Technical Report Documentation Page

1. Report No. FHWA/TX-03/4365-1	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle ISSUES TO CONSIDER IN DEVELOPING AN *INTERSECTION DESIGN GUIDE*		5. Report Date September 2002 6. Performing Organization Code	
7. Author(s) Kay Fitzpatrick, Angelia H. Parham, and Mark D. Wooldridge		8. Performing Organization Report No. Report 4365-1	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project No. 0-4365	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin Texas 78763-5080		13. Type of Report and Period Covered Research: September 2001-August 2002 14. Sponsoring Agency Code	

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Project Title: Urban Intersection Design Guidance

16. Abstract

The safe and efficient operation of an intersection is directly related to its design. For example, when signal heads or signs are poorly placed, motorists can make decisions that cause the traffic to proceed slower than optimal and, in worse cases, cause crashes. Decisions made during the design of an intersection occur after examining a series of tradeoffs. A document is needed that discusses all related geometric and operational issues involved in the design of an urban intersection. This document, to be called the *Intersection Design Guide*, would assist in producing an intersection design that results in accommodating motorists (including large trucks, where applicable) and other users (e.g., pedestrians and bicyclists) in a safe and efficient manner. At the conclusion of the project, the *Intersection Design Guide* is to be an online manual with appropriate connections to the Department's other online manuals.

17. Key Words Urban Intersections, Design Guidelines, Focus Groups, One-on-one Interviews		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 62	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ISSUES TO CONSIDER IN DEVELOPING AN *INTERSECTION DESIGN GUIDE*

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Report 4365-1
Project Number 0-4365
Research Project Title: Urban Intersection Design Guidance

Sponsored by the
Texas Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

September 2002

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. Kay Fitzpatrick, P.E. (TX-86762), Angelia H. Parham, P.E. (TX-87210), and Mark D. Wooldridge, P.E. (TX-65791) prepared the report. The engineer in charge of the project was Kay Fitzpatrick.

ACKNOWLEDGMENTS

The authors acknowledge the contributions of numerous persons who made the successful completion of this report possible.

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The research reported herein was performed by the Texas Transportation Institute as part of a study entitled “Urban Intersection Design Guidance” and was sponsored by the Texas Department of Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

BACKGROUND

The safe and efficient operation of an intersection is directly related to its design, and decisions made during the design of an intersection occur after examining a series of tradeoffs. The resources available to designers can limit effective intersection design. The wealth of information published in the past 10 years demonstrates that there are several new ideas on how to better design intersections. Unfortunately, if these ideas are not readily available or included in the reference materials used by designers, they will not become generally accepted or used.

PROBLEM STATEMENT

The prime objective of TxDOT Research Project 4365 is to produce a reference document that provides information on each of the design elements associated with an intersection and discusses related geometric and operational issues involved in urban intersection design. This research is designed to provide TxDOT and other interested parties with useful and practical information on operations and design for intersections.

Guidelines and good examples of intersection design will be housed in one document called the *Intersection Design Guide*. The *Guide* will include discussion on elements associated with intersections along with overviews of issues, potential alternatives, presentation of tradeoffs, and examples. Researchers completed an initial draft of the *Guide* in late 2002 and have submitted it to the TxDOT Project Advisory Committee (PAC) for review.

In its final form, the reference document will be a comprehensive online document. The intent is to have the final *Guide* available on the TxDOT web site as an online manual to facilitate use by TxDOT personnel and by designers at cities or consulting firms. The manual will have links to other TxDOT manuals and perhaps other web sites that could help direct a user to additional references.

PROJECT TASKS

The project is a three-year effort and is structured into two phases. The first phase (Phase I) took place during the initial 12 months of the project, and this report documents activities for Year One. During the first phase, researchers focused on gaining an understanding of the myriad of transportation-related issues associated with intersections through one-on-one interviews, focus groups, and a review of current information regarding intersections. The research team produced technical memorandums that summarized this information. The research team also developed a draft of the *Guide* by transforming the information gathered from the state-of-the-art and state-of-the-practice reviews into a document that can be used to design intersections. The second phase of the project will include identifying good examples for the design and operation of intersections, developing refinement of the guidelines, and conducting field studies (as selected by the Project Advisory Committee). This work will occur during the second and third years of the project.

The prime objective for this project is to produce a comprehensive document on intersection design. Additional objectives within this research project include:

- Convene a Project Advisory Committee (PAC) to help guide and direct the research.
- Hold at least one project meeting per year to gather the researchers, project director, and Project Advisory Committee together.
- Identify current methods and resources used by TxDOT, cities, and consulting engineers for designing intersections.
- Identify current plan review practices used by TxDOT and cities.
- Document good and inadequate examples of intersection designs. Develop examples that could be used within the guide.
- Develop draft guidelines for intersection design for review by the PAC during the first phase of the project.

- Identify gaps in the knowledge for designing various elements associated with an intersection.
- Conduct field studies on the identified gaps during later years of the project.
- Refine the draft guidelines based upon the reviews provided by members of the PAC and findings from the field studies.
- Produce the final set of guidelines as an online manual, with appropriate connections to other online manuals.
- Document significant project findings and recommendations so they are understandable and useful.
- Develop other materials, as directed by the Project Advisory Committee, to improve use of the project findings (e.g., web page, CD-ROM, training materials, etc.).

PROJECT ADVISORY COMMITTEE

The first task was to establish a Project Advisory Committee. Invitations to serve on the PAC were distributed to key stakeholders based on input from the TxDOT project director and program coordinator. Table 1 lists the members of the PAC for this project. This group is to meet at decision points throughout the project to provide guidance and direction to the research project. Researchers met with the PAC within the project's initial months to discuss the objectives and work plan, and to identify additional concerns that need to be addressed. A preliminary list of areas of concerns for intersections was provided, discussed during the meeting, and revised. The research team met with the PAC in the third quarter of the first year to review the findings from the interviews, focus groups, and the state-of-the-practice reviews. Based on the review and discussions held during the meeting, the research team refined the draft table of contents for the *Guide.*

Table 1. Members of the Project Advisory Committee.

Project Coordinator	Rick Collins, P.E.	TxDOT, Traffic Operations Division
Project Director	Elizabeth Hilton, P.E.	TxDOT, Design Division
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ORGANIZATION OF REPORT

This report is organized into the following chapters:

Chapter 1 (Introduction) presents background information and the objectives of the research effort.

Chapter 2 (Existing Resources) describes how information was gathered from the literature and state manuals to be used in the development of the *Urban Intersection Design Guide.*

Chapter 3 (Current Methods) presents the findings from focus groups and one-on-one interviews used to identify procedures used by practicing engineers when designing intersections.

Chapter 4 (Production of the *Intersection Design Guide*) presents the methodology being followed to develop the guidelines.

Chapter 5 (Potential Research) discusses several potential research areas that were identified during the first year of the project.

Chapter 6 (Summary) discusses the findings from the research effort.

CHAPTER 2

EXISTING RESOURCES

LITERATURE REVIEW

Several research studies have examined various elements of intersection design. Table 2 lists the papers or research reports that have already been examined by members of the research team as part of an National Cooperative Highway Research Program (NCHRP) Synthesis effort that concluded in 2001 (*1*). The list in Table 2 reflects work that was published during the 1990s. A summary of the major areas within intersection design that were explored during the 1990s are:

- alternative intersection designs (roundabouts, conversion of major conventional cross intersection into two smaller signalized intersections, median U-turn design, bowtie, paired intersections, jughandle, continuous flow, continuous green T, quadrant roadway intersection, super street design, grade-separated intersections, flyover, echelon interchange),
- median widths at intersections,
- driveway vertical curves,
- intersection sight distance,
- corner clearances,
- methods to determine if a left-turn lane should be used,
- length of the turn lane,
- guidelines for offsetting opposing left-turn lanes,
- triple left-turn lanes,
- right-turn lanes,
- large trucks,
- older drivers,
- pedestrians,
- crash models, and
- accident mitigation.

