate at multilane sites with both marked and unmarked crosswalks. Factors having no significant effect on pedestrian crash rate included: area (e.g., residential, central business district), location (i.e., intersection versus midblock), speed limit, traffic operation (one-way or two-way), condition of crosswalk marking (excellent, good, fair, or poor), and crosswalk marking pattern (e.g., parallel lines, ladder type, zebra stripes).

Current Research and Related Activity

While numerous treatments exist at unsignalized crossings, there is a growing concern that they are not effective. There is a need to identify and study enhanced treatments which may be more effective. Examples include the "Yield to Pedestrian" sign placed in the roadway, in roadway crosswalk lighting, median refuge islands, the placement of an advance yield line at midblock crosswalks, and overhead supplemental devices.

Little information exists about the effects of grade-separated crossings on pedestrian accidents. The safety effect of pedestrian refuge islands is unknown (FHWA, 1992). Grade-separated pedestrian crossings can be costly, yet still go unused.

Objectives of NCHRP Project 3-71: Innovative Pedestrian Treatments at Unsignalized Crossings include finding new engineering treatments to improve safety for pedestrians crossing high-volume and high-speed roadways at unsignalized locations, in particular those served by public transportation, and recommend modifications to the MUTCD traffic signal pedestrian warrant.

A factor usually missing from studies is "exposure"—computing rates that reflect how much pedestrian activity took place at study location.

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ACCESSIBLE DESIGN FOR THE DISABLED

Steps to accommodate the disabled in roadway design go back at least to the 1970s. The ADA of 1991 required that public rights of way, including sidewalks and crosswalks, be accessible to pedestrians with disabilities.

Previous Findings

Consumer Product Safety Commission hospital emergency room data concerning causes of injuries or death to wheelchair users involving motor vehicles from 1991 through 1995 were examined (NHTSA). The activity associated with the injury to wheelchair users could generally be classified into five categories, two of which involve roadway design interactions: collision between a wheelchair and a motor vehicle (1,819, or 26%), and falling onto or off of a ramp (407, or 6%). The majority (83%) of the wheelchair users whose injuries were related to collision with a motor vehicle involved passenger cars. Of the estimated 43 fatalities, all involved vehicle collisions.

In 1998, the American Council of the Blind (ACB) and the Association for Education and Rehabilitation of the Blind and Visually Impaired (AER) conducted surveys having similar questions to determine problems experienced by blind pedestrians during street crossings (Walkinginfo.org).

- 12 of 158 respondents had been struck by a car at an intersection, and 45 had their long canes run over (ACB).
- Many respondents indicated that they or their students sometimes had difficulty knowing when to begin crossing: ACB—91%; AER—98%.
- 79% of respondents indicated that blind students sometimes had difficulty determining the onset of the walk interval at intersections having exclusive pedestrian phasing (AER).

- 85% of respondents indicated that they were sometimes confused by unexpected features such as medians or islands (ACB).
- Many respondents indicated that they or their students had difficulty with push buttons: ACB—90%; AER—94%.

In trials conducted by another institute, 34% of those whom independently initiated crossings began crossing during the flashing or steady don't walk.

Roundabouts and channelized turn lanes present challenges different from other intersections for individuals with blindness and visual impairments, because the traffic is most often under yield control as opposed to stop control. Other problem situations include the gap for the wheel flange at railroad grade crossings, and surface drainage at accessible ramps.

Current Research and Related Activity

On June 17, 2002, the U.S. Access Board published draft rights-of-way guidelines (Docket No. 02-1) proposing to require pedestrian signals at roundabouts and channelized turn lanes that would create and identify gaps in the vehicle stream adequate for pedestrians who are crossing without vision cues.

Pertinent research projects include NCHRP Project 3-65: Applying Roundabouts in the United States and the research to be conducted in NCHRP Project 3-72: Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas. Other relevant resources are proceedings from the ITE/FHWA Roundabout Accessibility Summit.

Topics of research interest follow.