Table 2. Intersection-Related References Reviewed as Part of NCHRP Synthesis on *Recent Geometric Design Research.*

· Federal Highway Administration. *Roundabouts: An Informational Guide*. A report of the Federal Highway Administration, Report No. FHWA-RD-00-067, Washington, D.C. (2000). · Jacquemart, G. "Modern Roundabout Practice in the United States," Synthesis of Highway Practice 264. National Cooperative Highway Research Program, Washington, D.C. (1998). · Bared, J.G., W. Prosser, and C.T. Esse. "State-of-the-Art Design of Roundabouts," *Transportation Research Record 1579*, Transportation Research Board, Washington, D.C. (1997). · Maryland Department of Transportation. *Roundabout Design Guidelines*. A report of the Maryland Department of Transportation, Hanover (1995). · Florida Department of Transportation. *Florida Roundabout Guide.* A report of the Florida Department of Transportation, Tallahassee (March 1996).
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· Tipaldo, J. "A Discussion of Corner Sight Distance Requirements at Stop-Controlled Intersections within New York City," Transportation Research Board, Third International Symposium on Intersections without Traffic Signals, (1997). · Eck, R.W., and S.W. Kany "Roadway Design Standards to Accommodate Low-Clearance Vehicles," *Transportation Research Record 1356*, Transportation Research Board, Washington, D.C. (1992). · Harwood, D.W., J.M. Mason Jr., R.E. Brydia, and M.T. Pietrucha "Intersection Sight Distance," *NCHRP Report 383*, Transportation Research Board, Washington, D.C. (1996). · Gluck, J., H.S. Levinson, and V. Stover. Transportation Research Board. Impacts of Access Management Techniques. NCHRP 420. A report for the Transportation Research Board, Washington, D.C. (1999). · Pline, J.L. "Left-Turn Treatments at Intersections," *NCHRP Synthesis of Highway Practice 225*, Transportation Research Board, Washington, D.C. (1996).

Table 2. Intersection-Related References Reviewed as Part of NCHRP Synthesis on *Recent Geometric Design Research* (continued).

· Harmelink, M.D. “Volume Warrants for Left-Turn Storage Lanes at Unsignalized Grade Intersections,” *Highway Research Record 221*, Highway Research Board, Washington, D.C. (1967). · “Guidelines for Left-Turn Lanes,” 1991 ITE Committee 4A-22. · Idaho Transportation Department, *Traffic Manual*, A report of the Idaho Transportation Department, Section 12-454, Highway Approaches, (August 1994). · Modur, S., R.B. Machemehl, and C.E. Lee “Criteria for the Selection of a Left-Turn Median Design,” University of Texas, Austin, Research Report 1138-1F (January 1990). · Koepke, J. “Guidelines for Turn Lanes on Two-Lane Roadways,” First National Access Management, (1994).
· Transportation Research Board. *Highway Capacity Manual Special Report 209*. A report of the Transportation Research Board, Washington, D.C. (1985). · Federal Highway Administration. *Guidelines for Signalized Left-Turn Treatments*, FHWA-IP-81-4 A report of the Federal Highway Administration, Washington, D.C. (1981). · National Cooperative Highway Program Research Report 348. *Access Management Guidelines for Activity Centers*. Washington D.C. (1992). · AASHTO. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D.C. (1990). · Highway Access Regulation Ordinance, Lake County, Illinois. (1988).
· Colorado Department of Transportation, *State Highway Access Code*, A report of the Colorado Department of Transportation. (1985). · “Design Criteria for Left-Turn Channelization,” 1981 ITE Committee 5-S. · Transportation Quarterly, *Warrants for Left-Turn Lanes*, Volume 37, Eno Foundation, (1983). · Hawley, P.E., and V.G. Stover “Guidelines for Left-turn bays at Unsignalized Access Locations,” Second National Access Management Conference, (1996). · Kickuchi, S., P. Chakroborty, and K. Vukadinovic “Lengths of Left-Turn Lanes at Signalized Intersections,” *Transportation Research Record 1385*, Transportation Research Board, Washington, D.C. (1993).
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Table 2. Intersection-Related References Reviewed as Part of NCHRP Synthesis on *Recent Geometric Design Research* (continued).

· McCoy, P.T., J.A. Bonneson, S. Ataullah, and D.S. Eitel "Guidelines for Right-Turn Lanes on Urban Roadways," *Transportation Research Record 1445*, Transportation Research Board, Washington, D.C. (1994). · McCoy, P.T., and J.A. Bonneson "Volume Warrant for Free Right-Turn Lanes at Unsignalized Intersections on Rural Two-Lane Highways," *Transportation Research Record 1523*, Transportation Research Board, Washington, D.C. (1996). · Hasan, T., and R.W. Stokes "Guidelines for Right-Turn Treatments at Unsignalized Intersections and Driveways on Rural Highways," *Transportation Research Record 1579*, Transportation Research Board, Washington, D.C. (1997). · Mason, J.M. Jr., K. Fitzpatrick, D.W. Harwood, and J. True "Intersection Design Considerations to Accommodate Large Trucks," *Transportation Research Record 1385*, Washington, D.C. (1993).
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REVIEW OF STATE MANUALS

To have an understanding of current department of transportation (DOT) practices across the country, researchers conducted a search of each state's design manual via the Internet. Of the 50 states, only 21 had all or part of their design manuals online. Those states and their respective manuals are listed below:

- Arizona (Arizona Traffic Engineering Policies, Guides and Procedures; dated January 2000, revised May 2002) (*2*)
- California (Highway Design Manual; dated July 1, 1995, revised November 1, 2001) (*3*)
- Connecticut (Highway Design Manual; dated January 1999, revised December 2000) (*4*)
- Florida (Traffic Engineering Manual; dated March 1999, revised May 2002) (*5*)
- Florida (Pedestrian Planning and Design Handbook; dated April 1999) (*6*)

- Florida (Bicycle Facilities Planning and Design Handbook; dated July 1999, revised April 2000) (*7*)
- Idaho (ITD Design Guidelines and Standards; dated January 2001) (*8*)
- Iowa (Design Manual-English; dated September 1, 1995, reissued January 2002) (*9*)
- Louisiana (Bridge Design Metric Manual; revised February 2001) (*10*)
- Michigan (Road Design Manual; dated June 5, 1996, revised March 8, 2000) (*11*)
- Mississippi (Roadway Design Manual; dated January 2001) (*12*)
- Missouri (Project Development Manual; revised July 1, 2002) (*13*)
- New Jersey (Design Manual-Roadway, Metric Units; dated 2001) (*14*)
- New York (Design Manual; dated July 1972, last revised August 9, 2001) (*15*)
- North Carolina (Roadway Design Manual; dated January 2, 2002) (*16*)
- Ohio (Roadway Design Manual; dated December 1992, revised August 19, 2002) (*17*)
- Oregon (Bicycle and Pedestrian Plan; dated June 14, 1995) (*18*)
- South Dakota (Road Design Manual; dated March 14, 2002) (*19*)
- Texas (Roadway Design Manual; revised April 2002) (*20*)
- Utah (Roadway Design-Manual of Instruction; dated July 1998, revised August 2000) (*21*)
- Vermont (State Design Standards; dated October 22, 1997) (*22*)
- Virginia (Road Design Manual; revised September 2001) (*23*)
- Washington (Design Manual-English Version; dated June 1999, revised February 2002) (*24*)

In addition, there were several key reference documents considered during the state-of-the-practice review. These documents included the following:

- American Association of State Highway and Transportation Officials (AASHTO) A Policy on Geometric Design of Highways and Streets (commonly known as the *Green Book*) (*25*)
- AASHTO, Guide for the Development of Bicycle Facilities (*26*)