1. Flangeway gap treatments for light rail and other rail crossings of pedestrian routes for accessibility/usability by pedestrians who use wheelchairs.
2. Design approaches that eliminate ponding at curb ramps.
3. Pedestrian exposure at one versus two-lane roundabouts.
4. Effects of crossing distance and curb radius on roadway capacity, vehicle delay, and pedestrian and driver safety; evaluate driver sight distance issues where pedestrians cross at large-radius corners.
5. Curb height to assess the utility of less-than-6 in. curbs to facilitate curb ramp accommodation.
6. Optimal vehicle speed to maximize roadway capacity.
7. Compare vehicle capacity data for three- versus four-lane roadways.
8. Quantify usability effects of cross-slope and grade, rate of change, and combinations of cross-slope and grade on pedestrians who use manual wheelchairs and on pedestrians who use walking aids.
9. Engineering treatments at intersections for establishing crossing direction by pedestrians with vision impairments.
10. Roadway design in steep terrain and accessible pedestrian crosswalk cross-slopes at intersections: if the through road is on a grade, and there is no stop, are there "vehicle launching" risks when tabling the intersection to limit cross-slope to 2%?
11. Effects of speed bumps on drivers/passengers with disabilities.

Issues to consider include overall net results: while a particular roadway design might benefit one class of users, what effect will the overall public experience, and will there be an overall net benefit?

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PARKING ON ARTERIAL STREETS

There are two general types of on-street (i.e, curb) parking: parallel and angle. Angle parking allows more parking per linear foot of curb then does parallel parking.

Some advocate allowing on-street parking along arterial streets as a way to create a barrier between moving traffic and pedestrians, therefore improving the walking environment, and to calm traffic. Since it may allow more customers to park closer to their destinations, on-street parking (especially angle parking) is also felt to improve the business environment for abutting properties. Others oppose on-street parking on the grounds that it contributes to crashes and impedes traffic flow.

Previous Findings

Allowing or Prohibiting On-Street Parking

Parking was identified as a casual factor on 12% to 14% of all motor vehicle accidents in a National Safety Council annual tabulation of accidents in United States. In one study, the cost of parking accidents was found to be about half of the average (Rankin, 1971).

Curb parking was found to be directly involved in 17% to 18% of all accidents on urban streets; the rate of parking accidents per mile was eight times greater on major streets than on minor (Box, 1970). Humphreys et al. (1979) reviewed data from 10 cities, finding that over 50% of nonintersection crashes involved parking. McCoy et al. (1990) surveyed 135 mi of urban state highway with curb parking. Data were collected from 22,572 parallel spaces and 6,314 angle spaces in a number of cities and towns. Overall, 26% of the nonintersection accidents on major streets and 56% on two-way, two-lane streets were parking accidents.

Parallel or Angle Parking

Angle parking at 90 degrees allows more than twice the number of stalls per unit of curb length than does parallel parking (Alroth, 1999). Edwards (2002) advocated angle parking because it provides a wider buffer between sidewalks and driving lanes, which helps reduce vehicle splash, noise and fumes, and helps improve the perception of safety for the pedestrian.

Many consider angle parking to be more dangerous than parallel (Rankin, 1971). In a synthesis of a number of studies, Box (2002) found higher accident rates for angle parking than for parallel, with a few exceptions. A Nebraska study found higher accident rates for angle parking by any measure as compared with parallel parking (McCoy et al.,1990). Humphreys et al. (1979) concluded the crash rate increased with land use type: the lowest being associated with residential, and increasing with multifamily, office, and retail. The level of use rather than the parking configuration appeared to be the key to the midblock accident rate: for streets with over 600,000 parking space hours per kilometer per year, parallel parking is not safer than angle parking, given similar land uses. Zeigler (1971) said that parking at an extremely flat 22.5-degree angle with the curb was proven to be quiet safe and user-friendly.

Current Research and Related Activity

The pavement marking diagrams in recent versions of the MUTCD have called for a marked stall that is 8 ft wide. Some recent design publications have specified less width.

Research in Rhode Island is examining tradeoffs between bike lane width and parking width.

It may be that the scope should be "higher volume streets" rather than "arterial streets," because the common three tier functional classification system does not apply well to many older street networks. Streets that are classified as collectors may be in fact functioning as arterials.

Three issues that are the subject of ongoing debate are

- Should on-street parking be allowed along arterial streets;
- If parking is allowed, under what conditions should it parallel or angle;
- How much cross-section width should be allocated for a parked vehicle?