- AASHTO, Draft Guide for the Planning, Design, and Operation of Pedestrian Facilities (*27*)
- AASHTO, Roadside Design Guide (*28*)
- Federal Highway Administration (FHWA), Older Driver Highway Design Handbook (*29*)
- FHWA, Designing Sidewalks and Trails for Access (*30*)
- FHWA, Pedestrian Facilities User Guide – Providing Safety and Mobility (*31*)
- FHWA, Roadway Delineation Practices Handbook (*32*)
- Institute of Transportation Engineers (ITE), Design and Safety of Pedestrian Facilities (*33*)
- ITE, Geometric Design and Operational Considerations for Trucks (*34*)
- ITE, Geometric Design Criteria for Highway-Rail Intersections (Grade Crossings) (*35*)
- ITE, Guidelines for Urban Major Street Design (*36*)
- ITE, Traffic Engineering Handbook (*37*)
- ITE, Traffic Signal Maintenance and Design Survey (*38*)
- ITE, Traffic Control Devices Handbook (*39*)
- ITE, Alternative Treatments for At-Grade Pedestrian Crossings (*40*)
- ITE, Traffic Calming: State of the Practice (*41*)
- ITE, Transportation and Land Development (*42*)
- MUTCD 2000 (*43*)
- NCHRP Synthesis 299, Recent Geometric Design Research for Improved Safety and Operations (*1*)
- NCHRP Report 279: Intersection Channelization Design Guide (*44*)
- NCHRP Synthesis 225: Left-Turn Treatments at Intersections (*45*)
- NCHRP Report 375: Median Intersection Design (*46*)
- Texas Transportation Institute (TTI), Design Guidelines for At-Grade Intersections Near Highway-Railroad Grade Crossings (*47*)
- TxDOT, *Sign Crew Field Book* (*48*)
- TxDOT, Landscape and Aesthetic Design Manual (*49*)
- TxDOT, Draft Access Management Manual (*50*)

- Transit Cooperative Research Program (TCRP), Report 19: Guidelines for the Location and Design of Bus Stops (*51*)
- U.S. Access Board, Building a True Community (*52*)

Researchers reviewed each state's manual for information that was relevant for inclusion in the manual. Following is a summary of the information by chapters.

Chapter 1 – Intersection Function

Regarding the functional class of an intersection, the manuals for the states of New York, South Dakota, and Utah referenced the AASHTO Green Book. None of the manuals contained information or discussions on issues such as how to determine intersection function, criteria for different functional classes, and right-of-way needs.

Chapter 2 – Design Control and Criteria

Several of the design control and criteria issues were discussed in other state manuals including:

- Dimensions of design vehicles (California, Connecticut, Idaho, and New Jersey provided some basic information; however, they refer the reader to the AASHTO Green Book for more complete coverage of the topic).
- Designing for older drivers (chapter six of the Florida Traffic Engineering Manual and the Older Driver Highway Design Handbook).
- Capacity at an intersection (New Jersey, Texas, and Connecticut).
- Pedestrian issues as related to intersections (California, Texas, and Vermont).
- Americans with Disabilities Act (ADA) (Connecticut provided a cross link).
- Bicycle issues at an intersection (California and Vermont).

Issues being considered for the Texas *Intersection Design Guide* that were not discussed in other state manuals include: traffic, access control, safety, aesthetics, type of control, and utilities.

Chapter 3 – Design Elements

Several of the design elements issues were discussed in other state manuals, including:

- Sight distance discussion (California, Connecticut, Mississippi, New Jersey, South Dakota, Washington, and briefly by Louisiana).
- Sight distance briefly discussed and then reference to the Green Book (Texas, Arizona, New York, North Carolina, and Utah).
- Horizontal alignment (Connecticut, Mississippi, Texas, Utah, Vermont, and Virginia).
- Turning radius (California, Connecticut, Mississippi, Missouri, New York, and Ohio).
- Angle of approach of the roadways at an intersection (California, Connecticut, New York, Ohio, and Washington).
- Vertical alignment of roadways at an intersection (Texas).

Chapter 4 – Cross Section

In general, the topics for the cross-section chapter were covered by a majority of the manuals, such as the following:

- Lane arrangement of roadways approaching an intersection (Connecticut, Louisiana, Missouri, New York, Ohio, and Washington).
- Left-turn and right-turn lanes (California, Connecticut, Mississippi, Missouri, New Jersey, New York, North Carolina, Ohio, Oregon, South Dakota, and Washington).
- Median design (California, Connecticut, Louisiana, Mississippi, Missouri, New Jersey, New York, North Carolina, Ohio, South Dakota, Utah, and Washington).
- Channelization and islands (California, Connecticut, Idaho, Mississippi, Missouri, New Jersey, New York, Ohio, South Dakota, Utah, and Washington).
- Bicycle facilities (California, Florida, Mississippi, and Utah).

- Shoulders (not covered significantly and only mentioned in the manuals of Louisiana, Mississippi, and Ohio).

Chapter 5 – Roadside

Material to be included in the roadside chapter was also discussed in the following state manuals:

- Sidewalks and pedestrian ramps (California, Louisiana, North Carolina, Texas, and Virginia).
- Horizontal clearance (Vermont and Virginia).

Information on landscaping, street fixtures, and furniture was not significantly covered by any of the manuals. Information regarding four sections was found in only one manual each:

- Pedestrian bulbs were covered in the North Carolina Roadway Design Manual.
- Guardrail was included in the Virginia Road Design Manual (although several state manuals referenced the AASHTO *Roadside Design Manual*).
- Bus stops were discussed in the New York manual.
- Illumination was presented in the New Jersey Roadway Design Manual.

Chapter 6 – Drainage

Drainage relating to intersections was not significantly covered by any manuals. It was discussed briefly by the California, Ohio, and Texas manuals.

Chapter 7 – Street Crossing

Several issues being considered are not addressed in other state manuals, including: refuge islands, detectable warnings (although more manuals will now include this given the recent ADA requirements), and suggestions on treatments at major street crossings, residential street crossings, signal control crossings, and school-related crossings.

The design of sidewalks and street transitions at an intersection was covered by Florida, Louisiana, Texas, and Virginia. Crosswalks were addressed by Florida and Oregon.

Chapter 8 – Signals

The majority of the state manuals referenced the *MUTCD* for information on signals. However, Florida, New Jersey, and the Pennsylvania Traffic Design Handbook (not an online document) covered several of the topics being considered for this chapter.

Chapter 9 – Markings

Material in other state manuals on topics being considered for the marking chapter mostly referenced the *MUTCD.* Only Florida and Utah mentioned longitudinal lane markings.

Chapter 10 – Signs

The design of signs at intersections was included only in the Florida *Traffic Engineering Manual* and the Texas *Sign Crew Field Book* (*48*).

Chapter 11 – Influences from Other Intersections

The spacing of intersections was covered in the manuals of Connecticut, Utah, and Washington. The location of driveways with respect to intersections was only mentioned by Connecticut, and midblock median treatments were addressed by the Florida *Pedestrian Planning and Design Handbook* (*6*). Highway-Railroad Grade Crossing was not covered by any of the state manuals; however, there is a recent ITE recommended practice on the topic (*35*).

CHAPTER 3

CURRENT METHODS

To gain an understanding of how intersection design is accomplished, the research team strongly believed that this project required interaction with intersection designers. This information will be used to develop more usable and effective guidelines, to better present insight into the decision-making process, and to discuss how tradeoffs are considered during the design process. Researchers used two methods to initiate this interaction: focus groups and one-on-one interviews.

Two focus groups were assembled to discuss key elements within intersection design, and one-on-one interviews were scheduled to provide additional information from personnel in large urban areas. The focus groups were tied to other events; the first focus group was held at the PAC project kickoff meeting, and the second focus group was held as a morning workshop as part of the Winter 2002 TexITE meeting in Irving. The researchers attempted to ensure that a suitable cross section of designers (e.g., TxDOT, city, consultants) and a range of experience levels were represented. Additional information on the focus groups is provided in the following section.

Researchers conducted seven small group interviews in the cities of Dallas, Carrollton, Amarillo, and San Antonio during October 2001, December 2001, and June 2002. The employees of four cities, three consulting firms, and TxDOT were represented in the meetings. The views of those 24 individuals have been consolidated and are summarized in a following section.

FOCUS GROUPS

Two focus groups were conducted to identify and evaluate current procedures used to design intersections. The primary objective of the focus groups was to obtain expert opinions on specific topics regarding the design of urban intersections. The researchers hoped that the use of the focus group method would stimulate new ideas and creative concepts that could be used to design intersections.

The first focus group was the PAC for project 4365, which was established to provide guidance and direction to the research project. The PAC's participation in the focus group was two-fold; first, the focus group was used to obtain the committee members' expert opinions on the proposed topics; second, the focus group served as a pilot focus group to provide suggestions of topics to be included in an upcoming focus group. The PAC focus group was held in conjunction with the project kick-off meeting on November 5, 2001, at the San Antonio TxDOT District Office. Table 3 lists information on the participants of the focus group.

Table 3. PAC Focus Group Demographics.

Professional Engineer	City	Employer
Yes	Austin	TxDOT
Yes	Austin	TxDOT
Yes	Beaumont	TxDOT
Yes	Fort Worth	TxDOT
Yes	Irving	City
Yes	San Antonio	TxDOT

The second focus group was held in Irving, Texas, on January 25, 2002, in conjunction with the winter meeting of the Texas Section of the Institute of Transportation Engineers (TexITE). Participants were recruited with a flyer that was included in the meeting registration materials. Ten individuals volunteered to participant in the focus group, and Table 4 lists information for those participants. It should be noted that the members of the focus group at TexITE deal with design on a day-to-day basis.

Table 4. TexITE Focus Group Demographics.

Professional Engineer	City	Employer	Years of Experience
Yes	Amarillo	City	> 20
Yes	Dallas	County	0 - 5
Yes	Dallas	County	> 20
Yes	Dallas	Consultant	5 - 10
Yes	Dallas	Consultant	> 20
Yes	Denton	City	> 20
Yes	Fort Worth	Consultant	> 20
Yes	Houston	City	15 - 20
Yes	Houston	Consultant	> 20
Yes	Irving	City	> 20

Following is a summary of the responses for both focus groups by topic area.

- **Do you have a checklist for designing intersections?**
  Most members of *both groups* indicated that they did not have a formal checklist. There were concerns about a checklist becoming too complicated. However, most indicated that they would use one if one were available.

- **What software do you use when designing an intersection?**
  Both groups used MicroStation, Geopak, IGIDS, AASHTO Truck Turning Model, and HCS. Members of the *TexITE group* also used the TEXAS model, Auto Turn, NetSimm or CorSim, Eagle Point, and AutoCAD.

- **What reference materials do you use when designing an intersection?**
  Both groups mentioned the AASHTO *Green Book*, TxDOT *Design Manual*, *Highway Capacity Manual*, the *MUTCD*, and local requirements. One PAC member also uses the *Pavement Design Manual*.

- **What are the three major issues considered when designing an intersection?**
  There was generally agreement *within each group* on the following issues:
  - PAC: sight distance, ADA, going beyond the intersection, and utilities.
  - TexITE group: type of intersection, right-of-way (ROW), traffic volumes, and ADA/pedestrian compliance.

- **How does a new design differ from a re-design of an intersection?**
  Members in *both groups* agreed on the following issues: right-of-way, accommodating established patterns, and a re-design is a much bigger project.

- **What type of field studies do you conduct for an intersection re-design?**
  Responses from the two groups varied as follows:
  - PAC: surveys, accident studies, utility locations, topographic, and traffic counts.
  - TexITE group: pedestrian counts, traffic counts, bicycle counts and needs, speed data, and on-site observations.

- **What are the differences in designing intersections with arterials or local streets?**
  Responses varied widely between the two groups. The only common answers were utilities and traffic.

- **What additional information (to be included in the Design Guide) would make designing an intersection easier?**
  Members in *both groups* wanted to include: examples and documentation from the past, having all the information in one place, and visual aids. Other answers varied.

- **What type of format would you prefer for an intersection design guide?**
  Most of the participants agreed on a format with lots of pictures, examples, and a checklist. A checklist would include a site inspection. Many contractors do not always do a thorough review of things like the utilities and sometimes look only at the surface. The PAC also mentioned CD format, booklet form similar to MUTCD, decision trees, and the ITE Signal Design format.

INTERVIEWS

Researchers interviewed engineers and designers regarding the design of urban intersections. Although the engineers and designers were provided with a list of topic areas and typical questions prior to the interviews (see Tables 5 and 6), the discussion took the form of freeranging discussions of issues related to the design of urban intersections. Researchers used the list of topic areas to ensure that the coverage of issues was reasonably complete.

Table 5. Potential Questions for One-On-One Interviews.

POTENTIAL QUESTIONS

FOR ONE-ON-ONE INTERVIEWS

- Please show us a recent intersection design. We would like to discuss:
  - overview of the design,
  - some of the specific criteria you followed, and
  - limitations/challenges you had to consider in the design (e.g., location of a driveway, high percent of trucks, etc.).
- What are the major issues you believe engineers face in designing an intersection?
- What reference materials do you use in designing an intersection?
- In what areas could you use additional guidance?
- Do you have a checklist for designing intersections?
- What features would you always add to an intersection design if you could?
- What are some of the differences between a new design and a reconstruction?
- What are key differences in designing an intersection of local streets and an intersection of arterials?
- What software do you use when designing an intersection?

Please comment on the items listed in Table 6.

Table 6. List of Areas of Concern within Intersection Design.

<table>
<tr>
<td>Near Intersection
• When should another intersection’s design or operation affect the design or operation of the subject intersection? How should it be treated?
• When should a neighboring railroad-highway grade crossing affect the design or operation of the subject intersection? How should it be treated?
• How to handle overlapping features (e.g., turn bays) or queue of cars?
• Interconnection with other signals
• Utilities
• Drainage
  o type of storm drains
  o relationship of drains to curb return
  o cross grades to prevent “bird baths”

At Intersection
• Type of intersection
• Angle
• Grade
• Horizontal curve
• Distance to driveways
• Clear zones
• Sidewalks and pedestrian ramps
• Landscaping
• Sight distance
• Lighting
• ROW needs for mast arm placement
• Pedestrian facilities

Users (other than trucks)
• Large trucks
• Buses
• Pedestrians
• Bicycles
• ADA</td>
<td>Approach
• Lane arrangement
• Turn bays (right or left)
  o Offset left-turn bays
  o Length
  o Deceleration into bay
  o Approach taper
  o Multiple lanes
• Turning radius
• Medians
  o nose design
  o location of nose
• Pedestrian refuge
• Bulbs
• Channelization
• Storage on through lanes
• Signs
  o Size
  o Height of sign
  o Height of letters on sign
  o Self illumination
  o Street names
• Markings
  o Crosswalks
  o Stop lines

Signals
• Location of controller cabinet
• Mast arm/span wire
• Signal head
• Footings
• Pedestrian signal and buttons
• Interconnection with other signals
• Hardware
• Detectors</td>
</tr>
</table>

Design Issues

A wide variety of issues were raised in the discussions. Issues that received repeated interest among the engineers and designers interviewed included:

- Pedestrian issues: curb cuts, crosswalks, and protrusions, as noted in Table 7.
- Drainage: ponding and flow across the intersection, as noted in Table 8.
- ROW: conflicting or unknown locations for utilities, utility access, utilities clearance, obtaining ROW, establishing requirements, and customary practice, as discussed in Table 9.
- Traffic control device issues: wide medians, islands and pedestrians, mast arm length, number of signal heads, internally illuminated street signs, protected/permissive operations, marked crosswalks, illumination, and use of span wire, as discussed in Table 10.
- Intersection layout: dual lefts, turn bays, turn priorities, bicycles, sight distance, skew angle, traffic counts, cost estimates, driveways, pavement design, and acceleration lanes, as noted in Table 11.

Table 7. Pedestrian Issues.

Issue	Description
Curb cuts	Large radius turns may present a problem with curb cuts because they may be pulled back from the intersection too far to match up with the stop lines.
	Conduits for loop detectors are often broken during curb cut installation.
	Conflicts with drainage requirements for curb inlets and curb return.
	Conflicts with controller cabinets, signal poles, etc.
Crosswalk	Conflict with stop bar location. Vehicles stop past crosswalks and block the crosswalk if the crosswalk is placed at the start of the radius.
Protrusions	Protrusions beyond maximum 4 inches are present at many locations.

Table 8. Drainage Issues.

Issue	Description
Ponding	Contours are typically not included in the plans (or used if included).
	Grades should be reviewed to see if the potential for ponding is present. Slopes should be reviewed to determine whether they are too steep in any direction.
Flow across the intersection	Drainage across an intersection may present problems with safety and traffic capacity.
	Using gutter drains that extend across the intersection may present problems in some cases, requiring special attention, even at minor stop-controlled intersections.