The safety effects of on-street parking could be better examined using data from those locales that have improved their crash reporting processes by means such as using satellite crash location technology. The context of studies needs to be better defined: factors such as abutting land use type and street traffic volumes should be reported, and both data and findings should be stratified by context, so that findings taken from one environment are not applied without justification to other environments. A broader test of the flat angle parking advocated by Ziegler could prove interesting.

An examination of the effects of curb parking upon business and the community would be helpful. A confounding problem is that it is not uncommon for parking enhancements to be accompanied by other area improvements.

The allocation of cross-section width to parking and to bicycles should be incorporated into studies.

Additional research will be of little benefit unless an effective technology transfer method to get the information into the hands of practitioners and local political leaders is employed.

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BREAKOUT GROUP NOTES

Research Topic: Access Management

Overview

Access management is the systematic control of the location, spacing, design, and operation of interchanges, medians and median openings, and driveway and street connections to a roadway. In practice, an access management program entails the combination and integration of administrative, planning, design, operations, right-of-way, and legal aspects. In addition, roadway planning and design needs to be coordinated with land planning and site development. Although the concept evolved decades ago, access management is still a new topic in that it has not been widely adopted and implemented. Possible reasons for this include not being aware of the concepts, not understanding the concepts, not accepting the concepts as valid, or finding that the concepts are difficult to apply for administrative, political, or other reasons. The choice of median type (none, five-lane with TWLTL, or nontraversable) is an aspect of access management. Similarly, access management is sometimes considered to be an aspect of corridor management.

Summary and Recommendation

The discussion of this subject was combined with the section 2.4.2: TWLTL by the white paper author and the group. Please see those notes.

Research Topic: Design Speed vs. Operating Speed

Overview

Those charged with designing and operating the roadway system have observed that the speed a road is designed for, the posted speed limit, and the speeds at which drivers operate may differ. With increasing opposition by some to the speeds experienced on urban streets, and interest in CSD, there has been a renewed interest in relating design assumptions to the resulting operating speeds.

Priority

Low.

Discussion: Research in this area should include consideration of the philosophy of whether the design speed approach should be used and if it should be considered in urban areas. Is there an optional approach for urban street design (based on something similar) or are there so many other issues in urban areas that are more critical that it isn't even really necessary to take a design speed or speed approach to design? What are the primary considerations for the design of urban streets?

Summary and Recommendation

A comparison of urban street design and operating speeds may be in order. The consideration of pedestrian and prioritizing them is probably a more important and relevant approach in urban areas (see note above about other more critical consideration in urban street design than speed). There is an upcoming NCHRP Project 15-25: Alternatives to Design Speed for Selection of Roadway Design Criteria.

Research Topic: TWLTL (Five-Lane Versus Divided Roadway)

Overview

Access management is the systematic control of the location, spacing, design, and operation of interchanges, medians and median openings, and driveway and street connections to a roadway. In practice, an access management program entails the combination and integration of administrative, planning, design, operations, right-of-way, and legal aspects. In addition, roadway planning and design needs to be coordinated with land planning and site development. Although the concept evolved decades ago, access management is still a new topic in that it has not been widely adopted and implemented. Possible reasons for this include not being aware of the concepts, not understanding the concepts, not accepting the concepts as valid, or finding that the concepts are difficult to apply for administrative, political, or other reasons. The choice of median type (none, five-lane with TWLTL, or nontraversable) is an aspect of access management. Similarly, access management is sometimes considered to be an aspect of corridor management.

Priority

Moderate.

Summary and Recommendation

This discussion was combined with the access management section by the white paper author and the group.

1. Focus areas discussed in this included a need to evaluation the economics of access management and the frequency and cost of access-related crashes. These are potential focus areas of access management research. It was also noted that a number of state studies have been completed on access management but aren't considered regularly or available to most people. There was also an opinion that access management approaches were different in different sized communities—in large community there is a need to move traffic, but in many small communities there is an objective to stop/slow traffic for economic reasons. The economic impact by community size might be considered as a project. Safety was still considered the most important argument for access management—both pedestrians and vehicle safety.
2. Another potential research project: removing a raised median and the safety impacts of this activity. Does it depend on the roadway environment and what are those characteristics? (Bowman at Alabama did work in this area.)
3. Research subject: What about warrants for when to use particular types of medians?
4. Research subject: A comparison of operational and safety differences of a TWLTL on seven- and five-lane sections? Differences by roadway operating speed. When is one or the other used and where?
5. Research subject: The impact of full-paved shoulders and parking on a seven-lane roadway.
6. Research subject: A comparison of seven-lane roadway safety and operational impacts with that of raised median six-lane roadway (combine with subject No. 4 above).
7. Other potential subject: Implementation issues and advantages (safety and operations) related to cross access easements (interparcel connections) and backage roads. Possibly a synthesis.