Table 9. ROW Issues.

Issue	Description
Conflicting or unknown locations for utilities	This is an issue in most areas because ROW is limited, and locations are unknown or not precisely known. Contractors frequently find utilities when installing traffic signals and then move pole locations, leading to problems.
Utility access	Manhole placement recommendations are lacking.
Utilities clearance	Practicality may prevent some utilities from being moved (i.e., no reasonable alternative), or the utilities may not be cleared in a timely manner.
Obtaining ROW	It is difficult to obtain additional ROW, especially when convenience stores are at the intersection (frequent).
Establishing requirements	The amount of ROW required is difficult to determine in view of ADA, intersection sight distance (ISD), etc.
Customary practice	The amount of ROW typically required at an intersection may not be sufficient for future needs.

Table 10. Traffic Control Device Issues.

Issue	Description
Wide medians	On roadways with wide medians, motorists turn left and see another signal, sometimes stopping inappropriately. Pedestrian storage can be a problem on roadways with offset turns.
Islands and pedestrians	Pedestrians have trouble getting to islands with pedestrian buttons if they have to cross right-turn slip lanes.
Mast arm length	Multilane arterial-arterial intersections (especially six-lane arterials) may require excessively long mast arms and instead dictate nearside head placement. The maximum length is 45 ft, but some failures have been reported at that length. They may exhibit oscillation or droop. If 4 ft or greater medians are not present, the lack of pedestrian refuge may present a problem for signal timings on wide arterials.
Number of signal heads	The cost of signal head placement is very high, leading to a reduction in the minimum number of heads. They are centered over lane lines and use a minimum of two heads per direction.
Internally illuminated street signs	These are viewed as a maintenance and cost concern.
Protected/ permissive operations	Permissive operations may be a problem if a clear line of sight is obstructed by a grade change or a horizontal curve is present.
Marked crosswalks	It is unclear regarding when marked crosswalks should be used with signals. Some small cities do not want crosswalks because of maintenance.
Illumination	High volume intersection illumination designs are lacking.
Use of span wire	This may sag and be hit by trucks. Dallas has a design intended to minimize movement.

Table 11. Intersection Layout Issues.

Issue	Description
Dual lefts	These are disliked by some as an operational and safety problem.
	They provide operational efficiency, reducing required phase lengths.
Turn bays	If not provided, the mix of through and left-turn traffic may slow movement or block the intersection.
Turn priorities	Left-turn lanes are generally preferred over right-turn lanes if a tradeoff must be made.
Bicycles	Bicycle lane treatments are not clear.
Sight distance	Fencing may obstruct sight distance, requiring a corner clip or additional offset from the roadway.
Skew angle	If the intersection is skewed somewhat, drawbacks are present, but their extent is uncertain.
	It is unclear how much tangent is required if the skew is eliminated through use of an upstream horizontal curve.
Traffic counts	Detailed turning movement counts are needed. TxDOT projected counts are very imprecise and must be redone locally by hand.
Cost estimates	These are typically too low in preliminary planning, leading to problems with plans, specifications, and estimates (PS&E) development.
Driveways	It is difficult to move away from the corner when convenience stores are present. We need better "tools" to prevent them from being located so close to intersections.
Pavement design	If a composite design (i.e., concrete in intersection and asphaltic concrete pavement (ACP) on roadway) is used, desirable limits for the heavier design are unclear.
Acceleration lanes	These are generally not used by drivers.

Local Practices

Local practices discussed also included a variety of areas (see Tables 12 through 14). Significant areas included:

- Pedestrians: sidewalks, sidewalk width, sidewalk installation, curb cuts, and curb cuts on islands, as noted in Table 12.
- Intersection layout: curb radius, design vehicle, drainage profile through intersection grade lines, driveway restrictions, intersection sight distance, curb usage on islands, islands, driveways, work on city ROW, standard cross section, turn bay length, median end nose setback, raised medians, median width, pavement design, lane width related to bicycle route, dual left lanes, and lane width, as noted in Table 13.

- Traffic control devices: video detectors, use of directed illumination, illumination at stop-controlled intersections, markings at crosswalks, markings for lane line extensions through an intersection, markings for median nose delineation, signal cabinet location, signal detectors on bicycle route, island size to accommodate signals, pedestrian signal heads, pedestrian push button, pedestrian walking speed, signal pole location, protected left phasing, strobe warning in red, and turn bay storage, as noted in Table 14.

Some of the practices were substantially different depending on the area and respondent. Dual left turns were described as the typical design treatment at major roadway-major roadway intersections in Dallas, while they were purposefully avoided in Amarillo. Contrasts in design goals appeared to be a reason for the disparity; capacity was the concern in Dallas, while driver familiarity and design consistency was the concern in Amarillo.   Another variation was in the area of pedestrian clearance intervals. Some jurisdictions reported substantial efforts to customize clearance intervals by timing pedestrian crossings and providing special phase extensions, while others provided generous “generic” clearance intervals at all major intersections.

Table 12. Local Practices: Pedestrians.

Practice	Description
Sidewalk: width	Dependent on proximity to curb: 4 ft width with 4 ft recess 5 ft width if adjacent to curb
Sidewalk: installation	Installed by petition or when new roadways are constructed (city practice)
Sidewalks	Install on all major roadways except in industrial areas
Curb cuts	Installed even in locations where only signal upgrades are being installed
Curb cuts on islands	Ramp to top of island to avoid debris problems in depressed paths

Table 13. Local Practices: Intersection Layout.

Practice	Description
Curb Radius	Three lanes on roadway turning to: 30 ft Two lanes on roadway turning to: 40 ft Substantial truck traffic: 40 ft ALT: 50 ft
Design vehicle	WB50 on right turns (able to turn, not necessarily stay within lane lines) WB50 on outside turn lane only of dual lefts
Drainage profile through intersection grade lines	Minor road crossings should be based on valley gutters across the minor approach. Major road crossings should warp to "table" to facilitate through movements at speed.
Driveway restrictions	Minimum 150 ft from corner at arterial-arterial intersection
Intersection sight distance	Obtain clearance now for the ultimate intersection design (i.e., corner radius and lanes).
Curb usage on islands	Six inch mountable curbs should be used; offset 1-2 ft from lane
Islands: type	Raised islands are typically not provided unless the intersection is signalized. This prevents unnecessary impacts and accidents.
Driveways	Policy restricts corner lots to 150 ft of frontage to ensure that driveways can be offset from the intersection. Even if two driveways are used, the second can be placed an adequate distance away from the intersection.
Work on city ROW	"Right to Access" agreements are routinely obtained where necessary to work off the ROW.
Standard cross section	Major arterials have six lanes and are divided.
Turn bay length	Desirable: 1 ft/vph, but they may be only as long as practical.
Median end nose setback	For dual left turns, space nose 20-25 ft back from curb line. For single left turns, space nose 16 ft back from curb line. At skewed intersections, pull the nose back further, and check with turning templates. ALT: 15-20 ft back from curb line.
Raised medians	Approximately 100 ft of raised median is typically used at major intersections to prevent turns across the median in the area close to the intersection.
Median width	Minimum 4 ft used
Pavement design	Use the deeper section of the two intersecting roadways for the area of the intersection.
Lane width: bicycle route	Use 14 ft outside lane width.
Dual left lanes	Dual lefts should be provided at all major arterial-major arterial intersections to facilitate future growth. Prevents expensive, disruptive widening in the future. ALT: Base on turning volume, storage lengths, and opposing volumes.
Lane width	Increased width is provided on the outside lane in many instances to allow sharing with bicyclists (wide curb lane).

Table 14. Local Practices: Traffic Control Devices.

Practice	Description
Video detectors	It is easier to install when bridges or RR grade crossings prevent the installation of loop detectors.
Use of directed illumination	Use directed illumination to orient light downward and reduce light scatter and pollution.
Illumination at stop-controlled intersections	Streetlights should be placed diametrically opposite the stop signs to prevent conflicts in pole location.
Markings at crosswalks	To avoid excessive wear, use zebra strips that miss the wheel paths.
Markings for lane line extensions through intersections	Usage is recommended if lanes are offset and a crest vertical curve prevents a clear view across the intersection.
Markings for median nose delineation	Raised pavement markers are used to delineate median noses.
Signal cabinet location	Technicians must be able to see the intersection from the cabinet when they have the door open and are working in it. If placed too closely, base mounts may be used. Place as far from roadway as possible.
Signal detectors on bicycle route	Use quadrapole detectors and a special loop that detects bicycles.
Island size to accommodate signals	75 ft typically provides acceptable area to install a traffic signal on a raised island. ALT: 75 ft may not be large enough for three ramps and a pole.
Pedestrian signal heads	In locations with wide medians having sufficient storage space (much greater than the minimum 4 ft), install pedestrian heads in the median. Pedestrian heads are installed everywhere signals are put in as a value engineering recommendation, given their long life (est. at 50 years).
Pedestrian push button	In some locations, pedestrian buttons are installed that provide a longer crossing interval and audible warning (i.e., locations with significant handicapped population). Mixed response from public because they are only provided in certain locations. An audible message (chirp) is provided at requested locations.
Pedestrian walking speed	In problem locations, pedestrian speeds are sometimes checked in the field to set signal timing plans.
Signal pole location	Utilities are frequently discovered during pole foundation installation. Specifying maximum length mast-arms and then cutting them to fit was found to be a better solution than having to wait on an order that was placed once the exact location for the base was determined.
	No poles in medians to prevent accident impacts.
Protected left phasing	Use protected left turns only with high-speed approach traffic on boulevards.
Strobe warning in red	Where drivers may not be expecting the presence of a signal, strobe lights have been installed in the red lamp of the signal.
Turn bay storage	If protected-only phasing is used, turn bays may have to be lengthened to provide needed storage.

Software and References

Software and references were generally as expected. Key references were the AASHTO *Green Book* and TxDOT's *Roadway Design Manual.* Basic Computer Aided Design (CAD) software packages discussed in the meetings are listed in Table 15.

Table 15. Software and References.

Name	Use and Description
Software	
AutoCAD software	Commercial CAD package
AutoTurn software	Used to set turning radii and check clearances. Problem with dual lefts and trucks: uses truck in both lanes (unrealistic)
Geopak software	Design package used with CAD software
MicroStation software	Commercial CAD package, used by TxDOT
TRF 6 software	Turning count software described at Amarillo District
References	
MUTCD	Traffic control device design and placement
Pavement Design Manual	City of Dallas pavement design manual, includes typical intersection geometric layouts
ITE Signal Design	Traffic signal design

MAJOR ISSUES

The major issues found in the focus groups and interviews covered various aspects of design, construction, and operations. These issues were widely held to be concerns for both designers and engineers developing urban intersection designs. The findings from the focus groups and interviews will be used to refine the outline for the *Guide*. Key issues are presented in Table 16 and are discussed below:

- Compliance with ADA requirements and the conflict between those requirements and other design elements were concerns of many of the engineers and designers contacted. Designers reported conflicts between the desirable locations for pedestrian crosswalks (and attendant ramps) and signal poles, curb inlets, controller cabinets, etc. This is indicative of the generally restricted amount of room available in the immediate area of urban intersections.

Table 16. Examples of Major Issues.

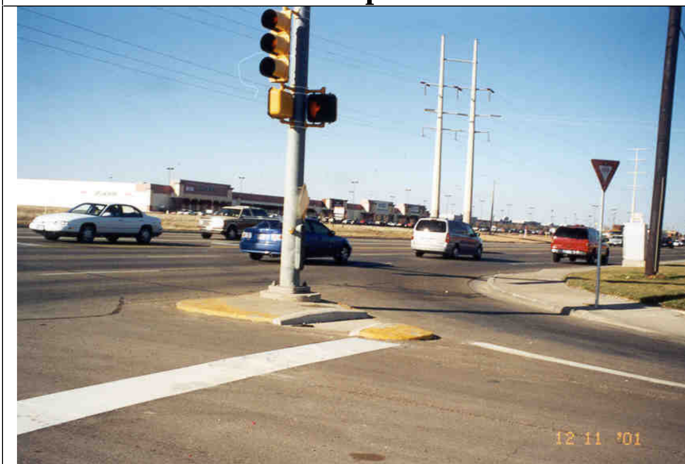
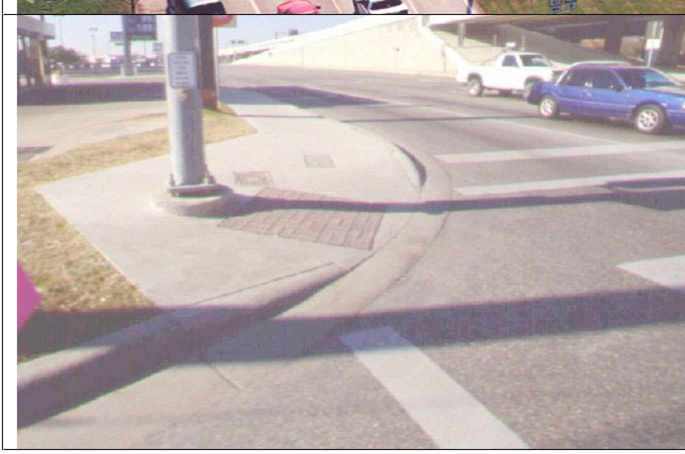
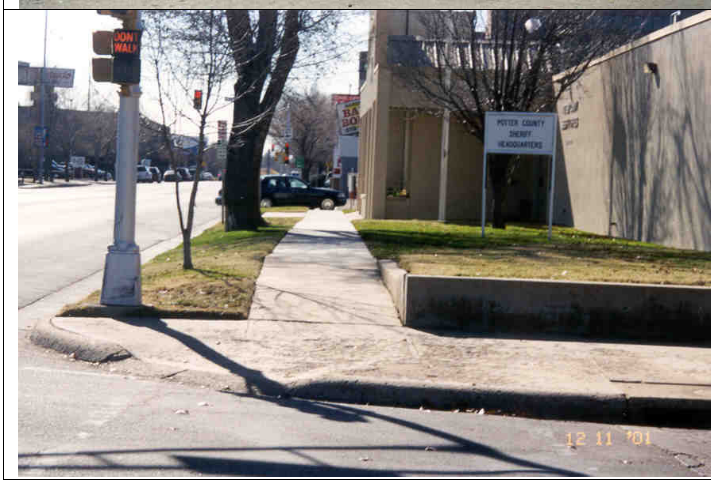
Example	Issue
	**Signals: hardware placement, pedestrian ramps and crossings, right-turn lanes, signal head locations, design of islands, etc.**
	**Design: median design, appropriate sight distance, left-turn bay designs, curb returns, driveway design, distance to railroad tracks, etc.**
	**ADA: conflicts between curb ramps and other roadway features, etc.**

Table 16. Examples of Major Issues (continued).

Example	Issue
	**Drainage: how to keep curb ramps clean and water (mud) from collecting at the bottom, and how best to drain water near an intersection**
	**ROW: determination of and obtaining adequate ROW at intersections (What if you need to widen the roadway?)**

- The availability of ROW to accommodate urban intersection requirements was another issue that concerned many of those contacted. Conflicts with existing utilities found during construction were commonly cited as a concern in the placement of traffic signal poles. Difficulty in obtaining sufficient ROW and satisfying future needs at intersections was also a major concern.

- Respondents cited traffic control devices as concerns, with wide-ranging issues related to their selection, placement, and operation being reported. Interactions with intersection layout together with concerns about traffic signal operations were frequently cited.

- Intersection layout issues also received a considerable amount of discussion. Satisfying drainage and cross-section requirements were found to be problematic. The use of turn lanes was a particular concern for urban intersections, with a variety of operational and design practices discussed.

CHAPTER 4

PRODUCTION OF THE *INTERSECTION DESIGN GUIDE*

OUTLINE

Researchers used reviews of recent publications along with engineering judgment to generate the first cut of the *Intersection Design Guide* outline. Revisions were made to this version based on findings from the focus groups and the one-on-one interviews (see Chapter 3). The PAC members received a draft outline prior to a meeting with the project advisory committee. Discussion on the chapters and the individual sections was held during the meeting. The draft outline was then refined based upon the discussion and comments. Following the meeting, the research team began to generate material for inclusion in the *Guide*. Additional refinements to the outline occurred during the development of the material. Table 17 lists the current draft outline for the *Guide*.