Research Topic: Midblock Pedestrian Crossings

Overview

The traditional consensus among traffic engineers is that midblock crosswalks are usually undesirable. According to the MUTCD, the only way a crosswalk can exist at a midblock location is if it is marked. The way that origins and destinations are placed relative to each other (such as placing a major building entry at midblock, with a parking lot directly across the street) can create a demand for midblock pedestrian movements.

Summary and Recommendations

There was an opinion expressed that many midblock crossings operate fine and that this may not be a high priority research area.

1. Research subject: The coordination of land use development planning/design and midblock crosswalk needs, designs, and other issues.
2. Research subject: Are midblock crossing problems related to traffic control and/or design components?
3. Research subject; How far are people willing to walk to cross a roadway and how is that related to the introduction of midblock, their design, and other crossing-related design issues?

4. Research subject: What is the opinion of pedestrians with respect to the width of roadway and safety?
5. Research subject: What is the degree of effectiveness for midblock crossings treatments? Is it related to the traffic control and marking (e.g., none, marked, activated flasher, continuous flashers, signal, and other). Operational and safety impacts are important.
6. Research subject: The safety and operational impacts of free-flow/yield right-turn lanes and changes to them. What about pedestrian safety and free-flow right turn lanes? When should free-flow right-turn lanes be used? What are the accessibility and vision impaired issues of free-flow designs, island designs, and roadway width? Corner radii, island shape and size, location of crosswalk, and lane width all have impacts. High? Project 3-71 may have some overlap with this.

Research Topic: Accessible Design for the Disabled

Overview

Steps to accommodate the disabled in roadway design go back at least to the 1970s. The ADA of 1991 required that public rights of way, including sidewalks and crosswalks, be accessible to pedestrians with disabilities.

Summary and Recommendations

There were 11 topics of interest provided in the white paper.

- No. 4 on the list: Curb radius, etc., impacts. This was discussed in 2.4.3 and might be combined with that proposed research project.
- No. 10 on the list: Steep terrain (considered by the intersection group?) includes good subjects to focus on.
- In particular under No. 10 on the list: roadway profile and design through steep terrain at intersections and designing for pedestrians that have accessibility problems were subjects of interest.

Research Topic: Parking on Arterial Streets

Overview

There are two general types of on-street (i.e, curb) parking: parallel and angle. Angle parking allows more parking per linear foot of curb then does parallel parking. Some advocate allowing on-street parking along arterial streets as a way to create a barrier between moving traffic and pedestrians, therefore improving the walking environment, and to calm traffic. Since it may allow more customers to park closer to their destinations, on-street parking (especially angle parking) is also felt to improve the business environment for abutting properties. Others oppose on-street parking on the grounds that it contributes to crashes and impedes traffic flow.

Summary and Recommendations

1. Proposed research: Guidelines for when the implementation of parking is not expected to cause safety and operations problems.
2. Proposed research: Pedestrian and bicyclist impacts of on-street parking? Angled versus parallel differences?
3. Proposed research: How much do bulbed crossings and parking on both sides shorten the crossing and improve or decrease safety/operations (i.e., pedestrians, bikes, and vehicles)?
4. Proposed research: What are the impacts of back-in parking? Completion of a definitive study on the safety and operational impacts for parallel and angle parking (with the addition of back-in designs). Also consider accessibility issues with respect to different on-street parking designs.
5. Proposed research: Is there, or should there be, work done on the need for a parking buffer (this is the area between through traffic and cars parked in angled spaces)? Would the addition of a particular width change the operational and safety impacts of angled parking maneuvers? What are the impacts of flatter angles on parking impacts (less then 45 degrees)?

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