STATUS

A preliminary draft for each chapter within the *Guide* was developed within the first year of the project. These draft chapters were provided to the project advisory committee members for their review. As the chapters were being developed, needed changes in the outline became apparent. In some cases, material that was originally prepared for one chapter would fit better in another chapter. For example, curb extensions were originally discussed in a short subsection of the street crossing chapter. It was later moved to a section in the roadside chapter. In other cases, new sections needed to be added to the manual. An example of a section added was the Highway-Railroad Grade Crossing section in the Near Intersection chapter. Several additional changes are envisioned for the document as the result of additional investigation into issues related to intersection design and the PAC review.

The major emphasis of Year Two for the project is to develop examples and schematics for inclusion in the *Guide*. Researchers will also take pictures of intersections to illustrate various points made in the *Guide*. The examples are to include information on "how could this situation be improved" and to document "good, bad, and ugly" examples and situations. Researchers also expect that the development of the examples will result in additional changes to the *Guide's* content.

Table 17. Current Draft Outline for the *Guide.*

Chapters	Sections
1: Intersection Function	1 – Intersection Design 2 – Types of Intersections 3 – Right-of-Way Needs 4 – Future Expansion Needs
2: Design Control and Criteria	1 – Users 2 – Driver Performance 3 – Intersection Characteristics
3: Design Elements	1 – Sight Distance 2 – Horizontal Alignment 3 – Turning Radius 4 – Angle 5 – Vertical Alignment
4: Cross Section	1 – Through Lanes 2 – Left-Turn Lanes 3 – Right-Turn Lanes 4 – Median Design 5 – Channelization 6 – Islands 7 – Bicycle Facilities 8 – Shoulders
5: Roadside	1 – Sidewalks 2 – Roadside Clearance 3 – Landscaping 4 – Pedestrian Bulbs 5 – Bus Stops 6 – Street Furniture and Fixtures 7 – Illumination
6: Drainage	1 – Drainage Objectives 2 – Cross Slopes 3 – Profile 4 – Curb and Gutter 5 – Ditches 6 – Relationship to Pedestrian Facilities

Table 17. Current Draft Outline for the *Guide* (continued).

Chapters	Sections
7: Street Crossing	1 – Sidewalk/Street Transitions 2 – Crosswalks 3 – Refuge Island
	4 – Detectable Warnings 5 – Major Street Crossings at Uncontrolled Locations 6 – Residential Street Crossings 7 – Signal Control Crossings for Pedestrians 8 – Signalized Intersections 9 – School-Related Crossings
8: Signals	1 – Heads 2 – Direction/Screening 3 – Signal Support System 4 – Overhead Mounting Types 5 – Mast-Arm Mountings 6 – Signal Cabinet Placement 7 – Pedestrian Signals 8 – Interconnection 9 – Detectors 10 – Right Turn on Red
9: Markings	1 – General 2 – Longitudinal Pavement Markings 3 – Raised Pavement Markers 4 – Stop and Yield Lines 5 – Word and Other Symbol Markings 6 – Crosswalks 7 – Parking Space and Curb Markings 8 – Examples
10: Signs	1 – General 2 – Signing for Older Drivers 3 – Street Name Signs 4 – Pedestrian Signs 5 – Regulatory Signs for Intersections 6 – Warning Signs 7 – Guide Signs 8 – Typical Applications
11: Influences from Other Intersections	1 – Nearby Intersections 2 – Highway-Railroad Grade Crossing 3 – Driveways 4 – Midblock Median Treatment

CHAPTER 5

POTENTIAL RESEARCH

During the initial year of this project, the research team identified several potential research areas. These issues are discussed in the following sections.

STOP BAR AND MEDIAN NOSE PLACEMENT

The operational characteristics of intersections on roadways with medians depend greatly on the design and location of the intersection stop bars and median nose. The design of those elements is affected by vehicle characteristics, turning speed, skew angle, and the width of the intersecting roadways. If defined inappropriately, delay may be increased at the intersection through increased lost time, turning vehicles may not be able to follow the desired path, and wheel strikes on the median may occur.

AASHTO provides turning radii and median nose design recommendations based on the intersection control radii and design vehicle. Information related to the location of stop bars is lacking, and dual left-turn movements are not addressed. The speed of the turning vehicles is addressed through the selection of the turning radii, with general recommendations provided for various turning speeds.

The provision of further design guidance regarding the design of median nose and vehicle stop bar location would help designers to provide intersection layouts that reduce erratic maneuvers, minimize lost time in the intersection, and provide consistent designs that fit motorists' needs.

Tasks that should be performed include:

1) field studies of intersections constructed with a variety of design values for left-turn radius, median width, number of turning lanes, and skew angle; and
2) follow-up laboratory studies to investigate driver behavior when encountering specific intersection layouts in the field.

These tasks should test the influence of skew angle, turning radii, design vehicle, and the number of turning lanes on the intersection layout.

EVALUATION OF PEDESTRIAN COUNTDOWN SIGNALS

In the United States, a pedestrian is struck and killed every 100 minutes, and another is injured about every eight minutes. Almost 70 percent of the fatalities occur in urban areas, and more than half of them occur at night. Many new crossing aids have been developed and are being implemented in an effort to make street crossing safer.

One new device, a countdown pedestrian signal or “ped head” signal, provides a visual countdown in addition to the walking pedestrian or hand graphic. The signals give pedestrians a more accurate reading of how much time remains to cross the street once the flashing hand is activated.

There are currently two types of countdown signals. The first unit contains two signal heads; one displays the countdown timer, and the other displays the walking person/hand indications. The second type is a single-head unit that contains both the countdown timer and pedestrian signal indications in one unit.

Although these devices have been installed in several states, they are still experimental and are not permitted by the current *MUTCD 2000*. However, they are included in Proposed Revision No. 2 of the *MUTCD 2000*, and it is likely that they will be included in the *MUTCD* in the future. The Proposed Revision includes information on the design and operation of countdown signals but does not include information on when the signals should be used. Guidelines are needed on where the countdown signals should and/or should not be used.

This project will:

- summarize the state of the practice regarding countdown ped head signals in other states and/or countries,
- evaluate the effectiveness of ped head installations in Texas using field studies,
- conduct personal interviews with city personnel and with pedestrians regarding countdown signals, and
- develop guidelines for when and where the countdown ped heads should be used.

USE OF LEFT-TURN LANES ON RURAL HIGHWAYS

Left-turning traffic from rural highways has increased with the growth of development in rural areas. Questions occur on when to provide a left-turn bay at a rural intersection. Even when a second lane is present, which provides the opportunity for passing the left-turning vehicle while still remaining on a through lane, there are still enough complaints and crashes associated with the turning vehicle to cause concerns.

Recent research has investigated the value of adding additional through lanes to a rural two-lane highway (e.g., Highway Safety Information System [HSIS] report titled "Safety Effects of the Conversion of Rural Two-Lane Roadways to Four-Lane Roadways by Council and Stewart, TRR 1665). The *Green Book* information on when to install a left-turn lane is based on work done by Harmelink in the late 1960s. These existing sources do not consider Texas conditions (such as the extensive use of shoulders to by-pass stopped drivers) and have other limits. Additional information on the safety and operational benefits of adding a left-turn lane at a rural intersection in Texas is needed.

This project should provide guidance regarding the addition of a left-turn treatment to a rural intersection. Guidance should consider:

- When is the left-turn lane needed (operation based and safety based)?
- What are the design controls for the treatment?
- What are safety effects of alternative treatments?

Potential treatments to consider include:

- shoulder by-pass lane,
- left-turn lane, and
- two-way left-turn lane.

The project should also investigate the tradeoffs provided for different treatment designs. For example, what width and length of the left-turn bay would improve safety and reduce delay, while also considering appropriate costs and available ROW? A left-turn lane that is too short could provide similar poor operations or safety concerns as the absence of a left-turn lane. These concerns include having vehicles slow or stopped behind the turning vehicle.

The research should provide results that cover operations at the intersection along with the expected safety impacts for the different design alternatives. The safety component should include the collection and detailed analysis of crash data at rural intersections with different design alternatives. Further, the impacts should be estimated empirically through a cross-sectional or retrospective before-and-after study where appropriate. The researchers are to also consider the no-treatment alternative.

The project is to provide guidance suitable for use by an engineer or designer in deciding whether to add a left-turn treatment at a rural intersection. The guidance should also include recommendations on the treatment design.

DESIGNING HIGHWAY/LOCAL ROAD INTERSECTIONS FOR IMPROVED OPERATIONS

Several farm-to-market, state highway, or US highway routes contain intersections with narrow local streets. The use of context-sensitive design principles when redesigning state highways and the consideration of traffic-calming needs on local streets could result in an increase in having narrow streets intersect with TxDOT highways. These intersections are frequently designed to provide a single lane for all through and turning movements from the local street approaches. In some cases, though, they may have a separate left-turn bay provided. In either configuration (single lane for left/through/right movements, or left-turn bay plus through/right lane), it may not be possible to operate the local roadway approaches under simultaneous green traffic signal indications because of the overlap in the left-turn paths for the local street approaches. As a result, traffic signals at such intersections are "split phased," meaning that the green signal indications are assigned to the cross-street approaches sequentially, rather than at the same time. Because of the restricted ROW and/or narrow pavement, the traffic signal operations are impacted, which could potentially result in reductions in intersection performance.

The proposed research would identify inter-related design and operations issues for these small intersections and develop a minimum design "footprint," or template, that would allow for flexible and efficient intersection signal phasing operations. Elements of this footprint/template would include local street approach lane width, lane configuration tradeoffs, alignment recommendations, and ROW recommendations. The templates would include provisions for left-turn bays, with sensitivity to design vehicle turning paths.

TRADEOFF FOR PEDESTRIANS AND VEHICLE OPERATIONS FOR DIFFERENT RIGHT-TURN LANE DESIGNS

The quality of operations and safety at an intersection with a free-flow right-turn lane varies depending upon whether the vehicle or the pedestrian is being considered. Free-flow right-turn lanes provide the opportunity for vehicles to maintain a higher speed as they move from one roadway to another, which in turn can provide for a more effective operation at the intersection. A tradeoff is that pedestrians have greater difficulties in crossing the street, especially when the pedestrian push button is located on the separator island. The pedestrian must first cross the free-flow right-turn lane before pushing the pedestrian button and requesting a crossing phase.

Members of the ADA community would prefer that all free-flow right-turn lanes be signalized to allow pedestrians the opportunity to stop the traffic. Stopping traffic can be critical for blind pedestrians, who could have difficulties in distinguishing when it is safe to cross; however, signalizing all free-flow right-turn lanes would increase the cost of the signal at an intersection, result in additional fixed objects being located at or near the intersection, and could reduce the efficiency of the intersection.

Different designs have been used for free-flow right-turn lanes. The shape of the separator island and whether that island is raised or flush are two examples of how the designs differ. The different designs have separate advantages and disadvantages for vehicles and pedestrians. For example, one type of design may increase the visibility of the pedestrian; however, it could require lower speeds for the turning vehicle. This research would investigate the tradeoffs between different design alternatives (including not using a free-flow right-turn lane).

Tasks that could be performed include:

1) field studies of intersections constructed with a variety of free-flow right-turn lane designs, and
2) follow-up studies to investigate driver and pedestrian behavior when encountering specific free-flow right-turn lane layouts in the field.

FEASIBILITY OF RIGHT-TURN LANES ON RURAL HIGHWAYS

Increasing roadway volumes have resulted in the practice of widening two-lane, two-way facilities by adding either a center two-way left-turn lane (TWLTL) or two additional through lanes. These designs can leave no effective shoulder area to be used for right turns and can result in potential safety problems for both right-turning and through vehicles, particularly at unsignalized intersections on high-speed rural roadways.

Research is needed to determine the extent of this problem in Texas and to determine when the addition of a right-turn lane is necessary and feasible, especially when widening is planned. Although previous research has investigated the feasibility of right-turn lanes, this information does not address Texas practices or conditions. AASHTO's 2001 *Green Book* states that speed-change lanes can preclude or minimize the disruption of the flow of through traffic by providing a tapered area for the acceleration or deceleration of vehicles entering or leaving the through-traffic lanes.

This project should provide guidance regarding the addition of right-turn lanes at unsignalized intersections on rural highways. This guidance should consider:

- safety effects of introducing a right-turning lane,
- when a right-turn lane is needed (based on volume, speed, curvature, and safety),
- right-turn lane design requirements (length, width, etc.), and
- cost and availability of right-of-way.

The project should include the collection and detailed analysis of crash data occurring on rural highways. Furthermore, the safety impacts should be estimated empirically through a cross-sectional or a retrospective before-and-after study, where appropriate. Researchers expect that other out-of-state jurisdictions will be surveyed to obtain information on the criteria they use to add a right-turning lane in a rural environment.

The project is to provide guidance suitable for use by an engineer or designer in the decision to add a right-turn treatment on rural highways.

CHAPTER 6

SUMMARY

Intersections are an important part of a highway facility because the efficiency, safety, speed, cost of operation, and capacity of the facility depend on their design to a great extent. Each intersection involves through- or cross-traffic movements on one or more of the highways and may involve turning movements between these highways. Such movements may be facilitated by various geometric design and traffic control, depending on the type of intersection.
The main objective of intersection design is to facilitate the convenience, ease, and comfort of people traversing the intersection while enhancing the efficient movement of motor vehicles, buses, trucks, bicycles, and pedestrians (*25*). Designers need current information regarding intersection design in an easily accessible and user-friendly format to design intersections that are both functional and effective.

The prime objective of TxDOT Research Project 4365 is to produce a reference document, the *Intersection Design Guide*, that provides this information. This research is designed to provide TxDOT and other interested parties with useful and practical information on operations and design for intersections. The project is a three-year effort and is structured into two phases. The first phase (Phase I) took place during the initial 12 months of the project, and this report summarizes the first-year activities.

During the first phase, one of the efforts was for researchers to focus on gaining an understanding of the myriad of transportation-related issues associated with intersections through one-on-one interviews, focus groups, and a review of current information regarding intersections. The major issues found in the focus groups and interviews covered various aspects of design, construction, and operations. These issues were widely held to be concerns for both designers and engineers developing urban intersection designs. Researchers used the findings from the focus groups and interviews to refine the outline for the *Guide*. Key findings are:

- Compliance with ADA requirements and the conflict between those requirements and other design elements are concerns of many of the engineers and designers contacted. Designers reported conflicts between the desirable locations for pedestrian crosswalks (and attendant ramps) and signal poles, curb inlets, controller cabinets, etc. This is indicative of the generally restricted amount of room available in the immediate area of urban intersections.

- The availability of ROW to accommodate urban intersection requirements is another issue that concerns many of those contacted. Conflicts with existing utilities found during construction were commonly cited as a concern in the placement of traffic signal poles. Obtaining sufficient ROW and satisfying future needs at intersections are also major concerns.

- Traffic control devices are cited as concerns, with wide-ranging issues related to their selection, placement, and operation being reported. Interactions with intersection layout together with concerns about traffic signal operations were frequently cited.

- Intersection layout issues also received a considerable amount of discussion. Satisfying drainage and cross-section requirements are problematic. The use of turn lanes is a particular concern for urban intersections, with a variety of operational and design practices discussed.

This information and information from the state-of-the-practice literature review were used to develop the draft chapters of the *Guide.* The *Guide* currently consists of the following 11 chapters:

Chapter 1 – Intersection Function
Chapter 2 – Design Control and Criteria
Chapter 3 – Design Elements
Chapter 4 – Cross-Section
Chapter 5 – Roadside
Chapter 6 – Drainage

Chapter 7 – Street Crossing

Chapter 8 – Signals

Chapter 9 – Markings

Chapter 10 – Signs

Chapter 11 – Influences from Other Intersections

The second phase of the project will include identifying good examples for the design and operation of intersections, developing refinement of the guidelines, and conducting field studies (as selected by the project advisory committee). This work will occur during the second and third years of the project.

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